Higher Order Aberrations and Relative Risk of Symptoms After LASIK

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ABSTRACT

PURPOSE: To understand what level of higher order aberrations increases the relative risk of visual symptoms in patients after myopic LASIK.

METHODS: This study was a retrospective comparative analysis of 103 eyes of 62 patients divided in two groups, matched for age, gender, pupil size, and spherical equivalent refraction. The symptomatic group comprised 36 eyes of 24 patients after conventional LASIK with different laser systems evaluated in our referral clinic and the asymptomatic control group consisted of 67 eyes of 38 patients following LADARVision CustomCornea wavefront LASIK. Comparative analysis was performed for uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), contrast sensitivity, refractive cylinder, and higher order aberrations. Wavefront analysis was performed with the LADARWave aberrometer at 6.5-mm analysis for all eyes.

RESULTS: Blurring of vision was the most common symptom (41.6%) followed by double image (19.4%), halo (16.7%), and fluctuation in vision (13.9%) in symptomatic patients. A statistically significant difference was noted in UCVA ($P=.001$), BSCVA ($P=.001$), contrast sensitivity ($P<.001$), and manifest cylinder ($P=.001$) in the two groups. The percentage difference between the symptomatic and control group mean root-mean-square (RMS) values ranged from 157% to 206% or 1.57 to 2.06 times greater.

CONCLUSIONS: Patients with visual symptoms after LASIK have significantly lower visual acuity and contrast sensitivity and higher mean RMS values for higher order aberrations than patients without symptoms. Root-mean-square values of greater than two times the normal after-LASIK population for any given laser platform may increase the relative risk of symptoms. [*J Refract Surg*. 2007;23:252-256.]

All optical systems including the human eye with or without refractive errors have optical aberrations of different types and grades.[1-6] Aberrations vary with age[7-11] and from corneal changes including corneal thickness, tear film interface, and lamellar flap creation.[12-15] Traditional refractive surgery has emphasized refractive correction for lower order aberrations. However, many patients who develop adverse symptoms after LASIK are likely to have induced aberrations, which correlate to the symptoms, refractive error, and corneal topography.[15-25]

Patient satisfaction largely results from two components: refractive accuracy of lower order aberration correction and minimal inducement of higher order aberrations. A personalized nomogram, consistent surgical technique, quality preoperative measurements, detailed staff, and reliable equipment are among the essential elements for achieving and maintaining refractive accuracy; however, no parameters define acceptable limits for postoperative higher order aberrations. Important studies have described wavefront aberrations after LASIK[17-25] and have correlated such aberrations with the symptoms.[18-20] The natural extension of this research is to try and correlate the magnitude of root-mean-square (RMS) values after LASIK with the likelihood or "relative risk" of the patient experiencing symptoms. Understanding and establishing such relative risk values are important to maximize patient satisfaction and provide justification for wavefront retreatments. The purpose of the present study is to provide a foundation for eventually establishing a relative risk stratification scale for visual symptoms due to higher order aberrations with ranges of RMS values after LASIK taken together with other patient factors (eg, pupil size).

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TABLE 1

Preoperative Parameters for the Symptomatic and Control Groups

Parameter	Mean±SD Control	Mean±SD Symptomatic	*P* Value*
Age (y)	39.04±9.68	41.13±10.75	0.67
Contrast sensitivity (Normalized[25])	0.84±0.17	NA	NA
BSCVA (logMAR)	−0.14±0.30 (approx 20/15)	NA	NA
Spherical equivalent (D)	−4.03±2.19	NA	NA
Pupil diameter (mm)	7.10±0.74	6.84±1.19	0.17
Male:female	24:38	14:10	0.46

SD = standard deviation, BSCVA = best spectacle-corrected visual acuity, NA = not available
**Using t test of means.*

TABLE 2

Postoperative Parameters for the Control and Symptomatic Groups

Parameter	Mean±SD Control	Mean±SD Symptomatic	*P* Value*
UCVA (logMAR)	0.04±0.27 (approx 20/20)	0.20±0.22 (approx 20/32)	.001 (1.5 line difference)
BSCVA (logMAR)	−0.14±0.30 (approx 20/15)	0.02±0.10 (approx 20/20)	.001 (1 line difference)
Contrast Sensitivity (Normalized)	83% of normal ±0.23	58% of normal ±0.34	<.001
Manifest sphere (D)	−0.21±0.63	−0.260±0.64	.701
Manifest cylinder (D)	−0.26±0.38	−0.61±0.60	.001
Manifest spherical equivalent (D)	−0.35±0.65	−0.57±0.62	.11
Manifest wavefront equivalent (D)†	−0.40±0.72	−0.54±0.75	.22

**Using t test of means.*
†Manifest wavefront spherical equivalent.

PATIENTS AND METHODS

A retrospective analysis of wavefront aberrations in 103 eyes of 62 myopic patients from the Boxer Wachler Vision Institute was performed. Patients were divided in two groups. The symptomatic group consisted of 36 eyes of 24 patients who were referred for second opinion after LASIK with different laser systems. Average time between LASIK surgery and presentation for evaluation in our clinic was 3.22±2.5 years (range: 99 days to 4.31 years). The asymptomatic control group comprised 67 eyes of 38 patients 3 months following LADARVision CustomCornea (Alcon Laboratories Inc, Ft Worth, Tex) wavefront-guided LASIK by a single surgeon (B.S.B.W.). The analysis of aberrations was performed at a 6.5-mm diameter with the LADARWave aberrometer (Alcon Laboratories Inc).

Wavefront measurements were made following pupil dilation with 1% tropicamide and 2.5% phenylephrine. Following data measurements, the adjustable analysis diameter was set at 6.5 mm, which effectively served as an artificial pupil. Patient symptoms were elicited and recorded by a technician during the history stage of evaluation from open-ended questions. All patients were assessed for logMAR uncorrected visual acuity (UCVA) and best spectacle-corrected visual acuity (BSCVA) (calculated by total number of letters divided by five to achieve lines), pupil size in dim light (2.0 to 2.5 lux) with infrared pupillometer (model 12A Pupilscan II; Keeler, Windsor, United Kingdom), manifest and wavefront refractions, and normalized contrast sensitivity with CSV-1000RS (VectorVision, Dayton, Ohio) at spatial frequency at 12 cycles/degree with best spectacle correction.[25] Patients with abnormal slit-lamp findings such as corneal scars within the flap boundaries or lens opacities were excluded from this study.

Wavefront aberrations were subdivided to total RMS and higher order RMS values up to fourth order. The analysis was performed using SPSS statistical software (SPSS, Chicago, Ill). Means and frequency distribution of aberrations in symptomatic and control groups were calculated and compared using unpaired *t* test. The groups were matched for age, gender, and pupil size (Table 1) and for postoperative manifest refraction spherical equivalent and wavefront refraction spherical equivalent (Table 2). Higher order RMS (3rd to 4th order), spherical aberration, and total, horizontal, and vertical coma values were analyzed to determine the percentage difference of aberrations in the symptomatic versus control group. An unpaired *t* test was used to calculate significance.

RESULTS

Blurring of vision was the most common symptom (41.6%) followed by double image (19.4%), halo (16.7%), and fluctuation in vision (13.9%) in symptomatic patients. The symptomatic group had statistically significantly worse postoperative UCVA (P=.001), BSCVA (P<.001), contrast sensitivity (P<.001), and

TABLE 3

Mean Root-Mean-Square in the Control and Symptomatic Groups

	Mean RMS±SD (μm)		
	Control	Symptomatic	*P* Value*
Total coma	0.3521±0.3112	0.6703±0.4939	.001
Vertical coma z(3, −1)	0.2529±0.2908	0.4872±0.4614	.006
Horizontal coma z(3, 1)	0.1825±0.1886	0.3708±0.3005	.001
Spherical aberration z(4, 0)	0.4662±0.2612	0.7383±0.2922	.003

RMS = root-mean-square
**Using t test of means.*

TABLE 4

Difference in Root-Mean-Square Values Between Symptomatic and Control Groups

Aberration (μm)	Symptomatic	Control	Percentage Difference	*P* Value
Total RMS	3.05	1.84	166	<.001
Higher order RMS	1.16	0.70	166	<.001
Spherical aberration	0.74	0.47	157	.003
Total coma	0.67	0.35	191	.001
Vertical coma	0.49	0.25	196	.006
Horizontal coma	0.37	0.18	206	.001

RMS = root-mean-square

manifest cylinder (*P*=.001) compared to the control group postoperatively (Table 2). Higher order aberration RMS was significantly higher in the symptomatic group (*P*<.001) than in the control group. Total coma (*P*=.001), horizontal coma z(3, 1) (*P*=.001), and vertical coma z(3, −1) (*P*=.006) were statistically more in the symptomatic group (Table 3). Spherical aberration z(4, 0) was significantly greater (*P*=.003) in the symptomatic group compared to controls (Table 3).

The percentage difference between the symptomatic and control group mean RMS values ranged from 157% to 206% or 1.57 to 2.06 times greater for higher order RMS, spherical aberration, and total, horizontal, and vertical coma (Table 4). Overlap of aberrations was noted in many patients.

DISCUSSION

Symptomatic patients on average had higher order aberrations 1.57 to 2.06 times greater in magnitude than asymptomatic patients. McCormick et al[25] conducted a similar study and reported that RMS values in symptomatic patients increase by 2.46 to 4.56 times for the same range of aberrations. However, their patient group also included patients with well-defined corneal irregularities, which may be one explanation why their RMS values were increased by a greater order of magnitude. One limitation of both studies was that measurements were only taken on one wavefront platform (CustomCornea and Zywave [Bausch & Lomb, Rochester, NY]). The mean RMS values for each group in our study are only applicable to the CustomCornea users as RMS values vary across platforms. However, percentage increases in RMS reported herein and also by McCormick et al should be relevant across different platforms. Based on these two preliminary studies, it seems that a two-fold increase in higher aberrations compared to the asymptomatic patients may result in an increased relative risk of symptoms.

It is important to understand what level of postoperative aberration increases the risk of patient symptoms in not only myopic LASIK, but also in hyperopic LASIK and lens-based surgery such as phakic intraocular lenses and accommodating lenses. One of the purposes of this article is to introduce the concept of relative risk. We hope that this initial work will provide the foundation for further prospective research, which allows the establishment of a relative risk scale for symptoms due to higher order aberrations based on

RMS values and other risk factors such as pupil size. A potential benefit of such a scale would be to provide some objective justification for wavefront retreatments. It could also help in patient selection for LASIK—a clinician could use the relative risk scale and his knowledge of the likely amount of higher order aberration induction that occurs to judge whether the patient would be at risk postoperatively. Another potential benefit is continued refinement of laser algorithms to aim to minimize the risk of symptoms. Customized ablation algorithms already compensate for induction of spherical aberrations by placing additional pulses in the periphery of the ablation profile based on previous work with aberrations and RMS values.

The concept of relative risk based on different levels of measurable continuous variables is already used extensively in medicine to stratify risk. Intraocular pressure and cup-to-disk ratios are used to gauge the risk of an individual having glaucoma. Levels of systolic and diastolic blood pressure are stratified to attribute relative risk of coronary and cardiovascular events.[26-28] We emphasize that like the examples given, we do not believe that RMS values should be viewed in isolation when considering whether a patient's symptoms are due to higher order aberrations. Other factors such as age, preoperative refractive error, residual postoperative refractive error, and pupil size may contribute to symptoms postoperatively. The diagnosis of primary open angle glaucoma is based on variables other than intraocular pressure such as cup-to-disc ratio, perimetry, gonioscopic evaluation, race, and age. Nevertheless, we believe that the level of RMS values, such as intraocular pressure, are important in determining the likelihood of a patient having symptoms.

Aberrations can be the cause of various symptoms postoperatively[18-20,23] and have been correlated to specific aberrations.[18-20] A strong correlation between visual symptoms and ocular aberrations, such as monocular diplopia with coma and starburst and glare with spherical aberration, has been shown previously.[20] Chalita et al[18,19] have shown that horizontal coma correlates with double vision, whereas vertical coma does not, demonstrating a greater sensitivity to horizontally oriented multifocality. For 5-mm pupil size, they found that double vision correlates with total coma and horizontal coma. For 7-mm pupil size, double vision correlated with total coma and horizontal coma but starburst inversely correlated with total coma. For a larger scotopic pupil size, a statistically significant correlation was noted between glare and spherical aberrations as well as glare and total aberrations.[18,19]

Various factors can affect the measurement of postoperative aberrations in the same corneas. In our study, we measured all aberrations at the same 6.5-mm analysis diameter to avoid the confound of not controlling for pupil size. It is important that the same diameter is used because a smaller analysis diameter or pupil of the patient being measured will mask aberrations and artificially lower displayed aberration values.[29-31] Conversely, too large analysis diameters or pupil sizes will artificially produce more aberrations. We also chose a 6.5-mm pupil size for analysis as this is the standard for the wavefront platform we used. Further studies should use the standard pupil setting for the wavefront platform used to allow reproducibility.

We made a meticulous effort to match the groups. They were matched for age, gender, pupil size, and spherical equivalent. Cylindrical power was 0.35 diopters (D) higher in the symptomatic group compared to the control group. Although it is possible that this residual cylinder difference could explain the adverse patient symptoms compared to the control group, the amount of cylinder (0.35 D) is small and unlikely to account for adverse patient symptoms. It is more likely that the patient symptoms resulted from the increased overall and specific higher order aberrations due to the magnitude of difference in RMS values between the two groups. Preoperative refraction, wavefront aberrations, and contrast sensitivity were unknown in patients in the symptomatic group and therefore could not be matched in the two groups. It is not known whether these factors would have had an effect on our results.

Because our study was retrospective, we have provided a baseline for future prospective studies to evaluate further what degree of increase in RMS values or measured aberrations is likely to result in an increased relative risk of symptoms. We hope the concept relative risk of higher order aberrations in refractive surgery will be the subject of further development.

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