

Correlation of Aberrations With Visual Symptoms Using Wavefront Analysis in Eyes After Laser in situ Keratomileusis

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ABSTRACT

PURPOSE: To evaluate the information assessed with the Alcon LADARWave wavefront measurement device and correlate it with visual symptoms in eyes previously treated with laser in situ keratomileusis (LASIK), and to analyze the influence of scotopic pupil size on visual symptoms.

METHODS: One hundred and five eyes of 58 patients who underwent LASIK were evaluated. Wavefront measurements were assessed using the Alcon LADARWave device. Visual symptoms were correlated to higher order aberrations in three different pupil sizes (5 mm, 7 mm, and scotopic pupil size). Generalized estimating equations were used for statistical analysis.

RESULTS: In eyes after LASIK, visual symptoms analysis showed positive correlation of double vision with total coma and with horizontal coma for the 5-mm and 7-mm pupil sizes, negative correlation between starburst and total coma for the 7-mm pupil size, positive correlation of double vision with horizontal coma, and glare and starburst with spherical aberration and with total aberrations. Scotopic pupil size had a positive association with starburst and negative association with double vision.

CONCLUSION: The LADARWave wavefront measurement device is a valuable diagnostic tool in measuring ocular aberrations in eyes after LASIK. A strong correlation between visual symptoms and ocular aberrations, such as monocular diplopia with coma, and starburst and glare with spherical aberration, suggest this device is valuable in diagnosing symptomatic LASIK-induced aberrations. Horizontal coma was correlated with double vision,

while vertical coma was not, demonstrating a greater sensitivity with horizontally oriented multifocality. [*J Refract Surg* 2003;19:S682-S686]

Laser refractive surgery is becoming increasingly popular with patients seeking an alternative to spectacles and contact lenses. Every year approximately 1.5 million patients worldwide undergo laser in situ keratomileusis (LASIK).¹ Although it is effective, the surgical modification of corneal shape might influence the optical quality of the eye, creating aberrations that will lead to distorted images.²

Standard laser refractive surgery eliminates conventional refractive errors, yet higher order aberrations (particularly spherical aberration) can be induced.³⁻⁵ Therefore, sometimes patients complain about poor quality of vision even when their visual acuity is 20/25 or 20/20. Some reports have shown that an increase in higher order aberrations after laser refractive surgery is correlated with a significant decrease in the quality of vision^{5,6}, especially under scotopic conditions.^{7,8}

Visual symptoms, such as starburst, halos, glare, and monocular diplopia, were reported as being significantly worse in some patients after LASIK.^{9,10} Before wavefront technology, corneal irregularities classified as irregular astigmatism were to blame; now we know that higher order aberrations induced by standard laser vision correction are responsible for these visual symptoms.

Wavefront aberration error is defined as the difference between the actual wavefront (leading edge of propagating rays) and the ideal wavefront in the plane of the eye's exit pupil.¹¹ Wavefront devices measure monochromatic aberrations¹², the magnitude of which impacts visual acuity and quality of vision.

We evaluated information captured with the LADARWave wavefront measurement device in

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Table 1
Odds Ratio and *P*-values of Generalized Estimating Equations to Assess the Association Between Patient Symptoms and Higher Order Aberrations for a 7-mm Pupil Size in Eyes After LASIK

	Halos		Glare		Double Vision		Starburst	
	Odds Ratio	<i>P</i> -value	Odds Ratio	<i>P</i> -value	Odds Ratio	<i>P</i> -value	Odds Ratio	<i>P</i> -value
Coma (total)	0.98	.95	0.83	.51	1.5	.014*	0.50	.038*
Horizontal coma	1.30	.60	0.80	.65	2.7	.024*	0.70	.28
Vertical coma	0.90	.57	0.80	.40	1.10	.72	0.60	.052
Spherical aberration	1.30	.73	1.70	.47	1.00	.96	0.80	.76
Other	1.70	.24	1.40	.37	0.80	.49	1.10	.83
Total aberrations	1.20	.68	1.10	.69	1.10	.47	0.80	.28

*Statistically significant

patients previously treated with LASIK for a variety of refractive conditions. Our goal was to correlate the magnitude of various aberrations with visual symptoms measured under different pupil sizes, as well as to analyze the influence of scotopic pupil size on the perception of visual symptoms.

PATIENTS AND METHODS

We enrolled 58 patients (105 eyes) who had undergone LASIK at the Cleveland Clinic Foundation or elsewhere between 1995 and 2001; 39 were male (67.24%) and 19 were female (32.76%). Mean age was 43.88 years (range 24 to 81 yr). All patients had a thorough ophthalmological examination, including manifest refraction in a dark room, corneal videokeratography (Zeiss-Humphrey, Dublin, CA) prior to dilation, cycloplegic refraction, and dilated wavefront measurement (LADARWave, Alcon, Orlando, FL). All wavefront measurements were performed by one technician and written informed consent was obtained from all patients. This study was approved by the Institutional Review Board of The Cleveland Clinic Foundation. Wavefront maps were analyzed using three different pupil sizes, 5 mm, 7 mm, and scotopic pupil size.

The LADARWave device measures spherocylindrical refractive errors (defocus and astigmatism) and higher order aberrations (divided into coma, spherical aberrations, and other terms of higher order aberrations). It uses a Shack-Hartmann sensor with an array of lenses that break up the reflected wave of light coming out of the eye into many focused beams. For an ideal eye, the reflected plane wave would be focused into a perfect array of point images, each image falling exactly on the optical axis of the corresponding lenslet. By contrast, the aberrated eye focuses the beams of a distorted wavefront into a displaced array of spots; each displace-

ment characterizes the slope of the aberrated wavefront at the corresponding lenslet. The wavefront can then be analyzed at the eye's exit pupil.

Patients were asked if they had any visual symptoms such as halo, glare, double vision, or starburst, and the answer was considered as yes or no, without grading symptoms as mild, moderate, or severe. The visual symptoms were compared with coma (total, vertical, and horizontal), spherical aberration, other terms of higher order aberrations, and total aberration measurements for a 5-mm, 7-mm, and scotopic pupil size. Scotopic pupil diameter was then correlated to visual symptoms, independent of the type and magnitude of higher order aberrations.

Generalized estimating equations were used to assess the association between symptoms and higher order aberration measurements. Results were considered significant at a *P*-value less than .05.

RESULTS

Table 1 shows the association between visual symptoms and higher order aberration for a 7-mm pupil size. There was a significant correlation of double vision with total coma ($P=.014$) and with horizontal coma ($P=.024$). Starburst was inversely correlated with total coma ($P=.038$). For a 5-mm pupil size, double vision was significantly correlated with total coma, as well as horizontal coma ($P=.008$ and $.014$, respectively; Table 2).

Analysis of visual symptoms and aberrations for the scotopic pupil size showed a statistically significant correlation between glare and spherical aberration ($P=.010$) as well as glare and total aberration ($P=.041$). Double vision was significantly correlated with horizontal coma ($P=.033$) and starburst showed a statistically significant correlation with spherical aberration ($P=.014$) and with total aberration ($P=.004$) (Table 3).

Table 2
Odds Ratio and P-values of Generalized Estimating Equations to Assess the Association Between Patient Symptoms and Higher Order Aberrations for a 5-mm Pupil Size in Eyes After LASIK

	Halos		Glare		Double Vision		Starburst	
	Odds Ratio	P-value	Odds Ratio	P-value	Odds Ratio	P-value	Odds Ratio	P-value
Coma (total)	2.80	.37	1.50	.69	2.60	.008*	0.6	.19
Horizontal coma	4.10	.32	2.90	.43	7.40	.014*	1.00	.95
Vertical coma	1.40	.46	0.97	.96	1.20	.76	0.60	.42
Spherical aberration	10.7	.18	6.4	.41	1.10	.90	1.50	.63
Other	7.70	.21	2.90	.38	1.20	.81	1.00	.97
Total aberrations	2.90	.28	1.00	.99	1.60	.09	0.91	.78

*Statistically significant

Table 3
Odds Ratio and P-values of Generalized Estimating Equations to Assess the Association Between Patient Symptoms and Higher Order Aberrations for a Scotopic Pupil Size in Eyes After LASIK

	Halos		Glare		Double Vision		Starburst	
	Odds Ratio	P-value	Odds Ratio	P-value	Odds Ratio	P-value	Odds Ratio	P-value
Coma (total)	1.80	.34	1.40	.61	1.60	.10	0.90	.86
Horizontal coma	2.90	.20	2.60	.21	3.70	.033*	1.50	.24
Vertical coma	1.00	.99	0.90	.80	0.80	.68	0.70	.42
Spherical aberration	3.00	.053	4.20	.010*	0.70	.49	6.20	.014*
Other	5.20	.13	6.00	.10	0.70	.40	2.30	.12
Total aberrations	2.00	.07	2.20	.041*	1.00	.77	1.90	.004*

*Statistically significant

Table 4
Coefficient and P-value to Assess the Association Between Pupil Diameters in Scotopic Conditions With Symptoms in Eyes After LASIK

	Halos	Glare	Double Vision	Starburst
Pupil Diameter				
Coefficient	0.08	0.46	-1.05	1.52
P-value	.78	.15	.011*	.001*

*Statistically significant

The association between scotopic pupil size and visual symptoms showed a positive correlation of starburst with pupil diameter ($P=.001$); there was a negative correlation of double vision with pupil diameter ($P=.011$) (Table 4).

DISCUSSION

Wavefront-guided treatments are now the focus of customized corneal ablation to correct ametropias and also minimize and/or not induce ocular aberrations. Wavefront analysis offers us a detailed map with defocus, astigmatism, and higher order aberrations.

There are several types of wavefront measurement devices that can be used to measure defocus, astigmatism, and higher order aberrations, and these devices have been incorporated most recently into a clinical setting to help in planning refractive surgery.¹³

We evaluated the correlation between the higher order aberrations measured with the LADARWave wavefront device with visual symptoms after standard LASIK procedures. We also investigated the association between scotopic pupil size and visual symptoms.

When analyzing higher order aberration values,

the pupil aperture used for this analysis played an important role in the results. When comparing the 7-mm and 5-mm measurements, there was a statistically significant difference between them, showing that larger apertures had more aberrations, especially in eyes after LASIK, because the peripheral area of the laser treatment was captured and measured.

When correlating visual symptoms with higher order aberrations, double vision was associated with horizontal coma at all pupil sizes analyzed, and total coma was associated with double vision for a 5-mm and 7-mm pupil size. No association was found between vertical coma and visual symptoms, showing that not only is the amount of coma important, but also its orientation.

Halos revealed a trend of association (not statistically significant) with spherical aberration for the scotopic pupil size ($P=.053$) and glare was significantly associated with spherical aberration and total aberration. These associations were not found for the 5-mm and 7-mm pupil sizes. Starburst also showed significant correlation with spherical aberration and total aberration for the scotopic pupil size. Less intuitively, for the 7-mm pupil size, starburst was inversely associated with total coma.

A remarkable observation is the strong correlation of most of the reported visual symptoms with one or more of the higher order aberrations when analyzed with the scotopic pupil size. This suggests that the best way of analyzing symptomatic patients is to consider the aberrations of the wavefront map when presented at the diameter of the scotopic pupil. This is because one can better analyze the aberrations that a patient experiences in dim light, when he or she is most symptomatic.

An additional correlation of pupil diameter under scotopic conditions with visual symptoms revealed a significant positive correlation with starburst, but a significant negative correlation with double vision. This negative correlation goes against the previous idea that large pupils are correlated with double vision. Rather, one could infer that double vision is correlated with small pupils. This seems less intuitive, but is further verified by noting that P -values of double vision in association with total coma and horizontal coma (Tables 1 and 2) are lower values (more significant) in the 5-mm than in the 7-mm pupil group. The reason for this negative correlation is unknown, but may be related to the fact that double vision due to horizontal coma at a smaller pupil size is more sensitive to the central asymmetry that represents double vision than at a larger pupil size.

In other words, the presence of horizontal coma within a smaller central area (small pupil) means a greater tendency for the vision to fight over the multifocality of coma than with a larger pupil, which can counteract the perceived asymmetry. Additionally, with a larger pupil there is a greater likelihood that coma-like asymmetry might be categorized as one of the other terms of higher order aberrations.

Conversely, the positive correlation of scotopic pupil size with starburst shows the importance of exercising caution when treating eyes with larger scotopic pupils, especially if one is expected to induce high levels of spherical aberration. Customized corneal ablations will hopefully minimize this symptom by more effectively correcting the laser-induced spherical aberration.

Our study has some limitations, which will necessitate further research. Future studies may allow determination of the relationship between higher order aberrations and contrast sensitivity, as well as ablation zone size, profile, and depth, to see if other parameters play an important role in contributing to visual symptoms. This study demonstrates the utility of using the LADARWave wavefront device in measuring postoperative LASIK ocular aberrations. Strong correlations exist between certain visual symptoms and specific higher order aberrations. These are most frequently noted when analyzing aberrations with a wavefront diameter equivalent to the scotopic pupil size. We recommend symptomatic postoperative LASIK patients be evaluated with the LADARWave wavefront device to best determine the nature of the ocular aberrations contributing to their visual symptoms.

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