Induced Secondary Astigmatism and Horizontal Coma after LASIK for Mixed Astigmatism

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Abstract

***Purpose*:** To describe a distinctive pattern of induced higher order aberration (HOA) after LASIK for mixed astigmatism

***Case reports*:** Wavefront-guided LASIK with iris recognition and eye tracking (Excimer laser: Technolas 217z; APT protocol; Microkeratome: Moria CB) was performed in six eyes with moderate to high mixed astigmatism for a nominal optical zone of 6.3 mm. The patients were re-examined beyond 9 months postoperatively.

***Results*:** Postoperative uncorrected distance visual acuities (UDVA) equaled preoperative corrected distance visual acuities (CDVA). The cycloplegic cylinder increased an average of about 2.50 D compared with dry retinoscopy. Significant increases in HOAs were detected with pupils dilated, specially in the amounts of secondary astigmatism (mean change=0.41 µm) and horizontal coma (HC) (mean change=0.29 µm). Large kappa angles were detected in all of the eyes studied (mean=7.45□).

***Conclusion*:** The bitoric ablation profile of mixed astigmatism LASIK may induce significant secondary astigmatism which causes a remarkable disparity between dry and wet refraction and manifests as an unusual skiascopic reflex during wet retinoscopy. A large kappa angle may cause tilted ablation and induce HC.

***Keywords*:** Mixed Astigmatism LASIK, Ablation Profile (Bitoric Photoablation), (Induced) Higher Order Aberration, Skiascopic Reflex, Secondary Astigmatism, Horizontal Coma, Kappa Angle

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Introduction

Induced higher order aberration (HOA) is a well-known adverse effect of keratorefractive photoablation. A number of factors are assumed to be contributory, including decentration of the ablation (treatment shift)[1]; astigmatism correction[2] and rotational misalignment (cyclotorsion)[3]; the patient's fixational behavior (patient cooperation and treatment drift)[4]; a small treated zone (and/or inclusion of a transitional zone in the functional optical zone)[5]; LASIK flap characteristics,[6] such as irregularities and microstriae in the flap[7]; the ablation depth and profile[8,9]; parallax in laser incidence; and corneal biomechanics.[6]

The purpose of this report is to describe significant induced HOAs in six eyes with moderate to high mixed astigmatism that underwent wavefront-guided LASIK, analyze the cases in depth, and discuss the implications.

Case Reports

Three cases of mixed astigmatism underwent bilateral wavefront-guided LASIK with the Technolas 217z excimer laser platform (advanced personalized treatment nomogram). Full cycloplegic refraction treatment in an optical zone of 6.3 mm was attempted. A microkeratome (Moria CB 130 head, France) was used to create flaps with superior hinges. Preoperative iris registration was carried out and intraoperative rotational alignment and lateral beam placement was controlled by iris recognition and eye tracking in X, Y, and Z axes.

Postoperative uncorrected distance visual acuity (UDVA) equaled preoperative corrected distance visual acuity (CDVA) in all but the left eye of case B, which was $^{20}/_{25}$ post-op. No eye lost CDVA. All patients expressed their satisfaction with the surgical outcome. However, when asked specifically, patient B mentioned blurred vision in his right eye, with bilateral halo, glare and blurring at night. A blue dot cataract opacity and the coincident Fuchs heterochromia in the right eye contributed to the visual loss (UDVA: $^{20}/_{40}$). Patient C also had complaints of halo and glare with negligible self-reported blurred vision.

Following cycloplegia, the cylinder by autorefractometry equaled the dry cylinder but retinoscopic reflexes were strangely dull but regular, without a fish mouth or a scissor motion. When an attempt to reach neutrality was made, an unexpected and remarkable rise in the manifest cylinder was observed (Table 1). Zywave cycloplegic aberrometry indicated significant induced secondary astigmatism and horizontal coma (HC). HOA data are presented in Table 2.

Kappa (κ) angles and pupil sizes were measured with Orbscan IIz in the mesopic state (with ambient luminance of 4 lux) and showed a range of 7.08° to 8.40° (mean κ=7.45°) and 3.5 to 5.0 mm (mean pupil diameter=4.15 mm), respectively.

Table 1. Preoperative and postoperative refraction

Case	Age			Preoperative		Postoperative			
				Dry refraction	Cycloplegic refraction	Dry refraction	UDVA Follow-up (months)	Cycloplegic refraction (PPR 3.5 mm)	Cycloplegic refraction (PPR exam diameter)
A	27	F	R	+0.75-6.50 × 180	+1.25 -6.50 × 180	+0.75-0.25 ×20	20/20 (15)	+1.98-1.26 ×06	+3.25-4.00 × 180
			L	+0.75-7.00 ×180	+1.75-7.00 × 180	+1.50-0.75 ×20	20/20 (15)	+2.45-1.20 ×02	+3.41-4.34 ×03
B	32	M	R	-0.75-4.00 × 35	+2.00-4.00 ×35	-0.50-0.50 ×45	20/40 (9)	+0.55-0.51 ×41	+2.24-2.19 ×30
			L	-0.75-4.50 × 160	+1.00-4.50 ×160	0.00-1.00 ×160	20/25 (9)	+1.07-1.10 ×147	+2.14-2.63 × 155
C	29	M	R	+3.00-4.00 ×180	+3.25-4.00 ×180	0.00-0.50 ×15	20/20 (13)	+1.89-0.89 ×12	+3.37-2.67 × 5
			L	+3.50-4.50 × 10	+3.50-4.00 ×10	+1.00-0.75 × 165	20/20 (13)	+1.91-0.79 ×171	+3.98-3.01 ×9

M: Male, F: Female, R: Right eye, L: Left eye, UDVA: Uncorrected distance visual acuity, PPR: Phoropter-predicted refraction

Table 2. Changes* in higher order aberrations root mean square (in µm) after LASIK for mixed astigmatism

Case		Total		Horizontal coma†		Spherical aberration†		Secondary astigmatism	
		Postoperative	Change	Postoperative	Change‡	Postoperative	Change	Postoperative	Change‡
A	R	0.81	0.12	-0.14	-0.41	-0.15	-0.22	0.71	0.61
	L	0.97	0.28	-0.27	-0.03	0.02	0.04	0.63	0.53
B	R	0.77	0.33	-0.36	-0.32	0.29	0.03	0.42	0.40
	L	0.80	0.35	0.55	0.47	0.24	0.15	0.42	0.33
C	R	0.80	0.49	-0.33	-0.34	0.19	0.17	0.36	0.26
	L	0.69	0.35	0.25	0.18	0.30	0.29	0.46	0.35

* Change: Postoperative value - preoperative value (direction of the horizontal coma was taken into account)
† Vertical coma changes were insignificant and those of spherical aberration were inconsistent.
‡ Marked induced horizontal coma was visible in four of the six eyes and marked induced secondary astigmatism was apparent in all six eyes.

Discussion

Postoperative residual astigmatism can be a simple lower-order cylinder undercorrection, or it may be the result of induced lower-order astigmatism or HOAs due to decentration and pupil eccentricity,[2] rotational misalignment,[10] or the ablation profile.[11]

Our observation that significant astigmatism appeared after pupil dilation implies that the cylindrical error is not of a lower order nature. The skiascopic reflexes in cycloplegia were also abnormal and quite different from undilated reflexes. In wavefront analysis, we came across high amounts of HOAs, notably secondary astigmatism (an average of 5.5 times increase) (Table 2). It was noted that the blurred vision in this condition was corrected by conventional spherocylinders and $^{20}/_{20}$ visual acuity (VA) was achieved. This in turn points to the symmetrical nature of the induced 'aberropia'[12] that is the case for secondary astigmatism.

It was noted that the autorefractometry cylinder did not change much after pupil dilation; this can be attributed to the small refracting zone of the conventional autorefractometers (maximum 4.0 mm); it is already known that these devices may not yield accurate results after keratorefractive surgery.[13]

The bitoric ablation profile for the correction of mixed astigmatism results in less tissue removal and is believed to be more effective than standard monotoric ablations with regard to astigmatism and defocus correction.[8,9] The induced HOAs might be less, specially when a wavefront-guided ablation with iris registration is performed.[2] Despite these, authors hypothesize that the extraordinary increase in secondary astigmatism is a direct consequence of bitoric ablation profile. We know that bitoric ablation includes independent positive and negative cylindrical ablations (Figure 1) and the induced secondary astigmatism could be due to the optical summation of that combined effect with blending zone. The proposed mechanism and our observations, in fact, challenge the presumed superiority of bitoric ablation over monotoric ablation profiles in terms of an effective optical zone and induced HOAs, at least with regard to secondary astigmatism.

HC also increased considerably in four of the six eyes (4.3 times increase on average; (Table 2). Despite that wavefront-guided photoablation with eye tracking and iris recognition is used to decrease induced HOAs[2,14] we still observe various degrees of misalignment and subsequent induced HOAs after laser surgery.[15] A large κ angle has been shown to cause inconsistent refractive outcomes.[16] All of our cases had relatively high κ angles (see above) and κ intercepts (mean=880 µm, range=800-1000 µm). A large κ angle with an intercept of more than 100 µm has been strongly correlated with the amount of induced coma after photoablation.[16]

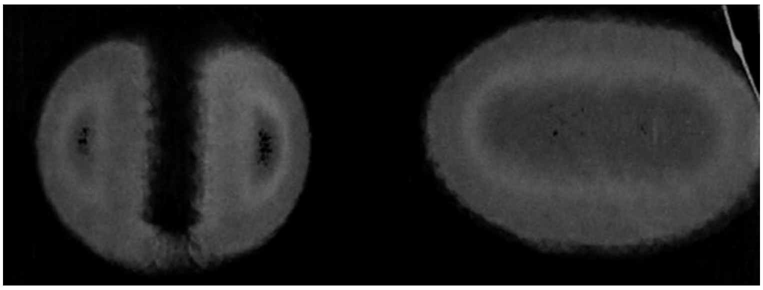

Figure 1. Breaking down of a bitoric ablation on a calibration plate (digitally enhanced); right side: myopic and left side: hyperopic components

Alternatively, pupil eccentricity has been shown to induce HOAs such as coma, trefoil and secondary astigmatism.[1,2] It is plausible that an oblique incidence of the laser beam onto the corneal surface relative to the pupillary and corneal geometrical axes, i.e. tilted ablation, would be associated with horizontally different ablation rates. This translates into induction of HC, which was observed in four eyes; the other two eyes had high HC preoperatively, which might have complicated the net post-wavefront-guided ablation effect. The mentioned mechanism has already been described as a cause of the induction of spherical aberration with conventional photoablation profiles,[17] and radial compensation is now routinely being factored into optimized protocols.[18] Notably, fellow eyes revealed HC in a mirror fashion in cases B and C; this should correspond to the geometric relations of the fellow eyes' κ angles.

In order to compensate for a large κ angle, some authorities' contention is to perform photoablation under a dilated pupil state when the κ intercept is essentially smaller.[16] Adoption of a topography-guided approach has also been suggested and seems appealing.[16] Manual adjustment of the laser beam centration is not currently recommended.[2]

Although HOAs affect optical quality, the most important determinant of postoperative visual performance is related to the residual spherocylindrical error.[19] Optical quality symptoms are mostly transient, and neuroadaptation[20] will often prevail in the long run. Our patients were beyond 9 months' follow-up and expressed their satisfaction despite having high amounts of HOAs in cycloplegia. None of the patients had disabling optical quality symptoms. Our patients' relatively smaller pupil sizes[20] might have contributed to the low frequency of subjective symptoms. However, the Orbscan IIz is known to underestimate the pupil diameters.[21]

Conclusion

Bitoric ablation for mixed astigmatism can induce high degrees of secondary astigmatism and may result in a small effective optical zone. This may manifest as a surge in the neutralizing cylinder during cycloplegic retinoscopy; the examiner should be aware that the skiascopic reflex is not identical to that of a conventional cylinder. A large κ angle, on the other hand, can induce high amounts of HC. These induced aberrations can cause visual fluctuations and night vision complaints, even though the patients may not be dissatisfied. The authors would like to highlight the importance of pupillometry in the preoperative assessment of mixed astigmatism and the inclination to set a larger optical zone. High κ angles should be recognized preoperatively and addressed on their own.

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References

1. Porter J, Yoon G, Lozano D, et al. Aberrations induced in wavefront-guided laser refractive surgery due to shifts between natural and dilated pupil center locations. J Cataract Refract Surg 2006;32(1):21-32.
2. Khalifa M, El-Kateb M, Shaheen MS. Iris registration in wavefront-guided LASIK to correct mixed astigmatism. J Cataract Refract Surg 2009;35(3):433-7.
3. Arba-Mosquera S, Merayo-Lloves J, de Ortueta D. Clinical effects of pure cyclotorsional errors during refractive surgery. Invest Ophthalmol Vis Sci 2008;49(11):4828-36.
4. Fea AM, Sciandra L, Annetta F, et al. Cyclotorsional eye movements during a simulated PRK procedure. Eye (Lond) 2006;20(7):764-8.
5. Rajan MS, Jaycock P, O'Brart D, et al. A long-term study of photorefractive keratectomy; 12-year follow-up. Ophthalmology 2004;111(10):1813-24.
6. Lipshitz I. Thirty-four challenges to meet before excimer laser technology can achieve super vision. J Refract Surg 2002;18(6):740-3.
7. Pallikaris IG, Kymionis GD, Panagopoulou SI, et al. Induced optical aberrations following formation of a laser in situ keratomileusis flap. J Cataract Refract Surg 2002;28(10):1737-41.
8. Albarrán-Diego C, Muñoz G, Montés-Micó R, Alió JL. Bitoric laser in situ keratomileusis for astigmatism. J Cataract Refract Surg 2004;30(7):1471-8.
9. Hassaballa MA, Ayala MJ, Alió JL. Laser in situ keratomileusis correction of mixed astigmatism by bitoric ablation. J Cataract Refract Surg 2003;29(10):1889-95.
10. Neuhann IM, Lege BA, Bauer M, et al. Static and dynamic rotational eye tracking during LASIK treatment of myopic astigmatism with the Zyoptix laser platform and Advanced Control Eye Tracker. J Refract Surg 2010;26(1):17-27.
11. Mao LN, Jiang WJ, Yang YB. [Clinical evaluation of laser in situ keratomileusis operation with three different ablative patterns]. Zhejiang Da Xue Bao Yi Xue Ban 2011;40(1):78-84.
12. Agarwal A, Jacob S, Agarwal A. Aberropia: a new refractive entity. J Cataract Refract Surg 2007;33(11):1835-6.
13. Siganos DS, Popescu C, Bessis N, Papastergiou G. Autorefractometry after laser in situ keratomileusis. J Cataract Refract Surg 2003;29(1):133-7.
14. Shen EP, Chen WL, Hu FR. Manual limbal markings versus iris-registration software for correction of myopic astigmatism by laser in situ keratomileusis. J Cataract Refract Surg 2010;36(3):431-6.
15. Bueeler M, Mrochen M, Seiler T. Maximum permissible torsional misalignment in aberration-sensing and wavefront-guided corneal ablation. J Cataract Refract Surg 2004;30(1):17-25.
16. Hehn F. Angle Kappa Management. In: Garg A, Alio JL, Lin J, editors. Mastering advanced surface ablation techniques. Jaypee Brothers Medical Publishers Ltd., 2008;327-33.
17. Holladay JT. Aspheric treatments reduce spherical aberration after cataract refractive surgery. Quality of Vision: Essential Optics for the Cataract and Refractive Surgeon. New Jersy: SLACK, 2007;39-46.
18. Holladay JT. Optical improvements in excimer laser surgery. Quality of Vision: Essential Optics for the Cataract and Refractive Surgeon. New Jersy: SLACK, 2007;83-92.
19. Arbelaez MC, Vidal C, Arba-Mosquera S. Excimer laser correction of moderate to high astigmatism with a non-wavefront-guided aberration-free ablation profile: Six-month results. J Cataract Refract Surg 2009;35(10):1789-98.
20. Panagopoulou SI, Plainis S, MacRae SM, Pallikaris I. The implications of pupil size and accommodation dynamics on customized wavefront-guided refractive surgery. In: Krueger RR, Applegate RA, MacRae SM. Wavefront customized visual correction: The quest for supervision II. New Jersy: SLACK, 2004;121-6.
21. Hsieh YT, Hu FR. The correlation of pupil size measured by Colvard pupillometer and Orbscan II. J Refract Surg 2007;23(8):789-95.