Wavefront Technology and Its Application in LASIK Surgery

Essay

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Master Degree in ophthalmology

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LIST OF ABBREVIATIONS

CSF .... Contrast sensitivity function

HOAs ...... Higher – order aberrations

LASIK .... Laser in-situ keratomileusis

OPL .... Optical path length

RMS .... Root mean square

CS ....contrast sensitivity

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CHAPTER 1 INTRODUCTION

1-1 Review of Basic Wavefront Optics

The Wavefront

Light is a source of energy that generates radiating waves of light, much like the waves that appear when a pebble is dropped into a water tank. The crest of the wave continues to move outward in a circular pattern. The curved line that follows the crest of the wave at any instant in time is called the wavefront. Said differently, for light, the wavefront joins the emerging light waves at a single point in time. When light emerges from a point source, this wavefront takes on a spherical shape. As the wavefront moves further and further from the source, a segment of the surface of the wavefront will get flatter and flatter, until the wavefront finally takes the shape of a plane.[1]

Figure (1-1)[1] shows the effect that a lens has on a parallel incident wavefront. The light passing through the thicker portion of the lens is delayed more than on the edges, making the wavefront curve inward. Since light travels perpendicular to the direction of the wavefront, this curved wavefront shape describes light that is focusing to a point. The same lens can be used for incident light that is diverging. When the diverging light passing through the lens emerges as a plane wavefront (parallel beam), that light is said to be originating from the primary focal point of the lens.[1]

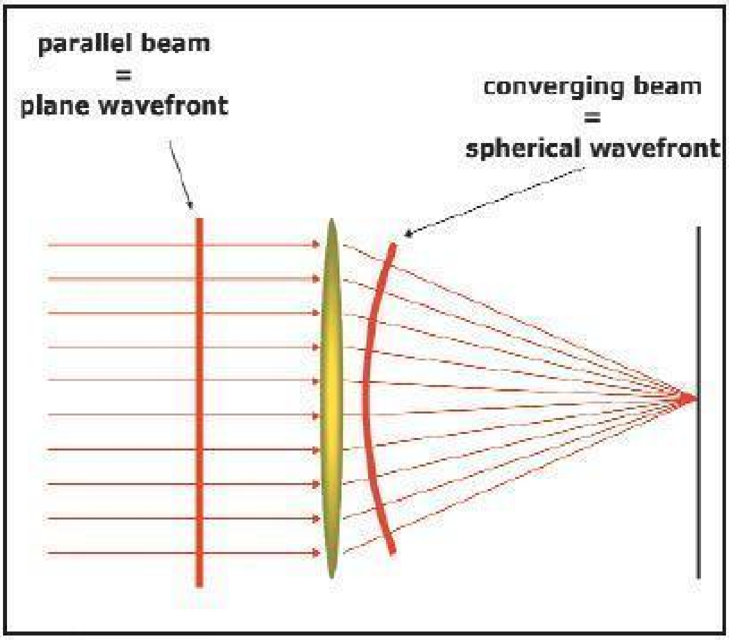

Fig (1-1): The relationship between Wave front and light rays. [1]

Wave Aberration

When the wavefront is interrupted by media of a different index, then the emerging wavefront shape is often one that is not planar, nor does it converge to a point or diverge as though it is coming from a point. This will occur if the surface of the interrupting media is not smooth or if the index of refraction of the media is not constant. A wavefront that deviates from its intended shape is called an aberrated wavefront. The wave aberration is defined as the difference between the actual aberrated wavefront and the ideal or intended wavefront *(figure1-2 A).* [1]

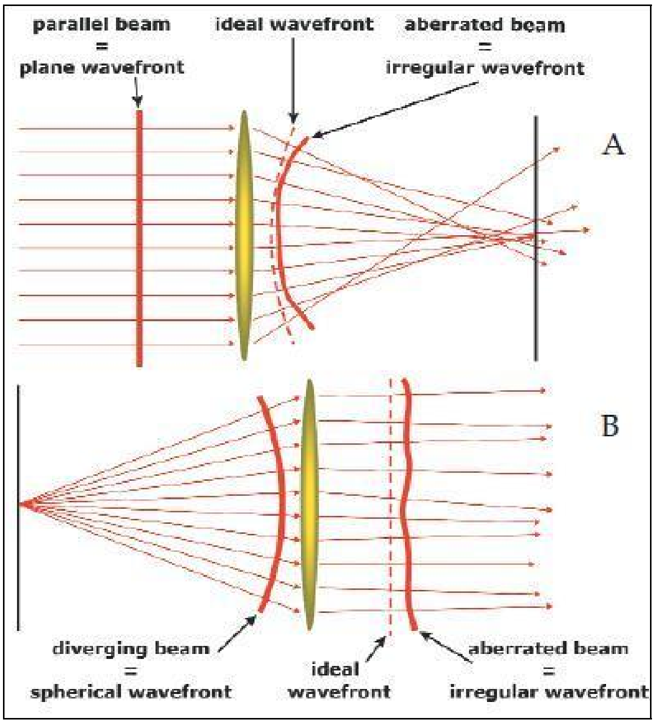

Fig (1-2): A. The aberrated Wave front for (A)light coming from a distant object and (B)light from the a approximate primary focal point of the lens. The emerging light neither converges to a point nor does it from a paraller beam, resulting in irregular –shaped Wave front. [1]

Since the wavefront defines a surface, the wave aberration also defines a surface, since it is simply a map of the separation between two surfaces *(figure 1-2 B).*[1]

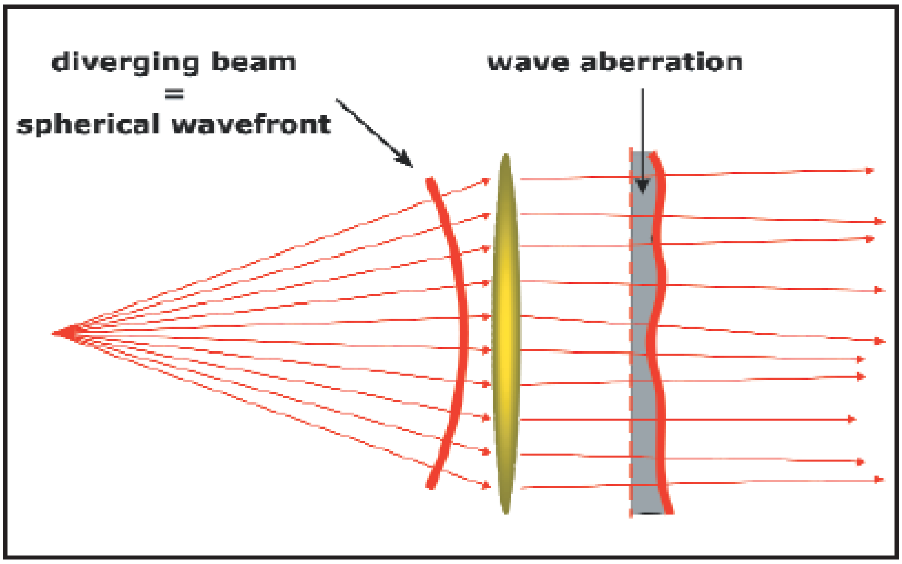

Fig (1-2): B The wave aberration, illustrated in gray, is the difference between the ideal wavefront and the aberrated wavefront. [1]

Zernike polynomial

Zernike polynomial is a set of shapes that are fitted to the wavefront data. The data are in two dimensions (over the pupil aperture) and the shapes are very complex. Each basis function has a coefficient, the value of which indicates the amount of that particular aberration that composes the wave aberration. [1]

The convenience of the Zernike polynomial is that it contains shapes that have some functional meaning, like defocus, astigmatism, coma, and spherical aberration. In addition, the Zernike polynomial has other complex shapes, with equally complex names, like quadrafoil or secondary astigmatism. These aberrations are present in the eye, however, and also need to be considered in the fit. [1]

Figure (1-3) [2] shows in two dimensions the first five radial orders (18 Zernike modes) in the Zernike Pyramid of aberrations (excluding piston, tip, and tilt) that are used to compose the eye's wave aberration. Each mode has a value that indicates its magnitude of wavefront error, usually expressed in microns, corresponding to its root mean square (RMS) or standard deviation across the pupil. [3]

These mathematical models are adequate for describing the wavefront measurements of the eye, because they are defined based on a circular form. The shape of the wavefront is described in the x and y coordinates; the third dimension, height, is described in the z-axis. The final figure is obtained from the sum of the Zernike polynomials describing all types of deformation. [4]

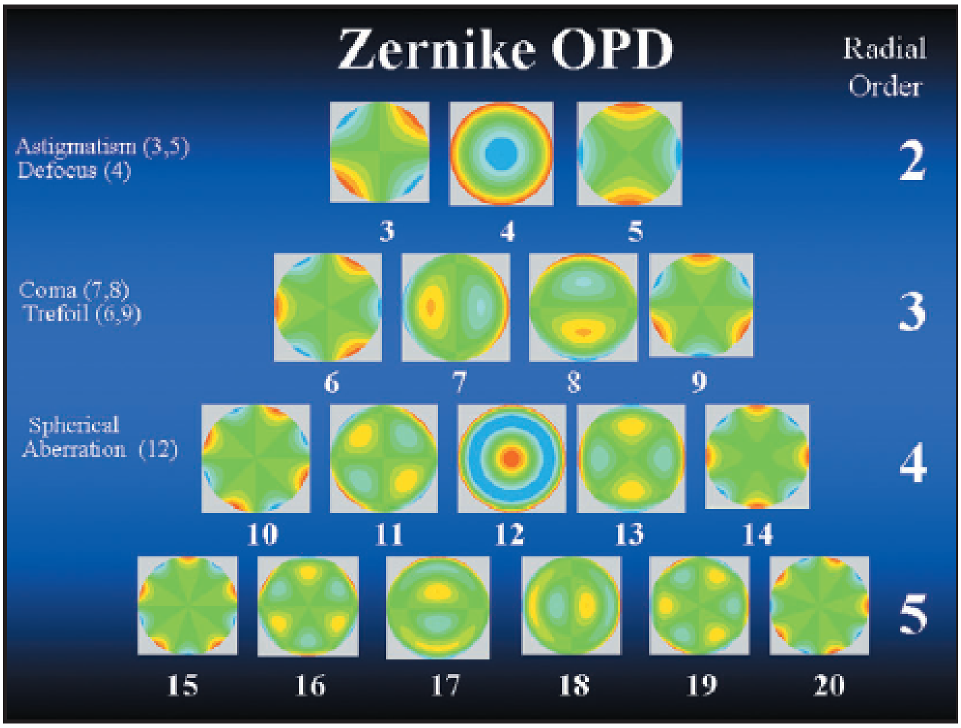

Fig (1-3): Aberrations based on zernieke polynomials. Quadrfoil (10, 14) secondary astigmatism (11,13) pentafoil (15,20) secondary trefoil (16,19) secondary coma(17,18) [2]

Aberrations can be divided into two groups: chromatic and monochromatic.

a) Chromatic aberrations

Are caused by the difference in distribution of incident polychromatic radiation throughout a medium, and depend on the wavelength of the light that penetrates the eye. They are influenced by variations in the refractive index of a material in relation to the wavelength of the light that travels through it.

This type of aberration cannot be corrected, because it depends on the composition of the ocular structures and not their shape. [4]

b) Monochromatic aberrations

Are related to a specific wavelength and include spherical refractive error (defocus), cylindrical refractive errors (astigmatism), and high-order aberrations (HAO) such as spherical aberrations and coma. Based on Zernike's polynomials, aberrations are described numerically.

First to fourth-order polynomials are shown graphically in ***(figure 1-4).*** [4]

Low-order aberrations

Low-order aberrations include the following:

- Order-zero (no order). These aberrations are characterized by axial symmetry and a flat wavefront.
- First-order. These linear aberrations correspond to tilting around a horizontal (x) or vertical (y) axis. They describe the tilt or prismatic error of the eye.
- Second-order. Spherical defocus and astigmatism. [4]