

Corneal irregular astigmatism after laser in situ keratomileusis for myopia

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Abstract

Aims—To quantitatively evaluate the changes in corneal irregular astigmatism after laser in situ keratomileusis (LASIK) in relation to the amount of laser ablation.

Methods—In 189 eyes of 116 patients undergoing LASIK for myopia, corneal topography was obtained before and 1 month after surgery. Using Fourier harmonic analysis of the topography data, corneal irregular astigmatism (asymmetry and higher order irregularity) was calculated.

Results—By surgery, asymmetry component significantly increased ($p < 0.0001$, Wilcoxon signed rank test), while higher order irregularity did not ($p = 0.767$). The increases in the asymmetry component significantly correlated with ablation depth (Spearman rank correlation coefficient $r_s = 0.440$, $p < 0.0001$). No significant correlation was found between changes in higher order irregularity and ablation depth ($r_s = 0.137$, $p = 0.074$).

Conclusion—LASIK significantly increases the asymmetry component of the cornea which is dependent on the amount of laser ablation.

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Laser in situ keratomileusis (LASIK) has been widely recognised as an effective surgical procedure for correcting myopia. Although most of the patients can attain a satisfactory level of uncorrected visual acuity after surgery, impairments of functional vision have been reported, such as reduction in contrast sensitivity and induction of glare disability.^{1,2} Corneal irregular astigmatism can be the cause of deteriorated visual performance after surgery. Slight to moderate abnormalities in corneal topography after LASIK have been demonstrated by several qualitative studies.³⁻⁶ Quantitative assessment of the changes in corneal irregular astigmatism after LASIK, however, has never been conducted except for one small study which reported increased wavefront aberrations of the cornea after LASIK.⁷ In eyes undergoing photorefractive keratectomy, Keller *et al* reported significant increases in the decentration component after surgery as calculated by the fast Fourier transform of the computerised corneal topography data.⁸

Transformation of periodic curves into Fourier harmonic components is widely used in electrical and biomedical engineering. Fourier analysis has been also used to mathematically

model the polar variations in videokeratographic power values.^{9,10} The harmonic components generated via this method have immediate clinical utility—for example, measures of corneal spherical equivalent power, regular astigmatism power and axis, and irregular astigmatism.⁸ In the current study, we used Fourier analysis to extract the non-spherocylindrical corneal power component from the videokeratography data of eyes undergoing LASIK. The aim of the current study was twofold—to quantitatively assess the induced changes in corneal irregular astigmatism by LASIK and to analyse the relation between those changes and the amount of myopic correction.

Patients and methods

LASIK was performed on 189 eyes of 116 patients with myopia, ranging in age from 19 to 53 years old (mean 27.3 (SD 6.2) years). There were 27 males and 89 females, and their preoperative refraction was -2.0 to -12.75 dioptres (D) (-6.9 (2.3) D). One hundred and nineteen eyes (63.0%), which underwent the combined spherical and astigmatic correction, had a refractive cylinder of 0.5–4.0 D (1.18 (0.75) D).

All surgeries were performed by two surgeons (TMB, KHL) using the VISX Star excimer laser system (VISX Inc, Santa Clara, CA, USA). Laser parameters included the following: wavelength, 193 nm; radiant exposure (fluence), 160 mJ/cm²; pulse repetition rate, 10 Hz; average ablation depth per pulse, 0.23 μ m on the cornea; aspiration air flow was used for debris removal; ablation zone diameter, 6.0 mm; transition zone, 0.35 mm. The automated corneal shaper microkeratome (Chiron Vision Inc, Irvine, CA, USA) was used to create a hinged flap of 160 μ m thickness. The amount of laser ablation was 80.5 (22.8) μ m, ranging from 30 to 144 μ m.

Corneal topography was obtained with the scanning slit topograph (Orbscan, Bausch & Lomb, Irvine, CA, USA) before and 1 month after surgery. The maps were rejected on the basis of poor image quality, inadequate fixation, or deficit of data in the central 4 mm cornea. The dioptric powers of the anterior surface on polar coordinates were downloaded as an ASCII file. Using Fourier series harmonic analysis, dioptric powers on a mire ring i , $F_i(\sigma)$, can be transformed into trigonometric components of the form⁹⁻¹²

$$F_i(\sigma) = a_0 + c_1 \cos(\sigma - \alpha_1) + c_2 \cos 2(\sigma - \alpha_2) + c_3 \cos 3(\sigma - \alpha_3) + \dots + c_n \cos n(\sigma - \alpha_n)$$

where a_0 is the spherical component of the ring, $2 \times c_1$ the asymmetry (tilt or decentration) component, $2 \times c_2$ the regular astigmatism

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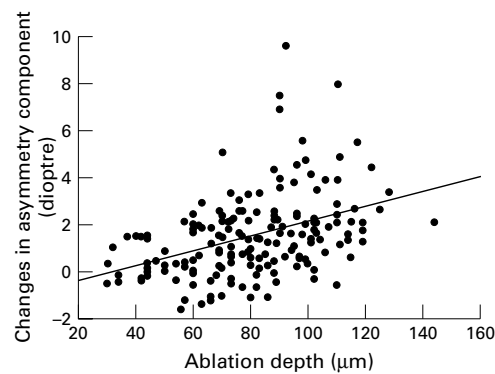


Figure 1 Significant correlation between the amount of laser ablation and changes in asymmetry component. (Spearman rank correlation coefficient $r_s=0.440$, $p<0.0001$).

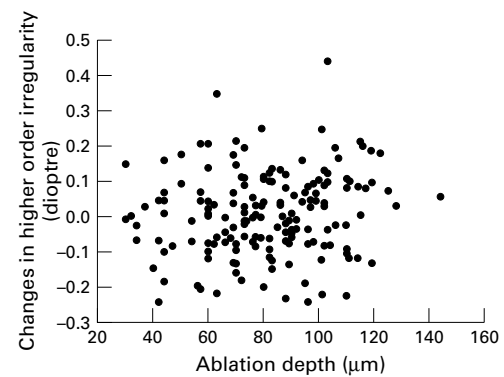


Figure 2 Relation between the amount of laser ablation and changes in higher order irregularity. There was no significant correlation (Spearman rank correlation coefficient $r_s=0.137$, $p=0.074$).

component, a_2 the phase (or axis) of regular astigmatism, $c_3 \dots c_n$ the higher order irregularity component. Among these, spherical equivalent power (a_0) and regular astigmatism (second harmonic component, $n = 2$) can be corrected by a spherocylinder lens, while the remaining components ($n = 1$ and $n \geq 3$) cannot, representing corneal irregular astigmatism. The lower terms, a_0 to c_2 , were first calculated, and thereafter the $c_3 \dots c_n$ term was obtained as the final loss of the approximation. The calculations were done for the 20 rings within the central 4 mm cornea, and values were averaged for the following statistical analysis.

Results

The data were analysed according to the performance of combined astigmatic correction. In 119 eyes which underwent the combined spherical and astigmatic correction, the asymmetry component significantly increased from 1.39 (0.60) D preoperatively to 3.25 (1.77) D postoperatively ($p < 0.0001$, Wilcoxon signed rank test), while higher order irregularity was 0.25 (0.10) D before and 0.25 (0.11) D after surgery ($p=0.990$). Similar results were obtained in the remaining 70 eyes which did not undergo astigmatic correction. The asymmetry component significantly increased from 1.24 (0.53) D preoperatively to 2.25 (1.29) D postoperatively ($p < 0.0001$), and higher order irregularity was 0.22 (0.12) D before and 0.22 (0.14) D after surgery ($p=0.596$).

In the total of 189 eyes, the asymmetry component significantly increased from 1.33 (0.58) D preoperatively to 2.88 (1.68) D postoperatively ($p < 0.0001$). Higher order irregularity did not fluctuate significantly with 0.24 (0.11) D before and 0.24 (0.12) D after surgery ($p=0.767$).

The induced changes in these refractive components were analysed in relation to the amount of laser ablation. The increases in the asymmetry component significantly correlated with ablation depth (Spearman rank correlation coefficient $r_s=0.440$, $p < 0.0001$, Fig 1). No significant correlation was found between changes in higher order irregularity and ablation depth ($r_s=0.137$, $p=0.074$, Fig 2).

Discussion

In the current study, we decomposed the corneal topography data into a series of trigonometric functions using Fourier harmonic analysis, and quantified the amount of asymmetry and higher order irregularity components. These two components cannot be corrected by a spherocylindrical lens and thus are thought to represent the corneal irregular astigmatism in a broad sense.¹³ In eyes undergoing photorefractive keratectomy (PRK), Keller *et al* employed a similar technique and reported that the asymmetry component significantly increased and higher order irregularity did not change by surgery.⁸ The current results obtained with LASIK are compatible; a significant increase in the asymmetry component and no change in higher order irregularity.

In this study, we also found that the changes in the asymmetry component significantly correlated with the magnitude of laser ablation. In radial keratotomy¹⁴ and PRK,¹⁵ it has been demonstrated that the increases in corneal wavefront aberrations were dependent on the magnitude of refractive correction. A clinical study of PRK has reported that the larger amount of attempted myopic correction led to the increasing incidence of subjective symptoms, such as glare and distortion, and a lower level of patient satisfaction.¹⁶ In order to avoid severe deterioration of corneal optical quality, extremely large levels of myopic correction should be avoided.

In the current series of patients, visual acuity results were excellent regardless of the increases in the asymmetry component. Thus, as far as the high contrast visual acuity is concerned, the increase in corneal irregular astigmatism after LASIK observed herein seems to be a subclinical phenomenon. To elucidate the exact influence of corneal irregularity on the visual performance, however, further studies are needed in which more in-depth parameters have to be investigated, such as contrast sensitivity, glare visual acuity, and modulation transfer function. In fact, several studies demonstrated that many patients experience reduced contrast sensitivity as a consequence of PRK¹⁷⁻²⁰ and LASIK.^{19, 21} Seiler *et al* found a high inverse correlation between

the effective aberration and visual acuity under glare conditions after PRK.²²

There should be several factors underlying the increases in the asymmetry component after LASIK, including the alignment strategy of the ablation zone.⁸ The excimer laser is centred on the corneal intercept of the line of sight—that is, the corneal point overlying the centre of the virtual entrance pupil rather than the corneal vertex. In contrast, Fourier derived terms are calculated relative to the videokeratoscope axis, which when correctly positioned is centred on, and normal to, the corneal vertex. The vertex and corneal intercept of the line of sight do not coincide. Thus, centring the ablation on the latter creates asymmetry when subsequently measured by the videokeratoscope. Another possible factor is the decentration of laser ablation. In previous studies, the average decentration of the LASIK ablation zone relative to the centre of the entrance pupil was reported to be approximately 0.9 mm.^{23–24} Although there are no data on the decentration of ablation relative to the corneal vertex, the amount of asymmetry component after LASIK would be influenced by the decentred laser ablation. Development and introduction of better centration method, such as an active eye tracking system,^{25–27} might help reduce the corneal irregular astigmatism induced by excimer laser surgery.

Currently, it is unclear whether and how the increases in asymmetry component influence the visual function after LASIK. In addition, no data are available at present about the long term time course of changes in asymmetry after surgery. Given the rapidly growing popularity of keratorefractive surgery, further investigation of the changes in optical quality of the cornea after surgery, by means of quantitative measures such as in the current study, is of critical importance.

None of the authors has a proprietary interest in any material or method mentioned here.

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