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Original research

Correlation between iris-registered static and dynamic cyclotorsions with preoperative refractive astigmatism in PRK candidates

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Abstract

Purpose: To evaluate static and dynamic cyclotorsions during photorefractive keratotomy (PRK) surgery in refractive surgery candidates and their correlations with preoperative factors.

Methods: This cross-sectional case series was performed in 138 eyes of 77 patients who underwent PRK surgery by Technolas 217z100. Iris registration was used to evaluate the degree of static and dynamic cyclotorsion. Wavefront measurements were performed in sitting position using Zywave (versions 3.1 and 3.2, Bausch & Lomb) Hartmann Shack aberrometer (Bausch & Lomb), and the cyclotorsion from upright to supine position was measured using iris image comparison. Dynamic cyclotorsions were measured by Advanced Cyclotorsional Eye Tracker (ACE) mounted on Excimer laser machine Technolas 217z100 during surgery.

Results: The mean absolute static cyclotorsion that was captured in surgery time was 3.37 ± 2.38° (range, 0.00 to 11.30), and the mean absolute dynamic cyclotorsion was 2.54 ± 2.50° (range, 0.00 to 13.60). There was a significant correlation between dynamic cyclotorsions and static cyclotorsions ($P < 0.001$ and $R = 0.704$). There was a strong association between preoperative refractive astigmatism and range dynamic cyclotorsion. Total pulses ($P = 0.009$), ablation depth ($P = 0.012$), gender ($P = 0.008$) had significant correlations with cyclotorsional movements.

Conclusion: The measurements of static and dynamic cyclotorsions are highly recommended for refractive surgery candidates with significant preoperative refractive astigmatism.

Keywords: Cyclotorsions; Astigmatism; Refractive surgery

Introduction

During laser excimer surgery, unpredictable ocular movements may happen. The most common movements are horizontal and vertical which are effectively compensated by dynamic eye trackers.[1] Cyclotorsions are another type of eye movements which are characterized by rotational movements of the eye around the optical axis.[1,2] Cyclotorsions are dependent on the motion and orientation of the body; therefore, rotation occurs as the body position changes.[3,4] Static cyclotorsion can happen when patients move from an upright or sitting position to supine position exactly before the surgery. Dynamic cyclotorsion is the measurement of cyclotorsion movements during the refractive surgery.[5,6] These movements are further divided in two categories, incyclotorsion and excyclotorsion. During incyclotorsion, the eyes nasally rotate inward which means the right eye turns clockwise whilst the left eye turns counterclockwise, and excyclotorsion revolves temporally outward rotation of the eyes that is counterclockwise rotation for the right eye and clockwise rotation of the left eye.[7]

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Several studies have suggested that higher amounts of cyclotorsion occur in monocular viewing conditions such as during laser excimer surgery.[8–10] In laser excimer surgery, one eye is covered by a microshield or a surgical drape and, consequently, causes the other eye to significantly rotate.[11]

The importance of cyclotorsional errors is more prominent in patients with high preoperative astigmatism and higher order aberrations. For example, three-degree axis change can cause 10% reduction of the optimal astigmatism correction in the laser excimer surgery.[12] Without compensation, these cyclotorsions can decrease the efficiency of the surgery outcomes and misplacement of laser ablation which subsequently induce irregular astigmatism and poor correction of the visual acuity.[13]

To optimize the success rate of this system, a component is required to considerably reduce the side effects of the surgery by putting the laser beam in an accurate position.[2,12]

There are several ways to correct the cyclotorsional errors. One way is to manually align limb marks to the ocular reticule of the laser microscope. On top of existing eye-tracking systems, laser manufacturers have added automated registration technologies able to compensate for the cyclotorsional movement and pupil centroid shift that occurs between the wavefront assessment, laser treatment in order to assure precise alignment of the wavefront map, and laser ablation in all axes. Iris registration is a new technique to restore maximum visual acuity with an advantage of keeping the laser on target while tracking cyclotorsional movement of the eye by surgeons.[8] According to previous studies, the benefit of iris registration technique during laser refractory surgery is controversial. Some studies have reported better outcomes with this technique when compared with traditional methods while the other studies have shown no advantage of utilizing the iris registration.[14–18]

In this study, we have assessed the amount of static and dynamic cyclotorsion in patients who underwent laser excimer surgery and evaluated some associated factors that may affect cyclotorsion errors and surgery outcome.

Methods

In this cross-sectional study, we measured the degree of static and dynamic cyclotorsion that occurred in patients who underwent photorefractive keratotomy (PRK), Personalized Wave-Front-Guided treatment (with 6 mm optical zone) to correct the refractive errors due to high astigmatism, myopia, and hyperopia. All surgeries were performed in Farabi Eye Hospital, affiliated with Tehran University of Medical Sciences and Health Services, between April and September 2012 by the same ophthalmologist. The Ethics Committee at Tehran University of Medical Sciences approved the study protocol, and the study was performed based on the tenets of the Declaration of Helsinki.

All patients in this study received PRK with the Technolas 217z100 excimer laser system (Bausch & Lomb). Inclusion criteria in this study were stable refractive errors for at least two years, spherical equivalent refraction less than 10.00 D, central keratometry of at most 48.00 (D) with inferior-superior (I–S) value less than 1.4 D, and best spectacle-corrected visual acuity of more than 20/25. The exclusion criteria were keratoconus, previous history of refractive or cataract surgery, collagen vascular disease, diabetic retinopathy, and irregular astigmatism.

Preoperation ophthalmic examinations included Snellen E chart visual acuity test, manifest and cycloplegic refraction, indirect ophthalmoscopy, corneal topography, applanation tonometry, slit-lamp microscopy, and wavefront measurements under mesopic condition (3 cd/m^2). Pupil diameter was measured using wavefront sensor, and all wavefront maps were standardized for pupil diameter of 6 mm. Corneal topography and wavefront measurements were performed in sitting position using the Orbscan IIz (Bausch & Lomb, Surrey, United Kingdom) and Zywave II, Hartmann Shack aberrometer (Bausch & Lomb), respectively.

Torsional data

The amount of cyclotorsion in supine position before surgery was measured by the iris registration system of Zyoptix 217z100 excimer laser and compared with preoperative sitting position which resulting static cyclotorsion. The amounts of dynamic cyclotorsion of right eye and then left eye were measured by Advanced Cyclotorsional Eye Tracker (ACE) mounted on Excimer laser machine Technolas 217Z during surgery.

Torsional movement data was collected as static cyclotorsion, the mean dynamic cyclotorsion, the lowest and the highest dynamic cyclotorsion, absolute range of dynamic cyclotorsion (absolute differences between the lowest and highest value for each eye). All eyes underwent three measurements, and the average of these quantities was used for the final analysis. A positive value of cyclotorsion indicates clockwise rotation of the eyes, and negative value presents counterclockwise rotation. Based on these definitions, encyclotorsion is defined as positive value for right eye and negative value for left eye while excyclotorsion is described as negative value for right eye and positive for left eye. We separately recorded the static encyclotorsion and excyclotorsion for each eye and evaluated the percentage of dynamic encyclotorsion or excyclotorsion or both.

Statistical analysis

We used one-sample *t*-test to analyze the amount of cyclotorsional movement, assessed significant torsion, and compared it with zero value. Linear regression and partial correlation were used to find significant correlation between suggestive factors (age, sex, laterality, refractive errors, total pulse, and ablation) and torsional movements (static and dynamic cyclotorsion, encyclotorsion, and excyclotorsion). Significant differences were considered as P-value < 0.05. All data were analyzed using Statistical Package for Social Sciences (SPSS) version 16 software for Windows (IBM Inc., Chicago, Illinois, USA).

Results

We recruited 77 patients for this study, and 138 eyes were evaluated. The mean age of the participants was 27.53 ± 5.82 years old (range, 20 to 56). Fifty eyes were from male participants, and eighty-eight were from females with a ratio of 1.76. There were 67 right eyes and 71 left eyes. The mean value of total pulses was 2834.4 ± 1258.12 (range, 731 to 7115), and ablation depth was 71.52 ± 28.5 μm (range, 20 to 156). Regarding refractive errors, the mean amount of myopia and astigmatism were 2.7 ± 1.7 D (range, 0.25 to 7.25D) and 1.4 ± 1.0 D (range, 0.25 to 5.50 D), respectively. Moreover, the mean amount of hyperopic refraction was 2.4 ± 1.4 (0.75−4.50) (Table 1).

The range of measurement time after the patient shifted into supine position was 30−60 s. The mean amount of static cyclotorsion was 0.64 ± 4.08° (range, −7.40 to 11.30 D). Only seven eyes (5% out of 138 eyes) did not rotate from sitting to supine position (Fig. 1). The mean absolute static cyclotorsion was 3.37 ± 2.38° (range, 0.00 to 11.30) which is significantly greater than zero value in one-sample *t*-test ($P < 0.001$, CI 95%: 2.96 to 3.76) (Table 2). In the male group (50 eyes), the absolute mean static cyclotorsion was 4.8 ± 3.06°, and in the female group (88 eyes), it was 2.96 ± 2.22° ($P < 0.001$). Sixty-three eyes (46%) showed static encyclotorsion, and static excyclotorsion occurred in 68 eyes (54%).

The mean amount of dynamic cyclotorsion that was captured in surgery time was 0.21 ± 3.57° (range, −13.60 to 11.30). One hundred and nineteen eyes (86%) rotated less than five degrees, 135 eyes (97%) less than 10°, and only three eyes manifested dynamic cyclotorsion more than 10° (Fig. 2). The mean absolute dynamic cyclotorsion was 2.54 ± 2.50° (range, 0.00 to 13.60). The mean range of dynamic cyclotorsion during surgery was 3.44 ± 1.52° (range, 0.70 to 9.90) which is significantly greater than zero as normal value ($P < 0.001$, 95% CI: 3.18 to 3.69) (Table 2).

Overall, 40 eyes (29%) revolved dynamic incyclotorsion, whereas dynamic excyclotorsion occurred in 42 eyes (30%), and 56 eyes (41%) rotated both incyclotorsion and excyclotorsion. The mean measurement and range of dynamic incyclotorsion and excyclotorsion are shown in Table 2. In 67 right eyes (48% of 138 eyes), 28 eyes (41% of 67 cases) showed incyclotorsion (mean value was 4.23 ± 2.34°), 27 eyes (40%) had excyclotorsions (mean value was −4.16 ± 2.84°), and 12 eyes (19%) had both incyclotorsions and excyclotorsions. In 71 left eyes (52% of 138 eyes), 12 eyes (17%) had incyclotorsions (mean value was −2.15 ± 2.02°) whilst 15 eyes (21%) manifested excyclotorsion (mean value = 2.91 ± 3°), and 44 eyes (62%) had mixed incyclotorsion and excyclotorsion. In this study, only three eyes (0.02) rotated more than 10° in dynamic cyclotorsion, and there were no eyes with no rotation during the operation.

There was a significant correlation between the mean dynamic and static cyclotorsions, showing an upward trend ($P < 0.001$ and $R = 0.704$) (Fig. 3).

There were statistically significant correlations between absolute amount of static cyclotorsion and gender ($P = 0.008$, Pearson correlation 0.21, male 4.8 ± 3.06° and female 2.96 ± 2.22°). However, there was no significant correlation between absolute static cyclotorsions and laterality (left vs. right eyes $P = 0.99$), astigmatism ($P = 0.97$), and age ($P = 0.45$).

As shown in Fig. 4, the main factor which has a significant correlation with dynamic cyclotorsion is total pulses ($P = 0.009$, Partial correlation 0.22).

There were no correlation with age ($P = 0.5$), gender ($P = 0.63$), eye side (right or left $P = 0.48$), myopia ($P = 0.59$), and hyperopic ($P = 0.35$). However, the absolute mean of mean dynamic cyclotorsion was significantly correlated with laterality (right eyes vs. left ones, $P = 0.001$, Pearson correlation = 0.43). The mean absolute amount of dynamic cyclotorsion in the right eyes was 3.67 ± 2.60°, while that of the left eyes was 1.48 ± 1.87°.

Table 1
Preoperative demographic features and refractive data in refractive surgery candidates.

Patient's characteristic	Mean	Standard deviation	Minimum	Maximum
Age (Year)	27.5	5.8	20	56
Total pulses	2864.4	1258.4	731	7115
Ablation depth (Micrometer)	71.5	28.5	20	156
Pachymetry (Micrometer)	546.6	36.5	462	679
Myopia (Diopter)	2.7	1.7	0.25	7.25
Hyperopia (Diopter)	2.4	1.4	0.75	4.50
Astigmatism (Diopter)	1.4	1.0	0.25	5.50

Discussion

Misalignment of photoablation due to cyclotorsions results in induced irregular tertiary astigmatism, leading to image distortion and high order aberration such as spherical aberration and coma, which cannot both be corrected even by prescribed glasses. In this study, we evaluated the amount of static and dynamic cyclotorsions during laser excimer surgery. We found the correlation between static cyclotorsion and the mean of dynamic cyclotorsion and gender. Moreover, there were significant correlations between the amount of dynamic cyclotorsion and astigmatism, laterality (right vs. left eyes) and total pulses.

There are various reports on the amount of static cyclotorsion in previous studies. In this study, the mean absolute amount of static cyclotorsion was 3.37 ± 2.38°. Prakash et al.[19] have reported the amount of cyclotorsion of 3.64 ± 2.79°, and Ciccio et al.[18] have noted the mean amount of static cyclotorsion is 4.05° in 1019 eyes undergoing wavefront-guided refractive surgery. In both studies, the reported static cyclotorsions are larger than our findings. However, Febbraro et al.[17] (mean static cyclotorsion, 3.08 ± 2.68°) and Arba-Mosquera et al.[20] (mean static cyclotorsion, 3.1 ± 4.1°) have reported a fairly similar amount of cyclotorsion compared to the present study.

As regards dynamic cyclotorsion, the mean dynamic cyclotorsion in our study is 2.54 ± 2.50°. This slightly larger than Chang et al.[4] (the mean dynamic cyclotorsion, 2.181 ± 1.392°) and lower than Prakash et al.[19] (the mean dynamic cyclotorsion is 3.81 ± 2.97°) and Febbraro et al.[17]

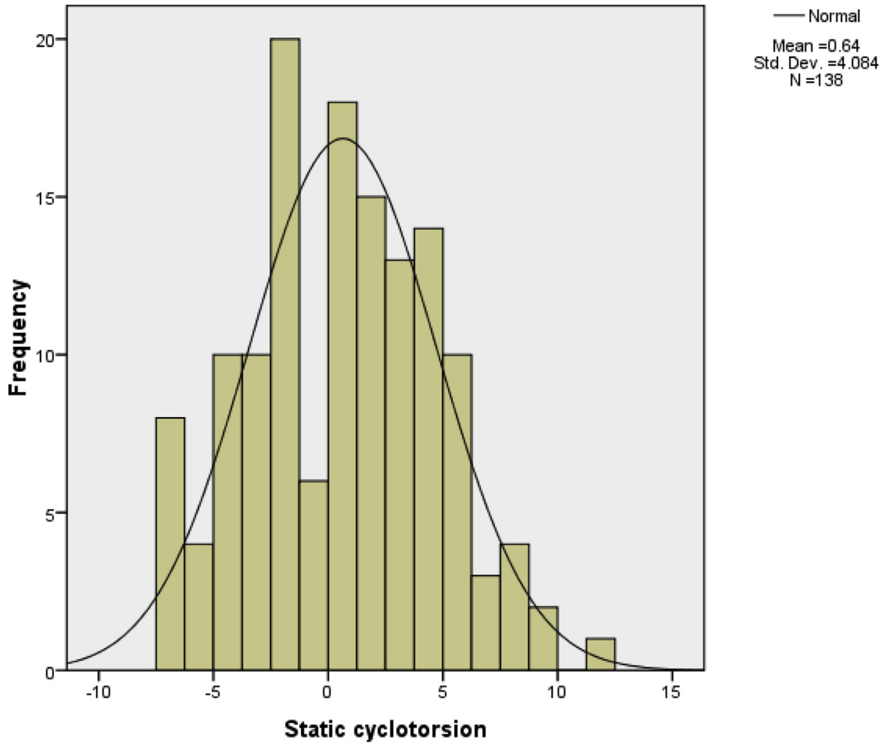

Fig. 1. Histogram distribution of static (preablation) cyclotorsion. It follows the normal curve distribution.

(the mean dynamic cyclotorsion, 3.39 ± 2.94°). The differences in the amount of cyclotorsions could be due to several factors such as different types of iris registration devices or dynamic eye trackers used for measuring, various types of laser excimer surgery, and demographic features (age, race, sex). There was no dominant tendency in eyes to rotate encyclotorsion or excyclotorsion in dynamic cyclotorsion.

We had only 3 eyes (0.02) rotate more than 10° in dynamic cyclotorsion although Chang[5] reported that 4% of eyes rotated more than 10°. Moreover, Chen et al.[15] have stated that even 2° of cyclotorsion induce higher order aberration 50% more than usual.

In our study, we found a significant correlation between static and mean dynamic cyclotorsion ($P < 0.001$). Prakash et al.[19] have reported the similar correlation between static and dynamic cyclotorsion and noted that the tendency of eyes to rotate before surgery can affect on the amount of cyclotorsions during surgery. However, Febbraro et al.[18] did not observe any correlation between static cyclotorsions and dynamic cyclotorsions, commenting that cyclotorsions are unpredictable movements. Furthermore, suboptimal positioning from sitting to supine before surgery can cause significant static cyclotorsion, and this position may induce significant dynamic cyclotorsion during surgery. This finding helps us to use better and advanced dynamic eye tracker to measure and compensate the dynamic cyclotorsions when we detect the high amount of static cyclotorsions before the ablation in order to have a less residual refractive error. Moreover, it is beneficial to reposition patients before surgery when significant amounts of static cyclotorsions are detected, which result in compensating static cyclotorsion and, consequently, smaller amounts of dynamic cyclotorsions due to optimal position.

In our study, there was a significant correlation between range of dynamic cyclotorsion and the amount of preoperative astigmatism, which could be due to difficulty for patients with high astigmatism to keep focusing on laser beam during surgery. On the other hand, the length of surgery in patients with high astigmatism is longer due to increased ablation time that may lead to greater cyclotorsional movements. This finding shows the importance of using dynamic eye tracker during

Table 2
Cyclotorsional movement statistics in examined eyes.

Cyclotorsional movement	Mean	Standard deviation	Minimum	Maximum
Static cyclotorsion (Degree)	0.64	4.08	−7.40	11.30
Absolute static cyclotorsion (Degree)	3.37	2.38	0.00	11.30
Mean dynamic cyclotorsion (Degree)	0.21	3.57	−13.60	11.30
Absolute mean dynamic cyclotorsion (Degree)	2.54	2.50	0.00	13.60
Range of dynamic cyclotorsion (Degree)	3.44	1.52	0.70	9.90
Absolute dynamic encyclotorsion (Degree)	2.70	2.45	0.00	8.80
Absolute dynamic excyclotorsion (Degree)	2.42	2.54	0.00	13.60

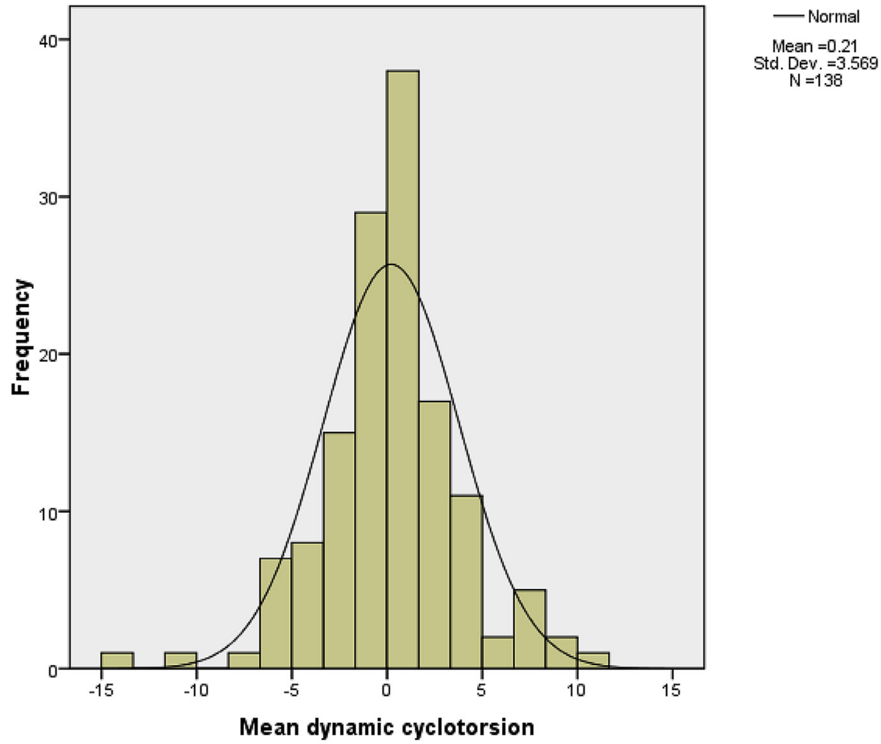

Fig. 2. Histogram distribution of dynamic cyclotorsion. There are few eyes rotating more than ±10°. Follows the normal curve distribution.

excimer surgery for patients with high astigmatism. Furthermore, faster or easier laser excimer technique can be used beside extensive preoperative evaluation in order to decrease the amount of residual astigmatism.

We found significant correlations between range of dynamic cyclotorsion movements during surgery and total pulses. Prakash et al.[19] have reported significant correlation between cyclotorsional movements and amount of pulses and

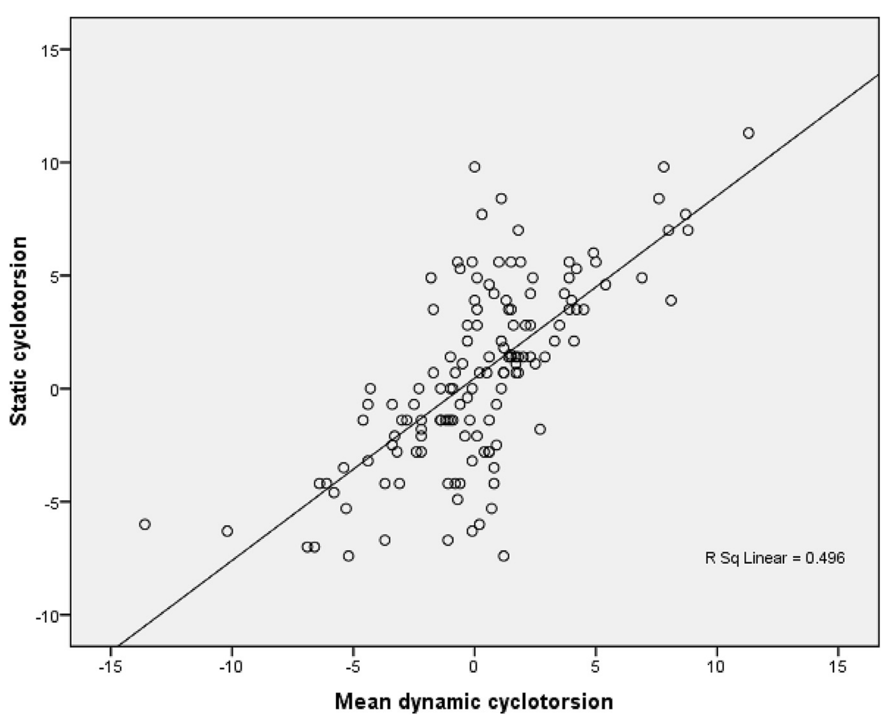

Fig. 3. Scatterplot reveals the relationship between static cyclotorsion on the y-axis and mean dynamic cyclotorsion on the x-axis. There was a significant correlation between static cyclotorsion and mean dynamic cyclotorsion, and the trend was obviously upwards.

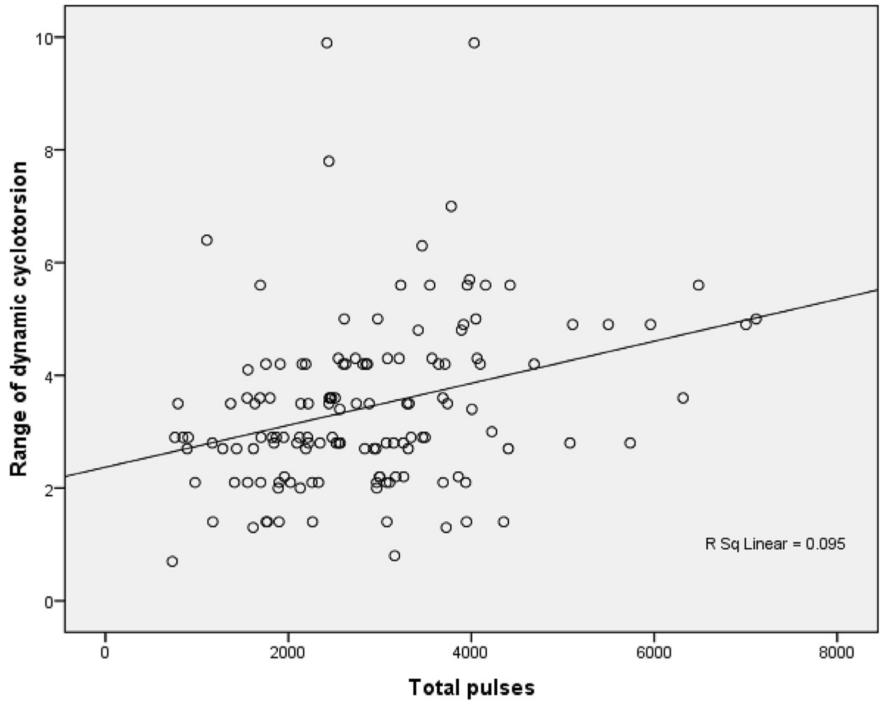

Fig. 4. Scatterplot between range of dynamic cyclotorsion on the y-axis and total pulses on the x-axis. The significant correlation between range of dynamic cyclotorsion and total pulses was seen.

partial correlation with ablation depth at time of surgery.[19] As the duration of surgery become longer, eyes get tired to focus on the laser guide beam and start to move. Also, there is more chance to move in eyes in longer time naturally. The factors related to the time of surgery are total pulses. We used partial correlation to control astigmatism refractive errors (confounding factor), causing an increase in total pulses and ablation depth. The other factors affecting these two variables are optical zone and type of treatment, both of which are constant in our study (Personalized Wave-front-Guided treatment with 6 mm optical zone). We can apply new excimer laser technique to reduce the length of surgery in order to have minor cyclotorsions or use of dynamic eye tracker when there is probability of long surgery time to compensate for these torsional movements to improve the surgical outcomes.

We noted that there was a significant correlation between the absolute amount of static cyclotorsion and sex ($P = 0.008$). This highlights the importance of using compensating devices like iris registration for better results in male candidates. Prakash et al.[19] reported a significant correlation of dynamic cyclotorsion with gender; however, they found a greater amount of cyclotorsion in the female group. Also in this study, the absolute mean of dynamic cyclotorsion was significantly correlated with laterality ($P = 0.001$). There was a greater tendency to rotate during the laser excimer surgery in the right eyes, which may be due to higher levels of anxiety during the first eye (right side) surgery.

There was not any significant correlation between cyclotorsional movements with age or myopic and hyperopic refraction. However, Prakash et al.[19] reported a significant correlation of dynamic cyclotorsion with age. The author stated that increased age might affect the cooperation of patients during surgery.[19]

There were some limitations in our study. First, we did not compare the result of this study with the outcome of surgery without using iris registration and dynamic eye tracker. Other limitations were small sample size and inclusion of both eyes in analysis. We did not measure the results of the surgery with registration either. Second, this study did not include patient follow-up to detect the residual refractive errors or any other complications to evaluate long-term efficacy of the dynamic eye tracker. For further studies, we recommend using another eye measurement tracker for cyclotorsional movements to compare repeatability and reliability of the results.

In conclusion, this study shows significant correlation between preoperative astigmatism and dynamic cyclotorsion. We observed a significant correlation between static cyclotorsions and dynamic cyclotorsions. We noted that the longer the length of surgery, the higher the degree of intraoperative cyclotorsion. There was a larger amount of preablation cyclotorsions in the male group and dynamic cyclotorsions in right eyes. In this study, we found that the amount of cyclotorsional movements in most patients were not significant (range $\pm 2°$).

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