Principles of Tscherning Aberrometry

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ABSTRACT

Higher-order optical errors of the human eye are often responsible for reduced visual acuity in spite of an optimal spherical or cylindrical refraction. These optical aberrations are of natural origin or can result from operations on the eye involving optical structures. The presented wavefront analyzer is based on Tscherning´s aberroscope. A collimated laser beam illuminates a mask with regular matrix pin holes which forms a bundle of thin parallel rays. These rays form a retinal spot pattern on the retina that is more or less distorted according to the optical errors of the eye. This retinal spot pattern is imaged onto the sensor of a low-light CCD camera by indirect ophthalmoscopy. The deviations of all spots from their ideal regular positions are measured by means of a personal computer, and from these values the optical aberrations are computed in the form of Zernike polynomials up to the 8th order. [*J Refract Surg* 2000;16:S570-S571]

In 1894, Tscherning published his investigations on optical aberrations of the human eye.[1] He concluded that such optical aberrations may detoriate vision but unfortunately there seems to be no way to correct them. This situation has been changed with the introduction of ArF excimer lasers for corneal laser surgery[2] and may be corrected by wavefront-guided laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK).[3] Nevertheless, Tscherning introduced a new way to determine optical aberrations in human eyes. He used an optical lens of about +4.00 diopters (D) with a grid at the lens surface that consists of equidistant lines. During the investigation, subjects were advised to fixate on a star and sketch their own optical aberrations. Here, the light of a star can be assumed to be parallel with a plane wavefront due to the enormous distance between the star and the subject's eye. Today, the use of modern technology such as lasers, CCD cameras, and personal computers enables us to convert the initial subjective method of Tscherning into an objective method for measuring the optical aberrations of a human eye.

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OPTICAL SETUP

In principle, the wavefront analyzer consists of two different optical path ways (Fig 1)—ingoing and outgoing optics.

The in-going optics consist mainly of a frequency doubled Nd:YAG laser (wavelength 532 nm), a dot pattern mask, and an aberroscope lens. The dot pattern mask creates 168 single light rays from the expanded beam of the Nd:YAG laser. A spot-free center for the mask design was chosen to avoid light reflections at different optical surfaces of the human eye that might reduce the quality of the retinal image. The diameter of the spot pattern at the cornea is 10 mm and the diameter of the retinal image can be kept constant at 1 mm by means of different aberroscope lenses. Here, the number of dots projected onto the retina depends only on the subject's pupil size and the mask design. The total illumination time is 40 milliseconds with a laser power far below the international safety requirements.

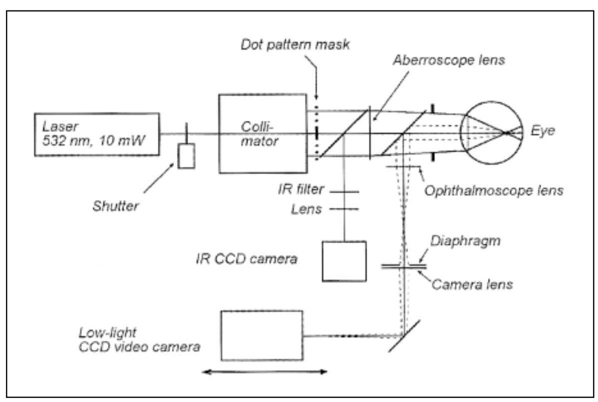

Figure 1. Scheme of the wavefront analyzer based on the principles of Tscherning aberrometry.

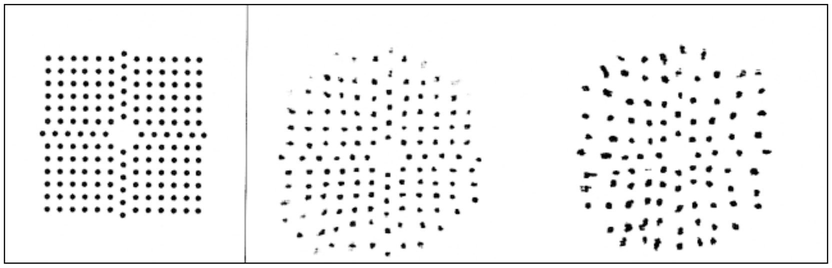

Figure 2. Examples of spot patterns. Ideal retinal image of a spot pattern for an emmetropic eye without optical aberrations (left). Examples of measured retinal spot patterns (middle and right). Both measured pictures clearly exhibit effects of ocular aberrations.

The out-going optic used in our measuring device is based on the principles of indirect ophthalmoscopy, as previously described. Here, the exit pupil was kept constant at a diameter of 1 mm and, thus, one might consider that the out-going optic is diffraction limited. The retinal image is grabbed by a highly sensitive CCD camera linked to a personal computer. The optical aberrations of the investigated eye can now be calculated by analyzing the retinal images. Basically each real spot position taken from the retinal image is compared to its corresponding ideal spot position. From the resulting deviations the wavefront aberration is mathematically reconstructed. The size of the ideal spot pattern is calculated by the use of the Gullstrand's eye model. We want to point out that this assumption does not alter the determination of the higher order optical aberrations because only the image magnification factor to convert the ideal spot pattern from the corneal to the retinal plane was derived from the Gullstrand eye model. The accuracy of the device was tested by measuring means of different telescopes assumed to be aberration-free.

One of the important factors in wavefront sensing is the correct centration of the subject's eye. The wavefront analyzer uses an infrared video system and a fixation target coaxial to the optical axis of the device to align the measuring system onto the line of sight of the subject's eye. Thus, the line of sight is determined as the reference axis for the purpose of measuring and calculating optical aberrations. The centration of the dilated pupil is done by means of infrared LEDs and a CCD camera that records the reflection of the LED light from the cornea. Besides this, the accurate alignment of the z-axis is done by centering the iris–reflex of a modified slit lamp onto the pupil center.

An important point when introducing new technology in ophthalmology is the reproducibility of measurements in patient eyes. From the more than 300 eyes (5 measurements each eye) measured with the Tscherning aberrometer, the absolute reproducibility for the sphere and cylinder was found to be ±0.08 D. The reproducibilities for the root mean square wavefront error and for the root mean square of the higher order optical aberrations are shown in the Table. The standard deviation for the root mean square was found to be in the order of 40 nanometers. In the case of a large pupil size (>7 mm) the Zernike polynomials up to the 8th order (45 Zernike coefficients) can be calculated with high accuracy.

Table
Reproducibility of the Wavefront Analyzer in an Eye with a 7 mm Pupil Diameter

Parameter	Range	± SD
Sphere	-12 to +6 D	0.08 D
Cylinder	up to -4 D	0.08 D
Axis	0° to 180°	2.0°
Root mean square	up to 10 µm	0.04 µm
Root mean square of higher order	up to 2 µm	0.02 µm

The image quality of the retinal light spots depends on the optical transparency of intraocular mediums passed by the in-going and the out-going optical pathways. Some opacities of the cornea—ocular lens or the vitreous body—can diminish considerably the intensity of these rays and, as a consequence, spots may not be detected by the image processing program.

These results as well as our practical experiences demonstrate that the wavefront analyzer, based on the principles of Tscherning aberrometry, is a useful and reliable device applicable under clinical conditions.

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