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# A design strategy of contact lens based on wavefront technology

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ABSTRACT

The design strategy of contact lens by the wavefront technology is presented in this paper. The back surface profile of the contact lens is acquired from the topography data of the anterior corneal surface, via a fitting procedure of least square, and the front surface profile is acquired from the ocular aberrated wavefront data, via a propagation procedure through tear film and lens medium. Eight eyes with different refractive errors are selected in this research, and the design procedure of the contact lens is validated. In a comparison of the ocular refraction errors with the refraction powers of the combination of tear film and contact lens, the maximum difference of the refraction power is 0.04 D for eight eyes and the maximum difference of the astigmatism angle is 10°. These are compared with the accuracy of clinical vision correction of 0.125 D nowadays. This approach is objective in vision correction, with much better accuracy, reliability and convenience as compared with traditional method.



## 1. Introduction

In 1508, Da Vinci, a famous artist in Renaissance period, had performed the experiment, in which he immersed his eyes in a container full of water in order to view clearly. These were noted in his book named *Codex of the eye* and the principium of the contact lens [1] was indicated unconsciously. The contact lens, as a device for refractive error correction, had developed for hundreds of years since its first emergence and attracted more and more attentions due to the improving fabrication techniques and materials as well as the design of customized refraction correction.

The power of the contact lens to correct the refractive error of the human eye is determined by the refraction measurements [1,2] which are divided into two groups, one is the subjective refraction and the other is the objective refraction. In subjective refraction, the refractive error of the patient is examined by the subjective visual perception of oneself to a definite stimulus. In objective refraction, the refraction error of the patient is obtained from the measuring results of the ocular instruments instead of his/her subjective visual feelings. At present, the procedure to acquire the refraction error for the contact lens prescription in clinic [1–3] is as follows. According to the refractive data from the measurement by autorefractor and the curvature data of corneal anterior surface from the measurement by keratometer, one type of trial contact lenses are chosen. Then the refraction of the patient who is wearing trial lens is adjusted with spectacle lenses to obtain the best visual quality. The results are transformed into the prescription of the contact lens employing the vertex correction formula. It can be seen that the measuring results rely on the subjective refraction and may be affected by the patient's psychology as well as the surrounding conditions. The precision of the subjective refraction is normally 0.125 D (diopter) while some patients may be insensitive to this strength of the refraction error. Therefore this method is not satisfactory nowadays.

The successful measurement of human eye's wavefront aberrations [4] is a great progress in ophthalmology at the end of the last century. With the technology of the wavefront aberrations the eye's optical defects can be investigated from the point of view of the diffractive optics, and the refractive correction can be realized from the point of view of the compensation of the aberrated wavefront. This technology has been advanced in the development of ophthalmic and relevant areas, and during the recent 10 years, the technique of visual correction has tremendous changes. The customized laser ablation of cornea guided by wavefront has become an increasingly popular surgery [5–8]. The spectacle lenses with wavefront technology were devised [9–11] at the beginning of this century, which the refractive power is determined by the wavefront measurement with Hartmann–Shack wavefront sensor. This is an objective method with a more accurate refractive error (precision of 0.1 D) provided.

There are many differences [1,12] between spectacles and contact lens although both of them are refractive correction devices. For example, comparing the distance of 12–15 mm between the surface of spectacles and cornea, contact lens is stuck on to the anterior corneal surface through tear film (about 6.5–7.5 μm in thickness). Besides, the base curve of the contact lens must be matched with the anterior corneal surface and the refractive power of the lens is finally determined by the curvature of its anterior

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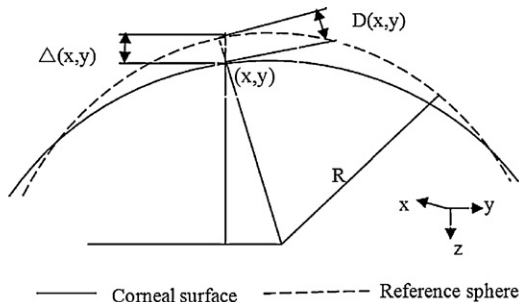


**Fig. 1.** Geometry drawing of corneal surface and reference sphere in the topography measurement with Orbscan II.

surface. So the design of a contact lens with wavefront technology should be distinct greatly from that of spectacle lens.

In this paper, the design strategy of contact lens by the wavefront technology is presented, for the first time to our best knowledge. Firstly the back surface profile of the contact lens is designed with the topography data of the anterior corneal surface obtained by Orbscan II system. Secondly the wavefront at the plane of the front surface of the lens is calculated with a propagation procedure of the ocular aberrated wavefront obtained by Hartmann–Shack aberrometer. At last the profile of the front surface of the contact lens is designed by an optimization procedure with the least square method.

## 2. Method

The central optical zone is the effective refraction region of the contact lens, which is normally about 7.0–8.5 mm in diameter. This optical zone is specifically assigned to the surface region of the contact lens in this paper.

### 2.1. Design of back surface of the contact lens

The Orbscan II system is adopted to acquire the topography of the anterior corneal surface [13,14]. The curvature radius of the reference sphere and the elevation data which are the relative altitude between the corneal surface and the reference sphere along the radial directions are obtained simultaneously. By means of calculation with MATLAB code, the elevation data is converted into the vertical distribution along the optical axis. The data of the vertical distribution is then used as the target in the optimization procedure to acquire the back surface of the contact lens, either as a sphere or as a toroid, with the least square method. In this way the back surface of the contact lens matches with the anterior corneal surface.

Fig. 1 shows the geometry of the corneal surface and its reference sphere in the topography measurement with Orbscan II system. The curve with solid line stands for the realistic corneal anterior surface and the dashed line stands for the fitted reference sphere. $R$ is the radius of the reference sphere, $D(x,y)$ is the radial altitude difference between the surface of virtual cornea and the reference sphere, and $\Delta(x,y)$ is the vertical distribution along the optical axis which can be expressed as:

$$\Delta(x,y) = \sqrt{R^2-(x^2+y^2)} - \sqrt{(R-D(x,y))^2-(x^2+y^2)} = \sum_{i=1}^{N} \alpha_i^c z_i(x,y) \quad (1)$$

where $z_i(x,y)$ represents the Zernike polynomials with $\alpha_i^c$ denoting their coefficients.

The configuration of contact lens' back surface is classified into 3 types which are sphere, asphere and toroid type. In the design of sphere surface, the curvature is constant at every point. The asphere surface, whose curvature is continuously changing along the radial direction including the ellipse, the paraboloid and the hyperboloid, provides a more comfortable wear than that of sphere, but its optical performance is not good. The toroid surface, with a maximum and a minimum curvature on two perpendicular meridians respectively, is employed in the case of a medium and high corneal astigmatism (≥1.50 D). Because of its perfect conformity to the anterior corneal surface, the lens with toroid back-surface possesses higher stability. In this paper, the sphere and toroid back-surface are chosen for different corneal astigmatism. The sag of the sphere surface can be written as:

$$Z_S = \frac{C_S(x^2+y^2)}{1+\sqrt{1-C_S^2(x^2+y^2)}} \quad (2)$$

and the sag of the toroid surface can be written as:

$$Z_T = \frac{C_1x_1^2+C_2y_1^2}{1+\sqrt{1-C_1^2x_1^2-C_2^2y_1^2}} \quad (3)$$

where $Z_S$ and $Z_T$ are the distance along the optical axis, $(x,y)$ is the coordinate on the surface perpendicular to the optical axis and $(x_1,y_1)$ is the coordinate with a rotation transformation of $(x,y)$ coordinate. $C_S$ stands for the curvature (in unit of $m^{-1}$) of the sphere, while $C_1$ and $C_2$ stand for the curvatures along the axis $x_1$ and $y_1$ respectively.

### 2.2. Wavefront propagation in contact lens and related medium

With the diffraction theory of angular spectrum [15], which has the same signification as the Kirchhoff principle, the wavefront propagation is discussed in the frequency domain, and it is convenient to apply the angular spectrum principle to the propagation calculation. The wavefront aberrations of the eyes are measured with the aberrometer and expressed with Zernike polynomials as:

$$W(x,y) = \sum_{i=1}^{k} \alpha_i Z_i(x,y) \quad (x^2+y^2 \le 1) \quad (4)$$

where $Z_i(x,y)$ is Zernike polynomial, $\alpha_i$ is the corresponding coefficient, $k$ is the number of items, and $(x,y)$ is the normalized coordinate. The complex amplitude of the ocular wavefront on the pupil can be expressed as:

$$u_0(x,y) = P(x,y) \quad \exp[jkW(x,y)] \quad (5)$$

where $P(x,y)$ is the pupil function and can be written as:

$$P(x,y) = \begin{cases} 1 & x^2+y^2 \le r^2 \\ 0 & else \end{cases} \quad (6)$$

where $r$ represents the radius of the pupil in wavefront aberration measurement. According to the angular spectrum principle, the angular spectrum $A_0$ corresponding to the complex amplitude of $u_0(x,y)$ can be written as:

$$A_0\left(\frac{\cos\alpha}{\lambda}, \frac{\cos\beta}{\lambda}\right) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} u_0(x,y) \exp\left[-j2\pi\left(\frac{\cos\alpha}{\lambda}x + \frac{\cos\beta}{\lambda}y\right)\right] dxdy \quad (7)$$

where $\lambda$ is the wavelength in wavefront aberration measurement, which is 0.555 μm in this case.