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A Comparative Assessment of Ocular Aberrations Before and After LASEK Surgery in Hyperopic and Hyperopic Astigmatism Patients

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Abstract

Background and aim: The studies have shown that by an increase in the aberrations and visual performance might be affected by the ocular aberrations after the corneal refractive surgery. This study was to investigate the effects of LASEK surgery on the ocular aberrations in hyperopic and hyperopic astigmatism patients.

Methods: In this analytical and descriptive study 35 patients (11 men, 24 women) having LASEK surgery using the Technolas 217 z were divided into 3 groups of preoperative hyperopia as mild (+0.50-+1.75), moderate (+2.00-+3.00), and high (+3.25-+5.00). The preoperative and 6 month postoperative UCVA, BSCVA, subjective refraction, HOAs values of coma, trefoil, spherical aberration, 2nd astigmatism, quadrafoil, pentafoil, total higher-order aberrations were measured with 6 mm pupils using the zywave II aberrometer. The mean spherical equivalent, hyperopia, cylinder, HOAs, and total aberrations were compared to LASEK surgery on optical qualify of the eye.

Results: Total aberrations significantly decreased after hyperopic LASEK in all of groups but HOAs increased after LASEK in three groups for a 6 mm pupil, especially 4th order aberration (Z40) and 2nd astigmatism (Z42). The largest increase occurred in spherical aberration and 2nd astigmatism. The Spherical aberration (Z40) was greater for high hyperopia group with larger hyperopia and moderate astigmatism. The spherical aberration showed a shift (toward positive values) of opposite sign. The 2nd astigmatism was greater for mild and moderate hyperopia group. Postoperative UCVA was same in mild and moderate hyperopia group and better than high hyperopia group.

Conclusions: Wave-front LASEK surgery using Technolas 217 Z was an effective, safe, and predictable procedure for treating hyperopic and hyperopic astigmatism patients with hyperopia up to +3.25 and astigmatism less than -3.00, but in hyperopic patients with hyperopia more than +3.25 due to a significant increase in high-order aberrations (HOAs) and further reduction of visual acuity didn't seem appropriate approach.

Keywords: Hyperopia; Astigmatism; Higher-order aberrations; LASEK surgery

Introduction

The refractive errors are the most common of all vision problems in the world and have always attracted scientists. In the past, refractive error was corrected only with glasses or contact lenses. Today, in addition to glasses and contact lens, refractive surgery procedures such as RK, PRK, LASIK, LASEK and Femtosecond are used. At the inception of refractive correction by refractive surgery procedures the sole purpose was correcting refractive errors and lack of dependence patients on glasses or lenses but numerous complaints voiced by patients, such as halos, monocular double vision and starburst were made scientists are looking for ways to improve the quality of their vision. The complaints can be seen even when surgery is successful and the prevalence of these complaints have been reported from 3 to 43% in different studies [1-4].

For normal eyes, the refractive errors are the most important optical defects and higher-order aberrations become of consequence only once these refractive errors are corrected [3]. With the advances in the wave-front analysis and laser technology, it is now possible to detect and surgically correct most of the optical aberrations and refractive errors of the cornea and other ocular media [5]. Several studies have shown that the corneal higher-order aberrations (HOAs) are increased after refractive surgery. Although most changes are in the anterior surface of the cornea, however, several groups have reported that postoperative changes also arise in the posterior corneal and changes in corneal aberrations in the eye would change the total ocular aberrations and will ultimately affect the optical performance of visual system [1,6-8].

Most of conducted studies in other countries about the aberrations, are on the normal population [1], or to compare myopia and hyperopia [9] or effects of LASEK surgery on aberrations have been compared by two different methods [10,11], however, few studies have been conducted on higher-order aberrations changes in hyperopic patients after wave-front LASEK surgery, because it is difficult to make conclusions about aberrations in hyperopic eyes from large-scale population studies as usually there were relatively few hyperopic eyes or age is a confounding parameter.

Wave-front LASEK can be done to reduce all higher-order aberrations or certain aberrations. It can also be customized to the patient [1]. Correction of irregular astigmatisms and higher-order aberrations by wave-front refractive surgery or glasses and contact lenses that are designed with the wave-front technology from a theoretical point of view will enable us to achieve the supernormal

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vision (natural and uncorrected vision 20/15 or better) [3]. Benefits of this surgery can include increased vigilance (e.g. visual acuity with Snellen chart) and visual quality (e.g. contrast sensitivity). Wave-front LASEK also reduces night vision problems after LASEK that are caused due to the increase aberrations. Different studies that have compared standard LASEK with wave-front LASEK show superiority of wave-front LASEK. However, there is limited evidence that the wave-front always is not superior to standard LASEK that does not have the optical broad zone, gentle slope to the periphery, eye trackers and other technical refinements. Studies have shown the higher-order aberrations can increase after wave-front LASEK, in particular, in eyes that their high-order aberrations were down before surgery. In addition, comparison of different laser platforms have shown varying degrees of improvement, some of them have led to advances in all higher-order aberrations while others have corrected only certain high-order aberrations. This shows that we need to improve the algorithms laser, and further studies are required to consistently deliver better results with wave-front LASEK compared to standard LASEK [6].

In this study, the basic question is:

Whether wave-front LASEK surgery in hyperopic and hyperopic astigmatism patients the following are changes that will lead to the improvement of aberrations?

Materials and Methods

In this study, 35 hyperopic and hyperopic astigmatism patients that had LASEK surgery with Technolas 217 Z in Negah super specialty hospital were studied. All patients were operated by a physician, and from March 2011 onwards. Surgery was performed in all patients with wave-front. In 31 patients, surgery was performed on both eyes and in 4 patients on one eye. Because refractive surgery requires great care, ophthalmologic and optometric full eye examination before the operation was carefully performed and patients were selected for surgery only when had all the necessary criteria. Subjects were selected based on the following inclusion criteria; age between 20 and 50 years, hyperopia between +0.50 and +5.00 diopters (D), refractive astigmatism up to -3.00. Excluded criteria were:

- Best corrected visual acuity with spectacles (BSCVA) of less than 20/60
- Pupil size less than 6 mm
- IOP higher than 21 mmHg
- Central corneal thickness less than 480 microns with pachymeter Nidek (Model UP-1000)
- History of trauma or eye surgery, eye diseases, systemic diseases such as diabetes and rheumatoid arthritis
- abnormal findings in the retina or optic disc

About the details, risks, and benefits were discussed with the patient and ocular examinations were performed with the full consent of them. Informed consent was obtained from each subject before participation. At the time of enrollment, all patients underwent comprehensive ophthalmologic and optometric examinations that included, uncorrected and corrected visual acuity (UCVA, BSCVA), refraction as objective and subjective, slit lamp evaluation, dilated fundus evaluation, corneal topography, and wave-front aberration measurements. Patients that had passed at least 6 months since their operations were called to the clinic for further examinations and similar examinations were repeated. All examinations were performed by an optometrist or ophthalmologist. Aberrometry was performed with a Zywave II aberrometer (Bausch & Lomb, Rochester, NY, USA) in a dark room. Aberrometry in patients who used hard or soft contact lenses was performed two to four weeks after removing the lens, respectively. As regards, LASEK surgery is different in depth and pattern ablation and are determined based on the amount of hyperopia and astigmatism, also aberrations before and after surgery depends on the amount of hyperopia and astigmatism, thus the patients were divided into three groups according to the amount of subjective hyperopia. Values between +0.50 and +1.75 have been considered in mild hyperopia group, between +2.00 and +3.00 in moderate hyperopia group and high hyperopia group between +3.25 and +5.00.

The necessary information was recorded in a special file, and then after data collection, statistical analysis of all tests was performed with SPSS 19 software. Tables, charts and statistical indicators were used to describe data, and paired T-test (in the case of normal data) or an equivalent test in nonparametric statistics (in case of non-normal data) was used for data analysis. Analysis of variance (ANOVA) was performed to explore effects of LASEK surgery on the aberrations in different groups of hyperopia.

Results

The study enrolled 35 patients (11 men, 24 women), four patients did not complete the study's follow-up protocol and were unavailable at the postoperative examination; their data were removed from the series. The final analysis included 31 patients. 58 eyes of 31 patients were studied. Of these numbers 23 eyes were in mild hyperopia group, 18 eyes in moderate hyperopia group and 17 eyes in high hyperopiagroup. A probability of less than 5% ($p<0.05$) was considered statistically significant. The parameters analyzed included (1) the mean of sphere, cylinder and spherical equivalent (2) the RMS of spherical aberration, coma, Trefoil, 2nd astigmatism, Quadrafoil and Pentafoil (3) The RMS of total aberrations and total HOAs up to the 5th order. The mean and standard deviation for each of the variables summarized in tables 1-3. The RMS for each of aberrations was calculated according to instructions of Optical Society of America, and Zywave II instructions [1,12,13].

Based on this information:

RMS of coma includes: The square root of the sum of squared coefficients of z_3^1, z_3^{-1}, z_5^1 and z_5^{-1}.

RMS of Trefoil is: The square root of the sum of squared coefficients of z_3^3, z_3^{-3}, z_5^3 and z_5^{-3}.

RMS of secondary astigmatism is: The square root of the sum of squared coefficients of z_4^2 and z_4^{-2}.

RMS of Quadrafoil is: The square root of the sum of squared coefficients of z_4^4 and z_4^{-4}.

RMS of Pentafoil is: The square root of the sum of squared coefficients of $z_5^5$and z_5^{-5}.

Root Mean Square (RMS) of higher-order aberrations (HOAs) is: The square root of the sum of squared coefficients of Z_3^1, z_3^{-1}, Z_3^3, z_3^{-3}, z_4^0, z_4^2, z_4^{-2}, z_4^4, z_4^{-4}, Z_5^1, z_5^{-1}, Z_5^3, z_5^{-3}, z_5^5 z_5^{-5}.

Effects of LASEK surgery on visual acuity

The following are all the data related to BCVA and UCVA in different groups:

In mild hyperopia group preoperatively, BCVA was 10/10 in

22 eyes (95.65%), 9/10 in 1 eye (4.34%), postoperative BCVA didn't change. Postoperatively, the UCVA was a 10/10 in 12 eyes (52.17%), a 9/10 in 7 eyes (30/43%), an 8/10 in 2 eyes (8.69%) and a 7/10 in 2 eyes (8.69%). The UCVA was a 9/10 in 19 eyes (82.6%). The safety index calculated by dividing the percentage of the postoperative BCVA on the percentage of preoperative BCVA [14,15]. So the safety Index was 1.00 for this group. The efficacy is calculated by dividing the percentage of postoperative UCVA on the percentage of preoperative BCVA [14,15]. So the efficacy Index was 0.52.

In moderate hyperopia group the corrected visual acuity with spectacle (BCVA) didn't differ before and after surgery, (i.e. preoperative and postoperative BCVA was a 10/10 in 23 eyes (100%). Postoperatively, the UCVA was a 10/10 in 9 eyes (50%), a 9/10 in 6 eyes (33.33%), an 8/10 in 3 eyes (16.66%). The UCVA was a 9/10 in 15 eyes (83.33%). The safety index and the efficacy Index were, respectively: 1.00 and 0.50 for this group.

In high hyperopia group with larger hyperopia and moderate astigmatism, the preoperative BCVA was a 10/10 in 14 eyes (82.35%), a 9/10 in 3 eyes (17.64%), however postoperatively, BCVA decreased so that the BCVA was a 10/10 in 12 eyes (70.58%), 9/10 in 4eyes (23.52%) and one eye (5.88%) had a BCVA of 7/10.

The postoperative UCVA also showed decrease, so the UCVA was a 10/10 in 7 eyes (41.47%), a 9/10 in 5 eyes (29.41%), an 8/10 in 3 eyes (17.64%), 7/10 in one eye (5.88%) and 6/10 in one eye (5.88%). The UCVA was a 9/10 in 12 eyes (70.58). The safety and the efficacy Index were, respectively: 0.86 and 0.50 for this group.

Effects of LASEK surgery on refraction

Table 1 shows the mean preoperative and postoperative hyperopia, cylinder and spherical equivalent refraction in three groups. The comparison of them shows that hyperopia, cylinder and spherical equivalent refraction successfully corrected after LASEK surgery.

Effects of LASEK surgery on Higher-order aberrations

The following are all the data displays available:

- The Root Mean Square of spherical aberration, coma, trefoil, 2nd astigmatism, quadrafoil, pentafoil
- The RMS of total wave-front aberrations up to 5th order
- The RMS of Higher-order wave-front: remaining wave-front aberrations after correction of the sphere and cylinder

The values of the parameters for each variable are shown in table 2.

Statistically significant changes in total wave-front aberrations and total HOAs after wave-front LASEK surgery were seen in the three groups. In mild hyperopia group, changes of 2nd astigmatism RMS ($p<0.01$) was statistically significant. In moderate hyperopia group, exception trefoil (P= 0.491) and quadrafoil (P= 0.521), changes of other aberrations were statistically significant. However in high hyperopia group, all aberrations significantly increased after surgery exception trefoil (P= 0.224).

Comparison of effects of LASEK surgery on the aberrations in the three groups of hyperopia

Comparison of mean difference of aberrations between the three groups of hyperopic and hyperopic astigmatism patients before and after LASEK surgery was performed by ANOVA to evaluate the effect of LASEK surgery on aberrations in the different groups. To compare between the groups, the aberrations were calculated before and after surgery then the mean differences analysis was performed using ANOVA. In fact the mean changes of aberrations were compared between groups.

Table 3 shows the mean difference of RMS of aberrations before and after surgery. The comparison of them showed that the mean difference of RMS of spherical aberration, coma, 2nd astigmatism,

	(+0.50 - +1.75)			(+2.00 - +3.00)			(+3.25 - +5.00)		
	Pre	**Post**		**Pre**	**Post**		**Pre**	**Post**	
	Mean ± SD	Mean ± SD	P-value	Mean ± SD	Mean ± SD	P-value	Mean ± SD	Mean ± SD	P-value
Sphere	+0.86 ± 0.29	0.50 ± 0.57	0.025	+2.18 ± 0.29	0.36 ± 0.42	<0.01	+3.95 ± 0.65	0.52 ± 0.98	<0.01
cylinder	-2.30 ± 0.72	-0.49 ± 0.37	<0.01	-0.93 ± 1.15	-0.30 ± 0.38	0.023	-0.81 ± 0.94	-0.45 ± 0.39	0.19
SE	-0.29 ± 0.59	0.25 ± 0.49	0.008	+1.71 ± 0.45	0.19 ± 0.33	<0.01	+3.53 ± 0.72	0.30 ± 0.64	<0.01
Pre=Preoperative Post=Postoperative SE=Spherical Equivalent									

Table 1: Preoperative and postoperative mean and standard deviation of sphere, cylinder and spherical equivalent in different groups of hyperopia.

	+0.50 - +1.75			+2.00 - +3.00			+3.25 - +5.00		
	Pre	post		Pre	post		Pre	post	
	Mean ± SD	Mean ± SD	P-value	Mean ± SD	Mean ± SD	P-value	Mean ± SD	Mean ± SD	P-value
Spherical aberration	0.13±0.10	0.14±0.13	0.90	0.10±0.09	0.26±0.18	0.005	0.24±0.19	0.40±0.18	0.02
Coma	0.22±0.16	0.29±0.18	0.073	0.23±0.12	0.35±0.17	0.012	0.24±0.13	0.66±0.21	<0.01
Trefoil	0.22±0.10	0.24±0.16	0.781	0.17±0.09	0.19±0.09	0.491	0.18±0.09	0.24±0.13	0.224
2nd astigmatism	0.08±0.05	0.29±0.14	<0.01	0.05±0.02	0.12±0.08	0.003	0.08±0.03	0.16±0.08	0.006
Quadrafoil	0.05±0.03	0.07±0.04	0.09	0.08±0.03	0.09±0.05	0.521	0.07±0.03	0.11±o.o5	0.023
Pentafoil	0.04±0.02	0.04±0.02	0.590	0.03±0.01	0.07±0.03	<0.01	0.04±0.03	0.07±0.03	0.029
HOAs	0.39±0.15	0.55±0.22	0.005	0.35±0.10	0.55±0.18	0.001	0.44±0.19	0.88±0.20	<0.01
Total aberrations	3.38±0.93	1.89±0.85	<0.01	3.25±0.76	1.82±0.66	<0.01	5.15±0.96	3.14±1.36	<0.01
Pre= Preoperative Post= Postoperative									

Table 2: The distribution of the mean RMS of aberrations before and after wave-front LASEK surgery on hyperopic and hyperopic astigmatism patients in the three groups of (+0.50 - +1.75), (+2.00 - +3.00) and (+3.25 - +5.00).

pentafoil, and HOAs was statistically significant (Figure 1). Therefore a one way analysis of variance showed that the effect of wave-front LASEEK surgery on spherical aberration (P= 0.023), coma (P=<0.001), 2nd astigmatism (0.001), pentafoil (P= 0.001), and HOAs (0.001) was significant.

Post hoc analysis using the Bonferroni also showed the following results

The mean difference of coma change between mild and high hyperopia group (P<0.001), and moderate and high hyperopia group (P=0.017) was statistically significant.

The mean difference of 2nd astigmatism change between mild and moderate hyperopia group (P= 0.003), and mild and high hyperopia group (P=0.004).

The mean difference of pentafoil change between mild and moderate hyperopia group (P=0.001), and mild and high hyperopia group (P=0.048) was statistically significant.

The mean difference of HOAs change between mild and high hyperopia group (P=0.002), and moderate and high hyperopia group (P=0.012) was statistically significant.

There wasn't statistically significant change in spherical aberration, trefoil, quadrafoil, and total aberrations after wave-front LASEK surgery between the different groups of hyperopia.

Discussion

Comparison of aberrations before and after LASEK surgery in hyperopic and hyperopic astigmatism patients showed that while defocus and astigmatism successfully corrected higher-order aberrations after LASEK surgery using described technique significantly increased. In this study, the results showed the mean RMS of 2nd astigmatism and total higher- order aberrations increased in all groups after surgery but the increase was not uniform in the different groups. Increase of 2nd astigmatism in mild hyperopia group was higher than the other two groups. About the RMS of higher-order aberrations the highest mean difference was related to high hyperopia group. The reason of this increase could be an increase in refractive error or age. The average age in mild, moderate and high hyperopia groups were (28.91 ± 8.49), (36.67 ± 9.33) and (32.47 ± 5.50), respectively. With increasing age, the balance of internal and corneal spherical aberration will be corrupted. So values of spherical aberration change from negative to positive with increasing age. Spherical aberration can change with accommodation, and during the accommodation it becomes more negative. Changes have the linear relationship with amplitude of accommodation. Average spherical aberration changes are -0.044 microns per diopter [16].

Some aberrations had minor changes just in one group. These minor changes cannot be definitively attributed to laser ablation. For example, horizontal coma (Z_3^1) and horizontal trefoil (Z_3^3) could be due

	+0.50 -+1.75	+2.00 - +3.00	+3.25 - +5.00	P-value
	Mean ± SD	Mean ± SD	Mean ± SD	
spherical aberration difference	0.01 ± 0.15	0.16 ± 0.21	0.17 ± 0.26	0.023
Coma difference	0.07 ± 0.18	0.19 ± 0.28	0.42 ± 0.24	<0.001
Trefoil difference	0.01 ± 0.22	0.02 ± 0.11	0.05 ± 0.17	0.757
2nd astigmatism difference	0.20 ± 0.13	0.08 ± 0.09	0.08 ± 0.10	0.001
Quadrafoil difference	0.02 ± 0.05	0.01 ± 0.06	0.03 ± 0.06	0.403
Pentafoil difference	0.00 ± 0.02	0.04 ± 0.03	0.02 ± 00.4	0.001
HOAs difference	0.16 ± 0.24	0.20 ± 0.21	0.44 ± 0.26	0.001
Total aberrations difference	1.48 ± 0.67	1.42 ± 0.62	2.00 ± 1.14	0.077

Table 3: The distribution of the mean difference between preoperative and postoperative aberrations RMS in hyperopic and hyperopic astigmatism in three groups.

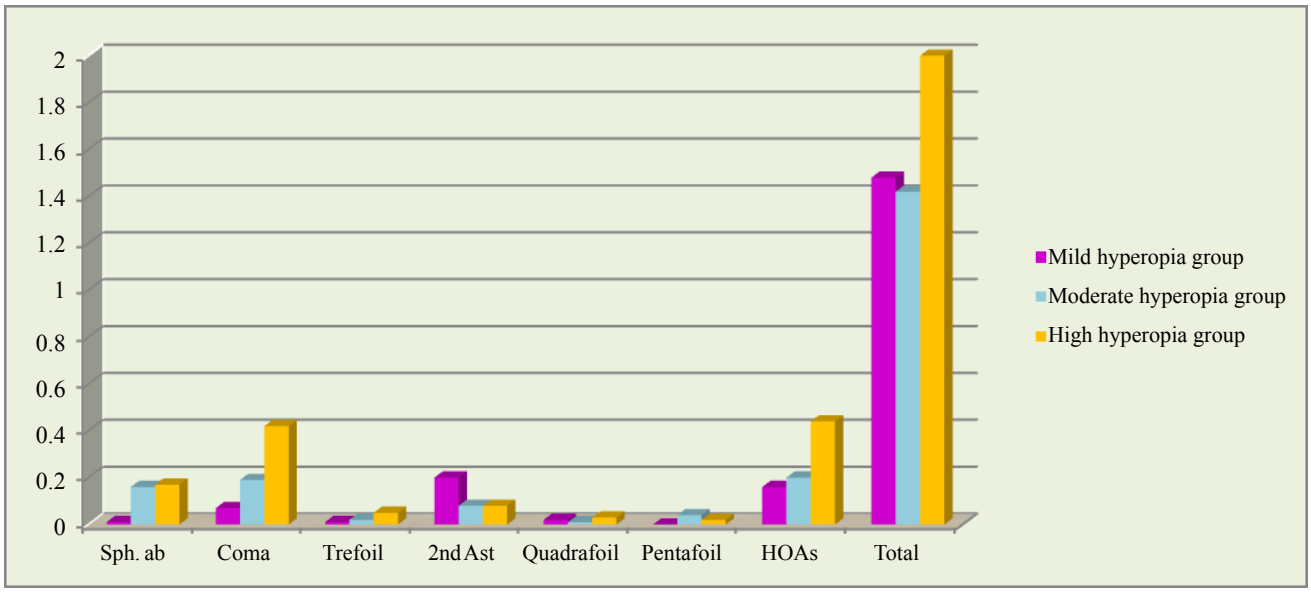

Figure 1: Comparison of mean difference of aberrations RMS before and after wave-front LASEK surgery in hyperopic and hyperopic astigmatism in three groups.

to the kappa angle (the angle between the line of sight and the pupillary axis), decenteration of the pupil and lens or tilt the lens [11]. Yang et al. have demonstrated when light conditions change from photopic to mesopic the pupil center moves toward the temporal (mean change 0.13 ± 0.007) and when the photopic condition changes to dilated state with cyclopentolate 1% the pupil center is transferred to the supero-temporal (mean change 0.18 ± 0.09) [17]. In another study conducted by the Award et al. influence of dilation of pupil with tropicamide 1% and phenylephrine 2.5% on higher-order aberrations were examined using aberrometer LADAR Wave and indicated that if the line of sight is taken as the reference axis higher-order aberrations with natural dilated pupil and dilated with drugs does not differ [8]. Therefore with regard to changes in the pupil center with its various diameters, minor changes can be attributed to measurement error.

Postoperative UCVA was same in mild and moderate hyperopia group and better than high hyperopia group. In the other hand, in high hyperopia group, HOAs changes were more than other groups, thus we can conclude aberrations are inverse with visual acuity and when higher-order aberrations (HOAs) increase visual acuity reduces. In this study, only visual acuity was discussed as an index of quality of vision. The sense of vision provides most of the information needed to perform daily tasks well and efficiently. However, given that many parameters of visual performance are compromised under conditions of low illumination [18], therefore, contrast sensitivity, low-contrast visual acuity, visual acuities measured at different levels of luminance, and glare should all be considered for better evaluation of visual quality.

Also, a variety of changes of aberrations in different groups of hyperopia after LASEK surgery showed that in all groups cannot be used at same platform for laser surgery. It seems that specific platform should be used for different hyperopic groups. So refinement of ablation algorithms was needed to avoid induction of higher-order aberrations. Although, HOAs changes were statistically significant; but further studies are necessary to prove that whether it is clinically significant. There are several ways to prove it. One of them is that the average aberrations are compared with the normal population. If the average aberrations are significantly different from the normal population, we should use better platform for treating these patients to reduce induction of higher-order aberrations.

Most of conducted studies about the aberrations in other countries, were on the normal population (Ivanoff et al. in 1953, Walsh et al. in 1984, Collins et al. in 1995 and Ponter, 2001) [1], or to compare myopia and hyperopia (Thomas Cohen et al. in 2005) [9], or effects of LASEK surgery on aberrations have been compared by two different methods (J. Bradley Randlemen et al. 2005) [10], or just the corneal high-order aberrations has been reviewed in myopic and hyperopic patients. But in this study the total aberrations of the eye in hyperopic and hyperopic astigmatism patients and in three groups (low, medium and high) were assessed before and after wave-front LASEK surgery. Therefore, this study was unique and its results were not comparable with other studies.

In summary LASEK surgery had different effects on different groups of hyperopia. The HOAs increase was not same in three groups (postoperative higher-order aberrations were significantly increased by a factor of 1.41 in mild hyperopia group, by a factor of 1.56 in moderate hyperopia group and by a factor of 2.00 in high hyperopia group). Therefore wave-front LASEK surgery using Technolas 217 Z was an effective, safe, and predictable procedure for treating hyperopic and hyperopic astigmatism patients with hyperopia up to +3.25 and astigmatism less than -3.00, but in hyperopic patients with hyperopia more than +3.25 due to a significant increase in high-order aberrations (HOAs) and further reduction of visual acuity didn't seem appropriate approach.

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