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Simulated effect of aspheric transition zone ablation profiles on optical aberrations after customized myopia ablation

Lihua Fang*

Key Laboratory of Nondestructive Test (Ministry of Education), Nanchang Hangkong University, Nanchang 330063, China

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ABSTRACT

Purpose: To understand and study the effect of transition zone on wavefront aberrations after laser refractive surgery is important for improving visual correction outcomes.
Methods: Based on the ablation profiles of optical zone and aspheric transition zone for wavefront-guided refractive surgery, the influence of aspheric transition zone on the induced wavefront aberrations was studied.
Results: The types of ablation profile of aspheric transition zone had a significant influence on the induced higher-order wavefront aberrations. The induced aberrations were mainly spherical aberration and coma. In addition, the profile #9 showed that the induced spherical aberration had a lower RMS value than that in other profiles and yet the induced secondary astigmatism was relatively larger. Furthermore, secondary spherical aberration in the profile #9 was slightly lower than that in other profiles.
Conclusion: The residual higher order aberrations may be decreased by creating an optimized transition zone and may be result in improving postoperative visual performance, but they cannot be eliminated.

1. Introduction

To deliver a customized correction, it is very important to understand the postoperative wavefront aberrations induced by cornea ablation profiles. This paper concerns the effect of aspheric transition zone on the induced optical aberrations after a wavefront-guided corneal ablation.

Transition zone, which connects the optical zone to the unaltered cornea, is applied in modern laser refractive surgery [1]. With transition zone being applied, the curvature is continuous at the boundaries among optical zone, transition zone and untreated cornea. Therefore, transition zone plays very important roles in improvement of the postoperative visual performance. A transition zone was used in photorefractive keratectomy for high myopia [2]. In addition, the use of transition zone during LASIK resulted in a low incidence of postoperative glare and halos [3]. However, the shape, exact size and the profile of transition zone have profound impact on the postoperative aberrations. Some researchers demonstrated that the aspheric transition zone was safe and predictable [4,5]. Our previous study conveyed that transition zone played a significant roles on the postoperative optical aberration [6]. Furthermore, in order to minimize the amount of induced aberrations, a multidynamic aspheric transition zone was applied in a laser system [7]. So the effect of the profiles of aspheric transition zone on the postoperative aberrations deserves further study.

The subclinical treatment decentration is inevitable during corneal refractive surgery and the decentration has been observed in several studies. These results revealed that the decentration had an important influence on the postoperative wavefront aberrations [8]. Wang et al. reported that mean pupil centroid shift was 0.29 mm during wavefront-guided corneal ablation [9]. Porter et al. found that the mean magnitude of the shift between the natural pupil center and dilated pupil center locations in wavefront-guided laser refractive surgery [10]. Decentrations during surgery may account for a partly portion of the postoperative increases in higher-order aberrations [11,12]. On the other hand, decentration produces significantly residual higher-order aberrations than cyclotorsional misalignment during wavefront-guided excimer laser corneal ablation [9]. Therefore, a Monte Carlo simulation was performed for simulating the treatment decentration in our study. In addition, the translation and rotation of ablation profile could be simulated theoretically by wavefront transformation [13].

Until now the influence of the ablation profile of transition zone on the induced optical aberrations of human eye with consideration of treatment decentration for a customized surgery has not been explicitly evaluated yet, for example the aspheric transition zone. In this study, we evaluated the relationship between the predicted residual aberrations and the ablation profiles for transition zone

* Corresponding author. Tel.: +86 013870884939.
E-mail address: fanglh71@126.com

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based on the corneal ablation profile. The effect of oblique incidence was also taken into account.

2. Methods

2.1. Subjects

In this study, 112 eyes of 56 potential refractive surgery candidates for correction of myopia were enrolled. Patients with connective tissue disease, amblyopia, cataract, retinal disease, keratoconus, and previous ocular surgery were excluded. The age of the patients ranged from 18 to 34 years (mean, 24.3 ± 4.8). The mean preoperative spherical equivalent was -5.39 ± 1.06 D (from -4 to -7.75 D) in right eyes and -5.28 ± 0.92 D (from -4 to -7.25 D) in left eyes, with D representing diopter. The distribution of the mean spherical power is shown in Fig. 1A. Additionally, the mean preoperative astigmatic power was -0.95 ± 0.82 D (from plano to -4.75 D) in right eyes and -0.96 ± 0.68 D (from plano to -2.75 D) in left eyes. Fig. 1B shows the astigmatic power as a scatter plot of the orthogonal components J_0 and J_{45}. This research followed the tenets of the Declaration of Helsinki, that informed consent was obtained from the subjects after a complete ophthalmic examination and an explanation of the nature and possible consequences of the research. The wavefront aberrations were measured using a Shack–Hartmann aberrometer [14] (WaveScan wavefront system, VISX, Inc., Santa Clara, CA) in the natural scotopic condition. All measurements were repeated at least three times for each eye, and the 3 best-matching measurements were used in this study. The wavefront aberrations for a 6-mm diameter pupil in all eyes were obtained by scaled transformation of Zernike aberrations. The contact lens wearers were excluded from this study.

2.2. Ablation profile for customized laser refractive surgery

The ablation depth at any arbitrary point in optical zone for customized laser refractive surgery can be obtained directly from the wavefront information according to the phase-conjugate principle.

$$D_c(x, y) = -\frac{W_p(x, y)}{(n-1)} \tag{1}$$

here n depicts the refractive index of cornea in visible light, and the value is 1.376 in this research. Also, (x,y) represents an arbitrary point in optical zone. In addition, the preoperative wavefront aberrations are expressed as a Zernike polynomial expansion.

$$W_p(x, y) = \sum_{n \text{ and } m} c_n^m Z_n^m(x, y) \tag{2}$$

2.3. Ablation profile in transition zone

In this section, the ablation profile in transition zone should be built. This profile was required to provide a smooth transition from the ablated regions to the untreated regions of the cornea. Aspheric transition zone has been demonstrated to be safe and predictable and the following equation for the aspheric profile, $d(x,y)$, is created:

$$d(x, y) = f_b(x, y) \cdot d_e(x, y) \tag{3}$$

here

$$d_e(x, y) = f\left(\frac{Ox}{2\sqrt{x^2+y^2}}, \frac{Oy}{2\sqrt{x^2+y^2}}\right)$$

It reveals the extended ablation depth in the transition zone, which is equal to the boundary value of the optical zone. Here, O indicates the diameter of optical zone.

Additionally, $f_b(x,y)$ indicates an aspheric blend function, which can give the normalized ablation depth in the transition zone. The function value ranges from one at the boundary between the optical zone and the transition zone to zero at the boundary between the transition zone and the untreated cornea. In order to achieve the blend function, an aspheric ablation function must be created as follows:

$$f_b'(x, y) = h - \frac{(x^2+y^2)}{R + [R^2 - (x^2+y^2)(Q+1)]^{1/2}} \tag{4}$$

or

$$f_b'(x, y) = \frac{\left[x_0 - \left(x^2+y^2\right)^{1/2}\right]^2}{R + \left\{R^2 - \left[x_0 - (x^2+y^2)^{1/2}\right]^2 (Q+1)\right\}^{1/2}} \tag{5}$$

here h indicates the nonzero value of ablation depth at the optical zone edge. The x_0 represents the width of transition zone. Also, Q conveys the asphericity. In addition, R depicts the radius of curvature of the ablation profile and it can be computed as follows:

$$R = \frac{(x_0)^2 + h^2(1+Q)}{2h} \tag{6}$$

In this study, the nine types of ablation profiles (from #1 to #9) were developed by changing the asphericity (Q value). Then, the aspheric blend function can be obtained through normalization.

$$f_b(x, y) = \frac{f_b'(x, y)}{h} \tag{7}$$

The relationship between the normalized aspheric blend function and transition zone width is shown in Fig. 2. The vertical axis depicts the normalized ablation depth and the horizontal axis

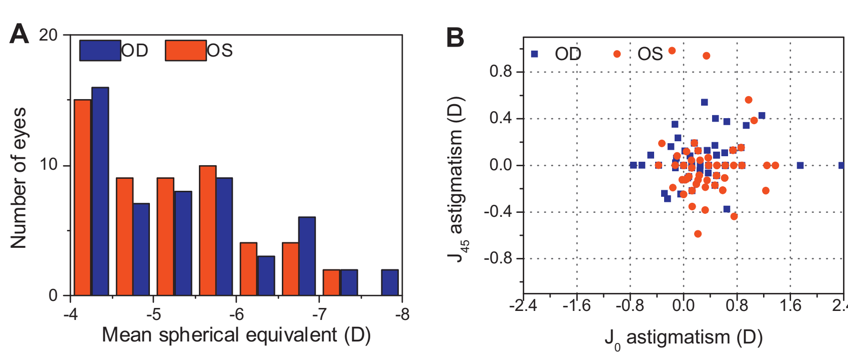

Fig. 1. Frequency distributions (OD = right eyes; OS = left eyes). A represents the spherical power of refractive error determined by the subjective refraction. B represents the astigmatism power determined subjectively. $N = 112$ eyes.