Effects of Static Cyclotorsion Compensation of Refractive Outcomes and Level of Vision in Excimer Laser Surgery

Kemal OZULKEN[1], Mehmet Ozgur CUBUK[2], Erdem YUKSEL[3]

ABSTRACT

Purpose: To evaluate the reliability and reproducibility of static cyclotorsion compensation (SCC) measurements made by software of WaveLight EX500 Excimer laser in patients undergoing Laser-Assisted in Situ Keratomileusis (LASIK) procedure.

Materials and Methods: A retrospective study was designed to compare the refractive and visual outcomes of LASIK procedure with or without SCC. Patients with astigmatism greater than or equal to 0.50 D that undergone LASIK surgery with SCC were included in the Group 1, without SCC were included in Group 2. The astigmatism of eyes in group 1 was also classified according to axis as with the rule (WTR), against the rule (ATR) and oblique. The preoperative and postoperative spherical error, astigmatic error, and axis of astigmatism were compared between different groups. Subgroup analysis of group 1 was performed between different types of astigmatism groups.

Results: Three hundred ninety-eight eyes of 199 patients were included in Group 1 and 126 eyes of 63 patients were included in Group 2. Postoperative spherical error was -0.003±0.36 (-1.00 +1.50) in group 1 and +0.11± 0.65 (-0.75 +1.50) in group 2 (p=0.04), Postoperative astigmatic error was -0.40±0.22 (-1.25 +0.50) in group 1 and -0.85± 0.22 (-1.25 -0.50) in group 2, (p=0.001). The mean magnitude of SCC was -0.95°±4.1. Postoperative astigmatic error was significantly higher in WTR than ATR and oblique group (p=0.044, p=0.039, respectively)

Conclusion: The cyclotorsion is reasonably compensated with using software of WaveLight EX500 Excimer in conjunction with the Wavelight Topolyzer Vario. Refractive outcomes could be better in the oblique group.

Keywords: Cyclotorsion, Laser-Assisted in Situ Keratomileusis, With the rule astigmatism, Against the rule astigmatism, Oblique astigmatism.

INTRODUCTION

Laser refractive surgery is an effective procedure for correcting refractive errors either by surface treatment or by applying laser under a corneal flap. However, ocular cyclotorsion during laser refractive surgery may significantly reduce the success of the refractive outcomes due to inadequate correction or induction of astigmatism and higher order aberrations.[1] During daily life, human eyes can perform significant torsional movements up to 15 degrees according to the motion and orientation of the patient's head and body.[2] Particularly, patients were noted to have a cyclotorsion of their eyes when shifted from the seated to supine positions ranging from 0 to 16 degrees, the amount of cyclotorsion was higher with monocular viewing conditions.[1-5] The cyclotorsion that exists when the position of patient shifted from upright to supine was known as static cyclotorsion (SC) and was an important reason for unfavorable results after refractive laser ablation procedures. Previously, it was shown that a 4 degrees misalignment can cause a 14% under-correction of astigmatism, 6 degrees a 20% under-correction and 16 degrees a 50% under-correction.[1] Not all laser platforms are able to automatically compensate the static and dynamic cyclotorsion.[6,7] Recently, some laser platforms have been developed which are able to measure and compensate cyclotorsional movement of eye.[8] One is WaveLight EX500 Excimer laser (Alcon, Fort Worth, TX, USA).

The current study aimed to compare the refractive and visual outcomes Laser-Assisted in Situ Keratomileusis (LASIK) procedure with or without cyclotorsion compensation (SCC). Furthermore, the reliability of SCC measurements was evaluated according to different types of astigmatism.

1- Ophthalmologist, MD, Ophthalmology Department of TOBB University, ETÜ Medicine School, Ankara, Turkey

2- Ophthalmologist, MD, Ophthalmology Department of İstanbul Training and Research Hospital, İstanbul, Turkey

3- Associate Prof., MD, Ophthalmology Department of Kastamonu University, Kastamonu, Turkey

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Correspondence Adress:
Kemal OZULKEN
Ophthalmology Department of TOBB University, ETÜ Medicine School, Ankara, Turkey

Phone: +90 312 292 9900
E-mail: kemalozulken@hotmail.com

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board/Ethics Board of Local Ethics committee and adhered to the Declarations of Helsinki. Before the procedure, informed patient consent was taken from all patients about the complications of the surgery.

A retrospective study was designed to compare the refractive and visual outcomes of LASIK procedure with or without SCC. We retrospectively reviewed the medical charts of patients undergone LASIK procedure with WaveLight EX500 Excimer laser January 2011 to January 2017.

Demographic data including age and gender, the preoperative degree of refractive error were recorded for each patient. Patients with astigmatism greater than or equal to 0.50D that undergone LASIK surgery with SCC, were included in the Group 1. Patients whose static cyclotorsion could not be measured by WaveLight EX500 Excimer laser platform, undergone LASIK surgery without SCC and these were included in control group (Group 2). Exclusion criteria were; a follow-up period of fewer than 6 months, a history of complications related to the excimer laser procedure. Furthermore, the astigmatism of eyes was classified according to axis and subgroup analysis of group 1 was performed. The axis of the cylindrical component was regarded as being with the rule (WTR) if the minus-cylinder axis was at 180±30º, against the rule (ATR) if the minus-cylinder axis was at 90±30º or oblique (i.e., other than either WTR or ATR). The eyes in group 1 also classified according to the amount of SCC as group 1a (< 3º), group 1b (< 6º), and group 1c (6º ≤).

Patients wearing soft contact lens were asked to remove their lenses for at least two weeks prior to performing the topography. Patients with hard contact lens were excluded from this study. Preoperatively uncorrected distance visual acuity (UCVA), bestcorrected distance visual acuity (BCVA), manifest refraction and ocular motility was tested. IOP measurement, slit lamp examination of the anterior segment and a dilated fundus examination was also performed.

Calculation of the SCC was based on comparisons of the corneal images obtained from the Wavelight Topolyzer Vario Diagnostic Device from the patient in the upright position and the images taken from WaveLight EX500 Excimer laser camera with the patient in the supine position. For imaging, the patients seated vertically and the head was positioned upright. The patient was asked to look at the fixation point at the center of the machine with both eyes open. No speculum or digital lid opening was performed. All measurements were performed by the same experienced technician. At least 3 measurements were made and only the best measurements were used in later analyses. After the upright analysis, the laser computer algorithm evaluates for landmarks beginning from the borderline of the pupil to outwards until the image is completely scanned or the number of the prerequisite crucial points is reached. Particularly, the shape of the iris and the vessels in the sclera provided sufficient information to calculate the cyclotorsion. Before the LASIK procedure the software of the excimer laser compares the 2 images (upright and supine), superimposes the crucial landmarks and calculates the angle of rotation.

All eyes underwent LASIK under topical anesthesia (alcaine eye drop, Alcon, Fort Worth, TX, USA) at the same center using a single excimer laser (WaveLight EX500 Excimer laser). The planned outcome target was emmetropia in all eyes included in the current study. Refractive acceptability criteria: SEq within ±1 D from target postoperative refraction is considered acceptable, astigmatism within ±0.75 D from target postoperative refraction is considered acceptable. All surgeries were performed by the same surgeon (K.O) and the corneal flaps were created by WaveLight FS200 femtosecond laser system (Alcon Laboratories Inc., Fort Worth, TX) in each case. Intraoperative Dynamic Cyclotorsion Control (DCC) was used in all cases.

After the surgery the patients were examined at 1 day, 1 week, 1 month, 3 months and 6 months. Post-operative refraction, topography and refraction were performed by the same surgeon (K.O). Postoperative astigmatism and the effect of cyclotorsional compensation were evaluated for each patient.

Statistical Package for the Social Sciences (SPSS) version 20.0 software was used for all statistical analyses. Descriptive statistics are presented as minimum, maximum and mean ± standard deviation. The amount of static cyclotorsion into those with a negative value (counter-clockwise) and those with a positive value (clockwise) was noted. Astigmatism analysis was performed with cycloplegic cylinder values compared. The preoperative and postoperative spherical error, astigmatic error, and axis of astigmatism were compared between group 1 and group 2. Subgroup analysis of group 1 was also performed between different types of astigmatism groups (WTR, ATR, oblique). Furthermore, the pre and postoperative astigmatic error were compared between different cyclotorsion subgroups. The paired samples t-test, independent samples t test and one way Anova were used for statistical analysis. A p-value less than 0.05 was considered statistically significant.

RESULTS

Three hundred ninety-eight eyes of 199 patients were included in Group 1 and one hundred twenty-six eyes of 63 patients were included in Group 2. The demographic characteristics of patients and the mean follow up time are shown in Table 1. All patients underwent LASIK surgery. All eyes had a preoperative BCVA equal to or better than 20/20.

Table 1: *Demographic Characteristics of Patients and Eyes.*

Parameters	Group 1	Group 2	P*
Mean Age(y)	28.6±6.6	29.1±5.4	0.26
Patients/eye	199/398	63/126	
Female/male	120/79	41/22	
Mean Follow-up Time(m)	6.0±0.0	6.0±0.0	
Pachymetry(μ) R/L	541.1±29.8	546±27.6	0.18

y: years, **m:** months, **R:** right, **L:** left, **D:** diopter, *independent samples t test

The preoperative and postoperative values of refractive errors were shown in Table 2. Postoperative spherical and astigmatic error were significantly higher in group 2 than group 1 (Table 2).

The mean magnitude of SCC was -0.95°±4.1. In 54 eyes the SCC was 0°(13.5%) and in 71 eyes the SCC was higher than 5°(17.8%). In eyes with a counter-clockwise rotation, the mean magnitude of SCC was -3.88°±2.29 whereas in eyes with a clockwise rotation, the mean magnitude of SCC was +3.71°±2.85.

There is no association between the amount of cyclotorsion and postoperative astigmatic errors (Table 3).

Two hundred ninety (72.9%) of 398 eyes had with the rule astigmatism, 60 eyes (15.1%) had against the rule astigmatism and 48 eyes (12.1%) had oblique astigmatism. The comparison of refractive errors between different types of astigmatism was shown in Table 4. The postoperative astigmatic error was significantly higher in WTR than ATR

Table 2: *Pre-operative and Post-operative Refractive Error of Eyes.*

Parameters	Group 1	Group 2	P*
Preop Spherical error (D) (range)	-1.82±2.74 (-7.75 +6.50)	-1.88±2.98 (-6.50 +5.00)	0.83
Preop Astigmatic error (D) (range)	-1.47±1.27 (-6.00 +2.25)	-1.71± 1.00 (-4.00 +1.00)	0.08
Preop Axis of Astigmatism	100.4±69.8 (0-180)	112.2± 63.3 (10-180)	0.12
Postop Spherical error (D) (range)	-0.003±0.36 (-1.00 +1.50)	+0.11± 0.65 (-0.75 +1.50)	0.04
Postop Astigmatic error (D) (range)	-0.40±0.22 (-1.25 +0.50)	-0.85± 0.22 (-1.25 -0.50)	0.001
Postop Axis of Astigmatism	90.0±60.5 (0-180)	93.3±67.8 (5-178)	0.62

Preop: Pre-operative, **Postop:** Post-operative, **D:** diopter, *independent samples t test

Table 3. *The Comparison of Astigmatic Errors Between Different Cyclotorsion Group.*

Parameters(n)	Group 1a (192)	Group 1b (135)	Group 1c (71)
Preop Astigmatic error (D) (range)*	-1.40±1.40 (-6.00 +2.25)	-1.53±1.16 (-5.50 +1.75)	-1.47±1.27 (-5.75 -0.50)
Postop Astigmatic error (D) (range)**	-0.43±0.18 (-0.75 +0.25)	-0.44±0.19 (-0.75 +0.50)	-0.46±0.25 (-1.25 +0.50)

group 1 (< 3º), group 2 (< 6º), and group 3 (6º ≤) n: eye D: Diopter Preop: Preoperative Postop: Postoperative One Way Anova - According to bonferroni adjustment p value was significant <0.05 *p=0.58 **p=0.11

Table 4. *The Comparison of Refractive Errors Between Different Types of Astigmatism.*

Parameters(n)	With The Rule (290)	Against The Rule (60)	Oblique (48)
Preop Spherical error (D) (range)*	-1.83±2.84 (-7.75 +6.50)	-1.38±2.36 (-6.25 +4.75)	-2.32±2.35 (-6.50 +5.00)
Preop Astigmatic error (D) (range)**	-1.66±1.33 (-6.00 +2.25)	-0.95±0.92 (-5.50 +1.75)	-0.98±0.86 (-4.00 +2.00)
SCC***	-1.0±4.2 (-10+10)	-1.0±3.9 (-10+10)	-0.45±3.94 (-8+10)
Postop Spherical error (D) (range)****	-0.01±0.37 (-1.00 +1.50)	-0.03±0.28 (-0.50 +0.50)	-0.07±0.33 (-0.75 +0.50)
Postop Astigmatic error (D) (range)*****	-0.42±0.22 (-1.25 +0.25)	-0.35±0.22 (-0.75 +0.50)	-0.34±0.17 (-1.00 +0.0)

n: eye, **D:** Diopter, **Preop:** Preoperative, **Postop:** Postoperative One Way Anova - According to bonferroni adjustment p value was significant <0.05 *The preop Spherical error was similar between groups (p=0.21) **The preop astigmatic error was significantly higher in WTR than ATR and oblique group(p=0.001, p=0.002 respectively). The preop astigmatic error was similar between oblique and ATR (p=1.0). ***The SCC was similar between groups (p=0.67).**** The postop Spherical error was similar between groups (p=0.24) *****The postop astigmatic error was significantly higher in WTR than ATR and oblique group(p=0.044, p=0.039, respectively). The postop astigmatic error was similar between oblique and ATR (p=1.0) and oblique group(p=0.044, p=0.039, respectively). The postoperative astigmatic error was similar between oblique and ATR (p=1.0).

Intragroup comparison of preoperative and postoperative axis of astigmatism was shown in Table 5. The postoperative axis of astigmatism was significantly different from preoperative values in WTR and ATR group (p=0.001, p=0.01 respectively) whereas the postoperative and preoperative axis of astigmatism were similar in the oblique group, (p=018).

The preoperative and postoperative BCVA were 1.0 for all groups. We did not observe a complication related to the LASIK procedure.

DISCUSSION

The static and dynamic cyclotorsion measurements on the WaveLight EX500 Excimer laser platform is based on an algorithm that registers landmarks and patterns on the iris. These landmarks taken from the corneal images obtained from the Wavelight Topolyzer Vario Diagnostic Device are recognized by the cameras of the laser system. The angular difference between the supine and upright images is recorded as the static cyclotorsion.

It was previously suggested that an average amount of cyclotorsional misalignment would lead a 14% under-correction of astigmatism increasing with larger angles of cyclotorsion.[9] The amount of static cyclotorsion that occurs in individuals has ranged from 0 to 16 degrees in published studies.[1-4,10] The rate of static cyclotorsion more than 5° was reported as 21% and 30% by different studies.[2,11] Because we classified static cyclotorsion as counter-clockwise and clockwise we have both positive and negative values. In the current study the amount of cyclotorsion was ranging from -10° to +10°. In 71 eyes (17.8%) the SCC was higher than 5°. In eyes with a counter-clockwise rotation, the mean magnitude of SCC was -3.88°±2.29 and in eyes with a clockwise rotation, it was +3.71°±2.8. Our findings were consistent with previous data.[2,5,11] According to these findings we thought that performing SCC is as crucial as DCC.

The 2 groups defined in the current study had statictically similar preoperative demographic characteristics and refraction error values (Table 1 and 2). Both groups underwent LASIK with using same laser platform and all surgeries were performed by the same surgeon (KO). Furthermore, any dynamic cyclotorsion during the procedure was automatically compensated in all eyes. Thus, we thought that any differences in postoperative results could be related to the use of SCC. Previously, it was shown that static cyclotorsion is accurately compensated for by the Schwind Amaris laser platform.[9,12] The compensation of static cyclotorsion in patients with moderate astigmatism produces a significant improvement in refractive and astigmatic outcomes than when not compensated.[9] Furthermore, Tomita M. et al.[13] reported better refractive outcomes in patients with myopic astigmatism after adding SCC. They also used Schwind Amaris laser platform.[13] To the best of our knowledge, this is the first study that evaluated the SCC capability of the WaveLight EX500 Excimer laser platform and the influence of the astigmatic axis on the accuracy and reliability of static cyclotorsion measured by WaveLight EX500 Excimer laser platform. Consistent with previous data[9,12,13] we found that patients undergone LASIK with SCC have better refractive outcomes. Additionally, the amount of static cyclotorsion did not influence postoperative astigmatic error (Table 3). Our results supported that LASIK with SCC using the the WaveLight EX500 Excimer laser platform is safe and predictable and yields better refractive outcomes.

In the current study, we also classified the eyes in Group 1 according to axis of astigmatism, (WTR, ATR, oblique). While the preoperative spherical error was similar between groups (p=0.21), the preoperative astigmatic error was significantly higher in WTR than ATR and oblique group (p=0.001, p=0.002 respectively). All groups received comparable optimized aspheric ablation profiles according to their manifest refraction and (with incorporation of cycloplegic refraction where appropriate) where any dynamic cyclotorsion during the procedure was automatically compensated for by the dynamic eye tracker. The current study shows that the mean postoperative refractive outcomes (spherical and astigmatic error) are significantly successful in all groups according to refractive acceptability criteria. However, mean postoperative astigmatic errors were higher in WTR group than ATR and oblique groups.

Table 5: *Intragroup Comparison of Preoperative and Postoperative Axis of Astigmatism.*

Parameters (n)	**With The Rule (290)**	**Against The Rule (60)**	**Oblique (48)**
Preop Axis	106.8±78.1	88.0± 16.2	77.3± 48.1
Postop Axis	85.0±57.6	110.5± 65.0	94.7± 67.2
p*	0.001	0.01	0.18

n: eye, **D:** Diopter, **Preop:** Preoperative, **Postop:** Postoperative, *Paired Samples t test.

Additionally, it was shown that the postoperative axis of astigmatism was significantly different from preoperative axis in WTR and ATR group, while the preoperative and postoperative axis of astigmatism were similar in oblique group. According to these results, we can conclude that the software of WaveLight EX500 is able to exactly lock on to eye position and compensate for the static cyclotorsion. Though we believed that the cyclotorsion compensation on Wavelight EX500 platform was more successful in oblique group in terms of astigmatic outcome, asymmetric distribution in the number of patients could influence our results. Additionally, the high preoperative astigmatism value in WTR group could also cause the difference of postoperative astigmatism.

The main limitation of this study is the retrospective design and asymmetric distribution in the number of patients. The lack of a control group is also another limiting factor. Additionally, there is no previous data that evaluates the influence of astigmatic axis on cyclotorsion in literature, therefore we could not compare our results with previous literature. Although our results support that the oblique types of astigmatism had better refractive outcomes after compensation of static cyclotorsion, it is questionable, because we could not explain the mechanism exactly. A prospective randomized double-blind studies present more valuable information.

In conclusion, the current study shows that static cyclotorsion occurs approximately 86.5% of eyes and can range from -10° to +10°. It was also shown that the cyclotorsion is very reasonably measured and compensated with using software of WaveLight EX500 Excimer in conjunction with the Wavelight Topolyzer Vario. The cyclotorsion compensation on Wavelight EX500 platform might have better refractive outcomes in the oblique group.

Compliance with Ethical Standards:

Funding: No financial support was received for this submission.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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