HAYDARPAŞA NUMUNE MEDICAL JOURNAL

DOI: 10.14744/hnhj.2022.82085
Haydarpasa Numune Med J 2024;64(1):40–47

hnhtipdergisi.com

ORIGINAL ARTICLE

Static and Dynamic Cyclotorsion Compensation with the Schwind Amaris Laser System: Twelve-Month Refractive and Visual Outcomes

Mehmet Kay[1], Ece Turan Vural[2], Hatice Elvin Yıldız[2], Burak Erdem[3]

[1]Department of Ophthalmology, Sancaktepe Sehit Prof Dr Ilhan Varank Training and Research Hospital, Istanbul, Turkiye
[2]Department of Ophthalmology, University of Health Sciences Turkiye, Haydarpasa Numune Training and Research Hospital, Istanbul, Turkiye
[3]Department of Ophthalmology, Ordu University Faculty of Medicine, Ordu, Turkiye

Abstract

Introduction: Static (SCC) and dynamic cyclotorsion compensation (DCC) were evaluated in myopic/myopic astigmatism patients undergoing transepithelial photorefractive keratectomy (T-PRK) or femtosecond laser in situ keratomileusis (F-LASIK).

Methods: This retrospective, nonrandomized case series research comprised 236 eyes from 118 patients who had T-PRK (137 eyes) and F-LASIK (99 eyes). The refractive results at the preoperative and 12th months were compared. The association between SCC and DCC values and pre- and postoperative refractive results was investigated.

Results: SCC in the T-PRK group was 3.34±2.69° and 3.54±2.73° in the F-LASIK group. SCC was 3.38±2.68° in all patients. DCC in the T-PRK group was 1.51±1.07° and 1.74±0.93° in the F-LASIK group. In all patients, DCC was 1.57±0.90°. There was no significant difference between the T-PRK and F-LASIK groups in SCC and DCC (p>0.05). The preoperative trefoil showed a significant association with SCC (p<0.05). DCC was shown to have a significant relationship with postoperative total HOA and trefoil (p<0.001, p<0.05, respectively).

Discussion and Conclusion: Even with aberration-free refractive surgery, successful corneal aberrations and refractive results were achieved 12 months after surgery with minimal SCC and DCC. SCC and preoperative trefoil, as well as DCC and postoperative total HOA and coma, had proportionate relationships.

Keywords: Cyclotorsion; Eye-tracker system; Refractive surgery; T-PRK; F-LASIK.

Ocular cyclotorsion movements during excimer laser applications may lead to undesirable results such as high-order aberrations (HOA), induction of astigmatism, and insufficient astigmatic correction[1]. Static cyclotorsion movements are compensation related to the vestibular system, which provides the body's orientation, and previous studies have reported amounts of static cyclotorsion up to 16° when transitioning from the standing or sitting position to the supine position[2-4]. Dynamic cyclotorsion is the cyclotorsion movement that occurs during laser ablation. Monocular vision conditions that occur with the closure of the other eye during refractive surgery contribute to the increase in cyclotorsion[5,6]. According to the study of Swami et al.,[7] a rotational shift of 4 degrees during alignment means 14%, 6 degrees 20%, and 16 degrees 50% mistaken correction in astigmatism.

Induction of aberrations such as spherical aberrations and coma may result in reductions in visual acuity and

Correspondence: Burak Erdem, M.D. Department of Ophthalmology, Ordu University Faculty of Medicine, Ordu, Turkiye
Phone: +90 553 284 89 24 **E-mail:** burakerdem89@gmail.com
Submitted Date: 09.05.2022 **Revised Date:** 05.08.2022 **Accepted Date:** 21.08.2022

quality[8]. Thanks to developing laser technologies, lasers with small spot diameters and high resolution are used in the correction of HOA. However, the smaller spot diameter made refractive correction more sensitive to eye movement errors[9]. In the formula C=2F x sinα, C is residual astigmatism and F is the initial astigmatism power. α indicates the amount of axis misalignment. Small changes in α affect the amount of residual astigmatism, also depending on the initial astigmatic power[10]. According to Bueeler's study, the margin of lateral alignment error of up to 200 µm for a 3.0 mm pupil diameter and 70 µm for a 7.0 mm pupil diameter is required to reach the diffraction limit in 95% of eyes[11]. Misalignment further affects postoperative visual outcomes in wavefront and topography-guided procedures or eyes with moderate to high astigmatism[12].

The aberration-free refractive surgery retains preexisting HOAs while correcting for biomechanical changes and fixing the refractive error[13]. The advantage of this procedure is that the patient preserves the habitual sight impression and the brain is not forced to go through a learning period to deal with extra irritating modifications[13]. However, since HOAs are not corrected with this method, creating new aberrations with torsional eye movements may result in unfavorable visual effects, such as glare and halo.

Previously, cyclotorsion compensation was provided manually by the limbal marking method, and this method could present with some misalignment[14]. Therefore, eye-tracker systems were developed to eliminate the problems that may arise from eye movements during laser ablation[15]. Eye-tracker systems work based on the iris recording features due to the unique image of the iris in correcting cyclotorsion[16]. The static rotational eye-tracker system is used to stabilize the patient's transition from sitting upright to lying down. Static cyclotorsion compensation (SCC) is achieved just before ablation begins. Comparisons are made with the iris images measured while the patient is in the sitting position. After the ablation starts, the dynamic cyclotorsion compensation (DCC) system is active to equalize the rotational eye movements[17]. However, despite all the developing technology, there is conflicting information in the literature about the positive effects of iris registration-based eye tracker systems on the refractive result compared to the manual technique[18-21].

In our study, we evaluated the effect of SCC and DCC provided by the eye-tracker system on the postoperative refractive outcome and other related factors in myopic and myopic astigmatism patients who underwent transepithelial photorefractive keratectomy (T-PRK) or femtosecond laser in situ keratomileusis (F-LASIK).

Materials and Methods

Study Design

In this retrospective, observational, consecutive, nonrandomized case series study, data from 164 eyes of 82 patients with myopia and myopic astigmatism who underwent T-PRK and F-LASIK surgery at the Haydarpaşa Numune Training and Research Hospital, Ophthalmology Clinic between April 2015 and January 2019 were analyzed from archived files. The relationship between SCC and DCC values during refractive surgery and pre- and postoperative refractive findings was evaluated. In our study, we acted in accordance with the Declaration of Helsinki and good clinical practices. All patients were informed about the surgery and written consent was obtained. This study was approved by the Haydarpaşa Numune Health Application and Research Center Directorate local Ethics Committee (Decision no 46418926-806.01.03).

Inclusion Criteria for the Study: Patients aged 18 years or older, refractive errors stable for at least two years, patients with a central corneal thickness greater than 500 microns, patients with a central corneal curvature below 46.00 D, patients with a scotopic pupil diameter of 6.5 mm or less after 5 minutes of dark adaptation, patients with best-corrected distance visual acuity (CDVA) of 0.2 and above according to the Snellen chart, patients with cycloplegic spherical refractive error between -1.00 D and -6.50 D, cylindrical refractive error ≤-3.00 D, patients with no more than 1.00 D difference between the manifest and the topographic value of the cylindrical refractive error, patients with a difference of 1.00D or less between manifest refraction and cycloplegic refraction.

Exclusion Criteria: Patients with suspicious thinning of the corneal topography and suspected steep keratometry, patients with nystagmus, diplopia, or decompensated strabismus, patients with previous eye surgery, trauma, or dry eye, glaucoma, uveitis, lens anomaly, keratoconus, corneal dystrophy, retinal diseases, patients with diabetes mellitus, collagen tissue disease, and other diseases that may predispose to scar formation, patients with systemic chronic drug use, patients during pregnancy and lactation were excluded from the study.

Examinations

Detailed anamnesis was obtained from all patients in terms of systemic disease and drug use. Dilated fundus examinations were performed, and intraocular pressures were measured by applanation tonometry. Tear functions were evaluated by break-up time and the Schirmer test. The corneal structure was evaluated with the SIRIUS topo-tomography device (Costruzione Strumenti Oftalmici, Florence, Italy). After taking at least three shots, values such as pupillary r values, ring formation, and cyclotorsion were optimized, and the most appropriate topographic measurement was taken as a reference. The thinnest point was recorded as the pachymetry value. The value at the central 3 mm was accepted as the curvature. HOAs of the cornea were recorded with a pupil of 4 mm. Uncorrected distance visual acuity (UCVA), best-corrected distance visual acuity (CDVA), manifest spherical and cylindrical refractive error, keratometry values, pachymetry, and corneal aberrations (total Hoa, trefoil, and coma) were recorded at preoperative and postoperative 1st, 6th, and 12th months.

Surgical Technique

Fluence tests were performed during all surgical procedures when the air temperature was between 19°C – 21°C and the humidity was between 45% - 50%. All surgical procedures were performed under topical anesthesia (3 drops of 0.05% proparacaine). Skin cleaning was done with 5% povidone-iodine. All surgical plans were prepared in the preoperative ORK-CAM program. The Schwind Amaris 1050 Hz excimer laser system (Schwind eye-tech solutions GmbH & Co.KG, Kleinostheim, Germany) that creates a beam of 0.54 mm spot size, performs 1D ablation in 1.3 seconds, and compensates for static and dynamic cyclotorsion with a 7D eye-tracking system was used during all ablations. Aberration-free ablation was performed in all patients.

F-LASIK Procedure: All LASIK flaps were created with Ziemer FEMTO LDV Z6 (Ziemer Ophthalmic Systems, Port, Switzerland) using a plastic disposable vacuum ring. A vacuum of 700 mbar was applied. Flaps were created with an incision speed of 27-30 seconds, pulse energy of 100nJ, and a frequency of >2MHz in approximately 35 seconds with a thickness of 110-120 microns. The flap width was kept 0.20 - 0.50 mm wider than the total ablation zone. The hinge was made superiorly and 0.50 mm wide and 4 mm long in all patients. Following the creation of the LASIK flap, ablation was performed with the Schwind Amaris 1050 Hz excimer laser device accompanied by an eye-tracker system. After the flap placement was completed, antibiotic drops were administered and an oxygen-containing silicone hydrogel contact lens was placed.

T-PRK Procedure: The T-PRK program was used with the Schwind Amaris 1050 Hz excimer laser device. Following the ablation, a sponge impregnated with 0.02% Mitomycin C was applied to the ablation area for 25 seconds. After the surgical procedure, the eyes of all patients were washed with balanced saline solution, topical antibiotic drops were administered, and silicone hydrogel contact lenses with high oxygen content were placed.

All patients were called for routine control on the 1st, 3rd, and 7th days postoperatively, and were evaluated in terms of the wound healing process and early complications.

Cyclotorsion Data

Patients were placed on the operating table facing the flat flashing fixation light, eliminating any head tilt. Control was provided with glabella centering lights to ensure the head was properly positioned. The chin position was ensured by the overlap of three illuminated lines. In all cases, the intraoperative eye-tracker system DCC was actively used. For SCC, the lowest repetitive measurements were taken before starting the operation, while for DCC, the average of measurements continued throughout the operation.

Statistical Analysis

SPSS 20.0 statistical program (IBM Statistics 20.0 for Windows) was used to analyze the data. Continuous variables were expressed as mean and standard deviation, and categorical and nominal variables were expressed as numbers and percentages. Normality test for continuous variables was done with Shapiro - Wilk test. It was observed that the data were not normally distributed. Mann-Whitney U and Sample t test was used for pairwise comparisons of independent variable groups. Friedman test was used for triple comparison of dependent variables. The Chi-Square test was used to compare independent nominal binary variables. Wilcoxon test was used to compare pre- and post-operative outcomes. The analysis of the relationship status of the independent variables between the groups was performed with the Spearman correlation test.

Results

A total of 236 eyes of 118 patients were included in our study. F-LASIK was applied to 99 eyes and T-PRK to 137 eyes. Only one patient underwent F-LASIK in one eye and T-PRK in the other eye. According to the refractive error of the eyes; myopic correction was performed in 66 eyes (24 F-LASIK, 42 T-PRK), and myopic astigmatism correction was performed in 170 eyes (75 F-LASIK, 95 T-PRK). Demographic characteristics and pre- and post-operative refractive findings of the patients are shown in Table 1.

Table 1. Demographic characteristics and refractive findings

	T-PRK Median (Min/Max)/n-%		**F-LASIK Median (Min/Max)/n-%**		**P**
Age (years)	26 (19/45)		27.22±4.02		0.766^{m}
Gender					
Female	79	57.7	51	51.5	0.482$^{X^2}$
Male	58	42.3	48	48.5	
Eye					
Right	69	50.4	49	49.5	0.854$^{X^2}$
Left	68	49.6	50	50.5	
Sphere (D)					
Preop	-2 (-1/-4.75)		-3.25 (-1/-6.50)		0.001^{m}
12 Mo Postop	-0.25 (0/-0.75)		-0.25 (0/-1.00)		0.194^{m}
Intra Group p	0.001^{w}		0.001^{w}		
Cylinder (D)					
Preop	-0.50 (0/-3.00)		-1.25 (0/-3.00)		0.001^{m}
12 Mo Postop	-0.25 (0/-0.50)		-0.50 (0/-0.75)		0.020^{m}
Intra Group p	0.001^{w}		0.001^{w}		
SE (D)					
Preop	-2.25 (-0.50/-4.75)		-3.75 (-2/-6.50)		0.001^{m}
12 Mo Postop	-0.25 (0/-1.00)		-0.25 (0/-1.00)		0.144^{m}
Intra Group p	0.001^{w}		0.001^{w}		
UCVA (logMAR)					
Preop	0.52 (0.15/1.30)		1.20 (0.15/1.30)		0.001^{m}
12 Mo Postop	0 (0/0.10)		0 (0/0.30)		0.001^{m}
Intra Group p	0.001^{w}		0.001^{w}		
CDVA (logMAR)					
Preop	0 (0/0)		0 (0/0.22)		0.001^{m}
12 Mo Postop	0 (0/0.05)		0 (0/0.22)		0.001^{m}
Intra Group p	0.319^{w}		0.333^{w}		
Total HOA (µm)					
Preop	0.17 (0.08/2.18)		0.88 (0.27/1.99)		0.001^{m}
12 Mo Postop	0.20 (0.06/1.56)		0.87 (0.3/1.82)		0.001^{m}
Intra Group p	0.002^{w}		0.020^{w}		
Trefoil (µm)					
Preop	0.10 (0.01/0.50)		0.10 (0.01/0.37)		0.925^{m}
12 Mo Postop	0.10 (0.02/0.66)		0.11 (0.04/0.47)		0.099^{m}
Intra Group p	0.370^{w}		0.426^{w}		
Coma (µm)					
Preop	0.07 (0.01/0.28)		0.11 (0.03/0.22)		0.007^{m}
12 Mo Postop	0.07 (0.0/0.46)		0.12 (0.03/0.44)		0.018^{m}
Intra Group p	0.036^{w}		0.286^{w}		
Pupil ofset	0.16 (0.01/0.56)		0.18 (0.05/0.42)		0.715^{m}
CCT (Micrometer)	544 (500/622)		551 (528/631)		0.035^{m}
Ablation depht ()	98 (32/136)		73 (45/112)		0.001^{m}
SCC (deg)	3.34±2.69		3.54±2.73		0.720st
DCC (deg)	1.51±1.07		1.74±0.93		0.312st

^{m}Mann-whitney u test/ X^2 Chi-square test / ^{w}Wilcoxon test/ stSample t test; T-PRK: Transepithelial Photorefractive Keratectomy; F-LASIK: Femtosecond Laser in situ keratomileusis; SE: spherical equivalent; UCVA: Uncorrected distance visual acuity; CDVA: Best-corrected distance visual acuity; HOA: higher-order aberration; CCT: Central corneal thickness; SCC: static cyclotorsion compensation; DCC: dynamic cyclotorsion compensation.

SCC was 3.34±2.69° in the T-PRK group and 3.54±2.73° in the F-LASIK group. In all patients, SCC was 3.38±2.68°. DCC was 1.51±1.07° in the T-PRK group and 1.74±0.93° in the F-LASIK group. DCC was 1.57±0.90° in all patients (All values are given as absolute values). The distribution of SCC and DCC data is given in Figures 1 and 2. There was no significant difference between the T-PRK and F-LASIK groups in SCC and DCC ($p>0.05$). When the correlation analyses were examined, a significant correlation was observed between SCC and only the preoperative trefoil ($p<0.05$)(Fig. 3), and there was no significant correlation with other parameters (In all correlation analyses, the data of the patients in the T-PRK and F-LASIK groups were combined). There was a significant correlation between DCC and postoperative total HOA and postoperative trefoil ($p<0.001$, $p<0.05$, respectively), and no significant correlation was observed with postoperative coma ($p>0.05$) (Fig. 4). There was no correlation between other parameters and DCC. Also, no significant correlation was observed between SCC and DCC ($p>0.05$) (Fig. 5).

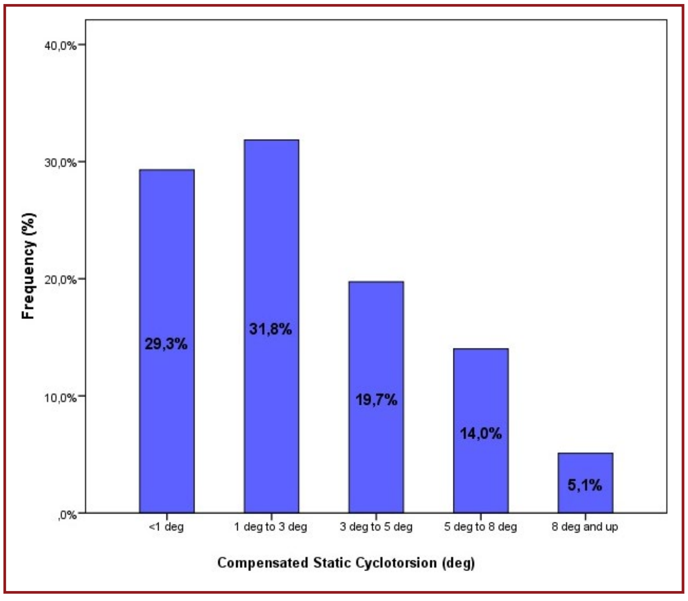

Figure 1. The Distribution of Compensated Static Cyclotorsion (SCC).

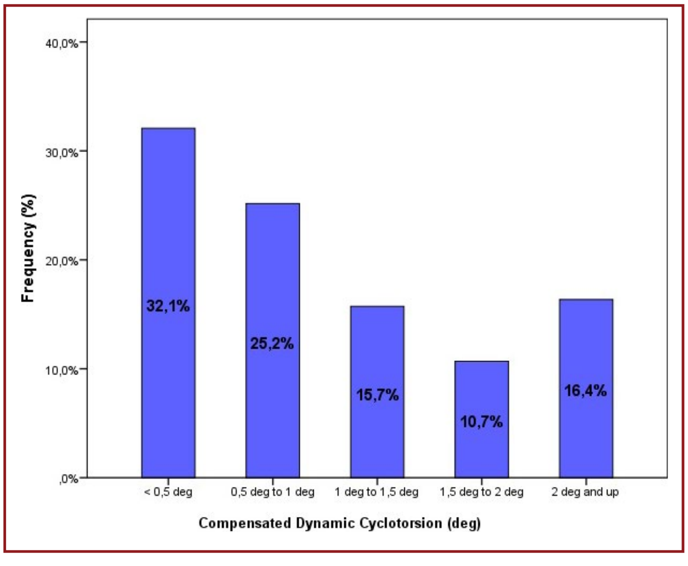

Figure 2. The Distribution of Compensated Dynamic Cyclotorsion (DCC).

No intraoperative complications were observed in any of the patients. Under- and over-correction values of +0.50 D spherical equivalent and above were accepted. There was no overcorrection compared to the spherical equivalent,

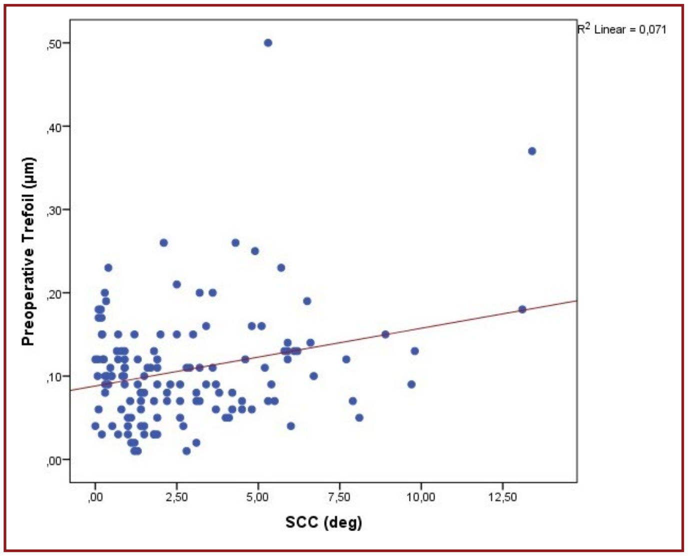

Figure 3. Static Cyclotorsion Compensation (SCC) with Preoperative Trefoil Scatter Plot.

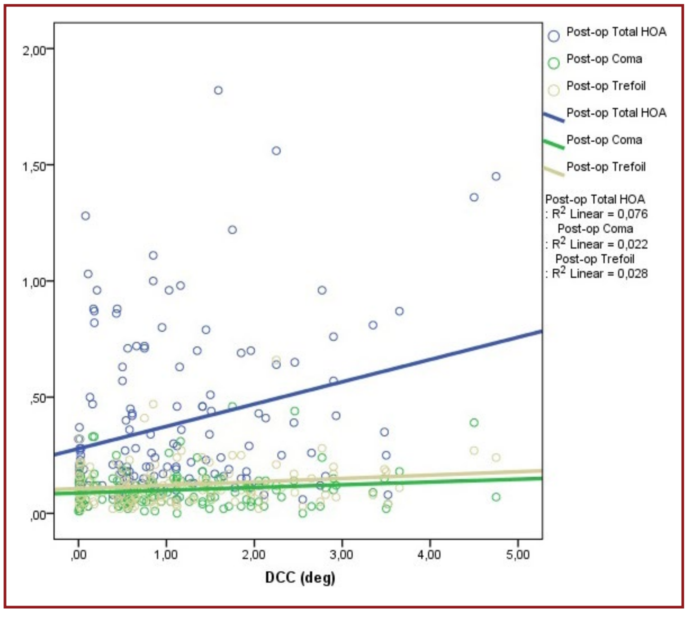

Figure 4. Dynamic Cyclotorsion Compensation (DCC) with Corneal Aberrations Scatter Plot.

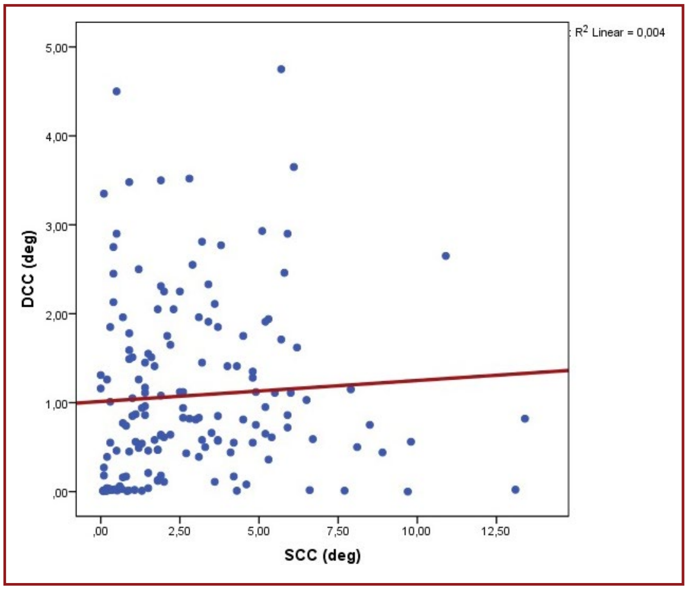

Figure 5. Static Cyclotorsion Compensation (SCC) and Dynamic Cyclotorsion Compensation (DCC) Scatter Plot.

but under-correction (+0.75 D SE) was observed in 8 patients in the T-PRK group. In the T-PRK group, 17.4% (24 eyes) of corneal stromal clouding was noted, but this was not Grade +2 or higher in any case. In the F-LASIK group, epithelial ingrowth was observed under the flap in 1 eye in the follow-ups.

Discussion

Our findings showed that even when wavefront-guided treatment was not used in T-PRK and F-LASIK procedures performed with the Schwind Amaris 1050 Hz excimer laser system using SCC and DCC, aberrations were not induced, and successful refractive results were obtained in the post-op 12th-month controls. However, in cases with high DCC, higher corneal aberrations were seen in the postoperative period. In addition, preoperative high trefoil values seem to be associated with high SCC.

During refractive surgery, shifts in the photoablation zone due to cyclotorsion can induce irregular tertiary astigmatism. This newly formed astigmatism is observed due to high aberrations such as coma and spherical aberrations[1,3,12]. Even if it does not cause a decrease in visual acuity, high aberrations can cause image distortion. It has been reported that up to 35% residual cylinder and up to 52% residual trefoil can occur when static cyclotorsion is not compensated[22]. Eyes with high astigmatism are more likely to experience these problems. We used SCC in all of our patients and achieved an average of 3.37 degrees. Previously, Prakash et al.[19] measured SCC in LASIK patients as 3.64 degrees, and Febbraro et al.[21] measured 3.08 degrees. Mohammadpour et al.[23] found the amount of SCC to be 3.37 degrees in patients who underwent PRK. Ciccio et al.[24] reported an amount of 4.05 degrees SCC. Further, Arba-Mosquera et al.[25] found the SCC to be 3.10 degrees. The amounts of SCC reported in these studies are similar to our findings. Furthermore, whereas spherical and cylindrical values were higher in the F-LASIK group, there was no significant difference in SCC between the T-PRK and F-LASIK groups in our study. The main point here may be that we make a precise position adjustment before starting the surgery. At the same time, it is possible to achieve good SCC despite large refractive errors with an advanced eye-tracker system.

In our study, we found the DCC, which helps compensate for cyclotorsion due to eye movements during the operation, to be 1.57 degrees on average. In previous studies, Mohammadpour et al.[23] obtained 2.54 degrees, Chang[17] 2.18 degrees, and Prakash et al.[19] 4.00 degrees. Arba-Mosquera et al.[25] found DCC as 1.36 degrees (all values given for SCC and DCC are absolute values). Even if there is not a big difference in DCC values found in the studies, differences between the exclusion criteria (wavefront-guided treatment, only cases with high astigmatism, etc.) may be the cause of these differences. A deeper ablation zone or the characteristics of the laser device can make the operation time longer. DCC is likely to be more active during longer operating times[25].

We did not observe any correlation between SCC and DCC in our study. Mohammadpour et al.[23] found a high correlation between SCC and DCC. Prakash et al.[19] reported similar results. However, Febbraro et al.[21] did not observe any correlation between SCC and DCC. DCC tends to partially offset the effects of SCC, so erroneous measurement of SCC before optimal alignment conditions are established can result in DCC being measured high as well[25]. The fact that we started surgery with the best possible SCC measurement in our patients may be the reason why we did not see a correlation between DCC and SCC.

DCC has been found to be high in patients with high astigmatism in previous studies because these patients do not focus on the laser beam[21,23]. At the same time, high DCC can be observed in high astigmatism as the depth of ablation will prolong the ablation time[24]. In our study, there was no correlation between preoperative astigmatism and ablation depth and neither SCC nor DCC. This is likely since most of the participants did not have high astigmatism.

In our study, we observed a high correlation between preoperative trefoil and SCC. Trefoil (or elliptical coma) causes the eye to perceive a point of light as a trifoliate cloverleaf pattern[26]. Therefore, patients with high trefoil may not be able to focus the fixation light well when they first lie on the operating table. This may explain the high SCC. However, we did not find any evaluation regarding this in previous studies. Further studies are needed to clarify the relationship between preoperative trefoil and SCC. Besides, those with higher DCC had higher total HOA and coma values in the postoperative 12th months. It has been previously shown that excessive eye torsion during ablation causes postoperative HOAs[27,28]. Also, Prakash et al.[19] reported that cyclotorsion increased with increasing age. However, we could not find a significant correlation between age and SCC or DCC in our study.

This study has some limitations. First of all, the eye-tracker system was used actively in all groups, and we do not have a control group that did not use the eye-tracker system. In addition, SCC and DCC become more important in cases with high astigmatism. In our study, the number of cases with ≥2.00 D astigmatism was only 10% of all cases.

Conclusion

There was a direct proportional association between SCC and preoperative trefoil, as well as DCC and postoperative total HOA and coma, in this research. However, we did not find a correlation between SCC and DCC. At the same time, the DCC correlation with age, ablation depth, and astigmatism, which has been shown in some previous studies, was not present in our study. These findings indicate that further studies are needed to understand the effects of SCC and DCC. However, our study demonstrated that successful corneal aberrations and refractive outcomes were achieved at 12 months postoperatively with low SCC and DCC, even when the aberration-free study was performed.

Ethics Committee Approval: This study was approved by the Haydarpaşa Numune Health Application and Research Center Directorate local Ethics Committee (Decision no 46418926-806.01.03).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: E.T.V.; Design: E.T.V.; Supervision: H.E.Y.; Materials: M.K.; Data Collection or Processing: M.K.; Analysis or Interpretation: B.E.; Literature Search: M.K., B.E.; Writing: M.K.; Critical Review: H.E.Y.

Conflict of Interest: None declared.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Aslanides IM, Toliou G, Padroni S, Arba Mosquera S, Kolli S. The effect of static cyclotorsion compensation on refractive and visual outcomes using the Schwind Amaris laser platform for the correction of high astigmatism. Cont Lens Anterior Eye 2011;34:114–20.[CrossRef]
2. Smith EM Jr, Talamo JH. Cyclotorsion in the seated and supine patient. J Cataract Refract Surg 1995;21:402–3.[CrossRef]
3. Tomita M, Watabe M, Yukawa S, Nakamura N, Nakamura T, Magnago T. Supplementary effect of static cyclotorsion compensation with dynamic cyclotorsion compensation on the refractive and visual outcomes of laser in situ keratomileusis for myopic astigmatism. J Cataract Refract Surg 2013;39:752–8. [CrossRef]
4. Kim H, Joo CK. Ocular cyclotorsion according to body position and flap creation before laser in situ keratomileusis. J Cataract Refract Surg 2008;34:557–61. [CrossRef]
5. Shen EP, Chen WL, Hu FR. Manual limbal markings versus iris-registration software for correction of myopic astigmatism by laser in situ keratomileusis. J Cataract Refract Surg 2010;36:431–6. [CrossRef]
6. Chernyak DA. Cyclotorsional eye motion occurring between wavefront measurement and refractive surgery. J Cataract Refract Surg 2004;30:633–8. [CrossRef]
7. Swami AU, Steinert RF, Osborne WE, White AA. Rotational malposition during laser in situ keratomileusis. Am J Ophthalmol 2002;133:561–2. [CrossRef]
8. Applegate RA, Howland HC. Refractive surgery, optical aberrations, and visual performance. J Refract Surg 1997;13:295–9. [CrossRef]
9. Bueeler M, Mrochen M. Simulation of eye-tracker latency, spot size, and ablation pulse depth on the correction of higher order wavefront aberrations with scanning spot laser systems. J Refract Surg 2005;21:28–36. [CrossRef]
10. Tunnacliffe AH, Hirst JG. Optics. 2nd ed. London, UK; Association of British Dispensing Opticians; 1996.
11. Bueeler M, Mrochen M, Seiler T. Maximum permissible lateral decentration in aberration-sensing and wavefront-guided corneal ablation. J Cataract Refract Surg 2003;29:257–63.
12. Brunson PB, Mann Ii PM, Mann PM, Potvin R. The impact of image registration for ablation orientation on clinical outcomes after wavefront-optimized refractive surgery in eyes with myopia and astigmatism. Clin Ophthalmol 2020;14:3983–90. [CrossRef]
13. Arbelaez MC, Vidal C, Arba-Mosquera S. Excimer laser correction of moderate to high astigmatism with a non-wavefront-guided aberration-free ablation profile: Six-month results. J Cataract Refract Surg 2009;35:1789–98.
14. Popp N, Hirnschall N, Maedel S, Findl O. Evaluation of 4 corneal astigmatic marking methods. J Cataract Refract Surg 2012;38:2094–9. [CrossRef]

15. Taylor NM, Eikelboom RH, van Sarloos PP, Reid PG. Determining the accuracy of an eye tracking system for laser refractive surgery. J Refract Surg 2000;16:S643–6. [CrossRef]
16. Pajic B, Cvejic Z, Mijatovic Z, Indjin D, Mueller J. Excimer laser surgery: Biometrical iris eye recognition with cyclorotational control eye tracker system. Sensors (Basel) 2017;17:1211.
17. Chang J. Cyclotorsion during laser in situ keratomileusis. J Cataract Refract Surg 2008;34:1720–6. [CrossRef]
18. Moshirfar M, Chen MC, Espandar L, Meyer JJ, Christensen D, Christiansen SM, et al. Effect of iris registration on outcomes of LASIK for myopia with the VISX CustomVue platform. J Refract Surg 2009;25:493–502. [CrossRef]
19. Prakash G, Agarwal A, Ashok Kumar D, Jacob S, Agarwal A. Comparison of laser in situ keratomileusis for myopic astigmatism without iris registration, with iris registration, and with iris registration-assisted dynamic rotational eye tracking. J Cataract Refract Surg 2011;37:574–81. [CrossRef]
20. Chen X, Stojanovic A, Stojanovic F, Eidet JR, Raeder S, Øritsland H, et al. Effect of limbal marking prior to laser ablation on the magnitude of cyclotorsional error. J Refract Surg 2012;28:358–62. [CrossRef]
21. Febbraro JL, Koch DD, Khan HN, Saad A, Gatinel D. Detection of static cyclotorsion and compensation for dynamic cyclotorsion in laser in situ keratomileusis. J Cataract Refract Surg 2010;36:1718–23. [CrossRef]
22. Arba-Mosquera S, Merayo-Lloves J, de Ortueta D. Clinical effects of pure cyclotorsional errors during refractive surgery. Invest Ophthalmol Vis Sci 2008;49:4828–36. [CrossRef]
23. Mohammadpour M, Khorrami-Nejad M, Chini-Foroush N. Correlation between iris-registered static and dynamic cyclotorsions with preoperative refractive astigmatism in PRK candidates. J Curr Ophthalmol 2018;31:36–42. [CrossRef]
24. Ciccio AE, Durrie DS, Stahl JE, Schwendeman F. Ocular cyclotorsion during customized laser ablation. J Refract Surg 2005;21:S772–4. [CrossRef]
25. Arba-Mosquera S, Arbelaez MC. Three-month clinical outcomes with static and dynamic cyclotorsion correction using the SCHWIND AMARIS. Cornea 2011;30:951–7. [CrossRef]
26. Brar AS, Kaur M, Nair S, Titiyal JS. Aberrometry and wavefront analysis. In: Kaur M, Nair S, Titiyal JS, editors. Current concepts in refractive surgery: Comprehensive guide to decision making & surgical techniques. New Delhi: Jaypee Brother Medical Publishers; 2021.
27. Arba Mosquera S, Verma S. Effects of torsional movements in refractive procedures. J Cataract Refract Surg 2015;41:1752–66. [CrossRef]
28. Arba Mosquera S, Arbelaez MC. Use of a six-dimensional eye-tracker in corneal laser refractive surgery with the SCHWIND AMARIS TotalTech laser. J Refract Surg 2011;27:582–90. [CrossRef]