Clinical Experience With the Tscherning Aberrometer

Maik Kaemmerer, PhD; Michael Mrochen, PhD; Peter Mierdel, PhD; Hans-Eberhard Krinke, PhD; Theo Seiler, MD, PhD

ABSTRACT

PURPOSE: With the aberrometer based on Tscherning's principle, measurements of wavefront aberrations of human eyes with high accuracy and reproducibility are available for standard diagnostic investigations.

METHODS: During investigational and clinical trials, wavefront-aberrations of about 300 human eyes were measured and evaluated within the last few years.

RESULTS: measurements are presented in terms of Zernike coefficients and as height maps that can be converted directly to ablation profiles for wavefront-guided laser treatments.

CONCLUSION: The Tscherning aberrometer is a simple optical device with high accuracy appropriate for routine clinical investigations on optical aberrations of the human eye. [*J Refract Surg* 2000;16:S584-S587]

Based on the principle of Tscherning aberrometry (well known since the end of the 19th century[1]), Mierdel[2] and Mrochen[3] described an objective method of this aberrometer developed and used in Dresden, Germany. The goal of this paper is to describe the measurement procedure under clinical conditions and to summarize the results of some clinical trials with this new diagnostic tool.

PATIENTS AND METHODS

Clinical Measurements

The measurement procedure with the Tscherning Aberrometer is subdivided into five single steps: (1) grabbing of the retinal images, (2) image enhancement, (3) detection of the retinal spot positions, (4) calculation of the wavefront aberration, and (5) presentation of the results.

After the aberrometer was correctly centered on the line of sight of the patients eye, approximately five to ten retinal images were grabbed by means of a CCD camera and a standard personal computer (PC). From these images it was possible to determine the geometrical mass centers of each of the retinal spots.

The next step was to calculate the shift of each retinal spot from its ideal position. An ideal, distortion-free grid in the retinal plane was reconstructed by means of a grid spacing calculated from the length of Gullstrand's eye model and the position of the CCD camera in the aberrometer (depended on the ametropy of the investigated eye). From these deviations it was possible to determine the slope of the wavefront aberration. Some mathematical algorithms were needed to calculate the actual wavefront aberration in terms of Zernike polynomials from these slopes (two-dimensional least-square fit). The result of the whole procedure is a set of polynomial coefficients that describe the wavefront aberration of the investigated eye in terms of standard optical errors like astigmatism, coma, or spherical aberration (Table 1).

Finally, the measured wavefront-aberration was presented as a height map with a diameter depending on the investigated pupil size (Fig 1). Additionally, the exact refraction of the investigated eye, the root mean squared error (rms), and the maximal height (peak-valley [pv]) of the measured wavefront aberration were calculated. The entire procedure took about 2 minutes per measurement. Most of the time was needed for image enhancement and spot-detection algorithms.

Clinical Studies

With this objective Tscherning aberrometer, we performed multiple clinical studies over the past few years. Initially, we measured the average optical errors of eyes with a normal visual acuity of 20/20 or better. Later, we investigated the wavefront aberrations induced by standard refractive surgery

From the University of Dresden, Dept. of Ophthalmology, Dresden, Germany (Kaemmerer, Mrochen, Mierdel, Krinke) and the University of Zurich, Dept. of Ophthalmology, Zurich, Switzerland (Seiler).

Dr. Kaemmerer is a scientific consultant for WaveLight Laser Technology AG, Erlangen, Germany.

Correspondence: Maik Kaemmerer, PhD, Augenklinik, Fetscherstr. 74, 01307 Dresden, Germany. Tel: 49.351.4583767; Fax: 49.351.458.4335; E-mail: kaemm@aberrometer.de

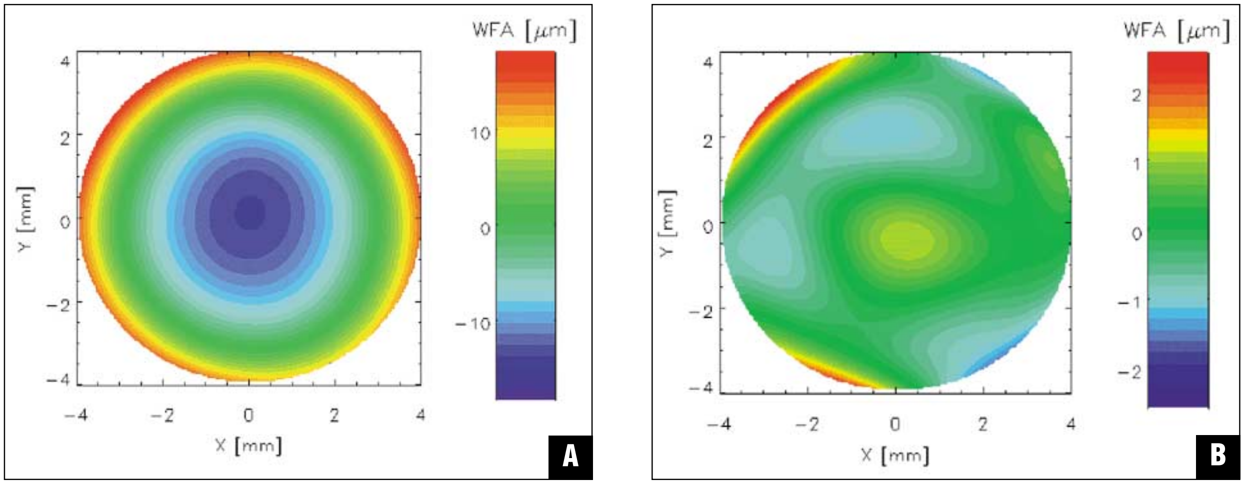

Figure 1. Wavefront aberration of a human eye height maps. **A)** All ocular aberrations included, and **B)** after subtracting sphero-cylindrical part.

treatments. In this manuscript, only the results of these two studies are discussed, but we also investigated the influence of drugs, accommodation, and soft contact lenses on the optical errors of normal eyes and the wavefront aberrations of patients with keratoconus and after cataract surgery. Additionally, the first wavefront-guided LASIK treatments worldwide were performed in our clinic based on Tscherning aberrometer[4] measurements.

RESULTS

Optical Aberrations in Normal Eyes

We measured the ocular aberrations in 130 normal eyes with the aim of collecting information on the "normal" optical error profile of the human eye. Additionally, we wanted to know if there was any correlation between the aberrations and other parameters within the patient groups. The demographic and refractive data of the investigated population is summarized in Table 2.

The most important result of this study was that in principle the human eye is a good optical system. As shown in Figure 2, all of the Zernike coefficents are nearly zero on average. We found only a negative amount of vertical coma (P = .015) and a slight amount of positive spherical aberration significantly different from zero (P = .01). Comparing the ocular aberrations of left and right eyes, we found significant differences, as reported by Howland and Howland.[5] In particular, some third and fifth order aberrations, which describe so-called three- and five-fold aberrations, changed their sign between the left and right side. Besides this, no significant difference between female and male patients was found relating to their ocular aberrations.

Additionally, we defined five age groups (Table 3) and compared them to obtain information on age dependency of wavefront aberration. The result was that the mean root mean square value did not change significantly between the first three age groups (18 to 40 years; Fig 3). In patients over

Table 1
Zernike Coefficient Conversion (Single Index to Double Index)

C_n^m	m	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
n														
0								C_0						
1							C_1		C_2					
2						C_3		C_4		C_5				
3					C_6		C_7		C_8		C_9			
4				C_{10}		C_{11}		C_{12}		C_{13}		C_{14}		
5			C_{15}		C_{16}		C_{17}		C_{18}		C_{19}		C_{20}	
6		C_{21}		C_{22}		C_{23}		C_{24}		C_{25}		C_{26}		C_{27}

Example: Spherical aberration reported here as C_{12} is C_4^0 in the double index scheme.

Table 2
Demographic and Refractive Data for 130 Eyes Measured for Wavefront Aberration

Age (range)	32.9 ± 11.3 yr	(range, 18 to 63 yr)
Sex		
Female (%)	82	(63.1)
Male (%)	48	(36.9)
Eye		
OD (%)	64	(49.2)
OS (%)	66	(50.8)
Manifest refraction (D)		
Sphere (range)	-1.70 ± 2.16	(-7.50 to +2.25)
Cylinder (range)	-0.44 ± 0.49	(0 to -2.75)

Table 3
Age Groups of 130 Eyes Measured for Wavefront Aberration

Group (range, yr)	No. Eyes	Age (yr) Mean ± SD
I (18 to 22)	22	20.0 ± 1.6
II (23 to 30)	33	25.2 ± 1.9
III (31 to 40	36	35.6 ± 2.2
IV (41 to 51)	22	46.8 ± 2.3
V (52 to 63)	17	59.4 ± 2.5

40 years of age, the wavefront aberration increased significantly (group III-IV: P = .01; group IV-V: P = .022). This was caused by a change of third-order optical errors (in particular the vertical coma) and spherical aberration with the age of the investigated eyes (Fig 4).

Optical Aberrations Induced by Refractive Surgery

Many patients complained about a loss of night vision and best spectacle-corrected visual acuity after refractive surgery. To investigate the correlation between this deterioration of vision and changes of ocular aberrations induced by surgery, we compared preoperative and postoperative wavefront measurements in 27 eyes of 25 patients who underwent photorefractive keratectomie (PRK) with the Multiscan system (Schwind, Kleinostheim, Germany).[6] Manifest spherical refraction ranged from +2.25 to -7.00 D and astigmatism ranged from -0.25 to -2.50 D. All eyes had a preoperative best spectacle-corrected visual acuity of 20/25 or better and no other ocular diseases. The optical zone of all treatments was greater or equal than 6 mm. In Figure 5, the measured change of the higher-order root mean square value within the optical zone (pupil size 5 mm) is shown; it increased by a factor of 3 to 5, on average. The reason for the increased

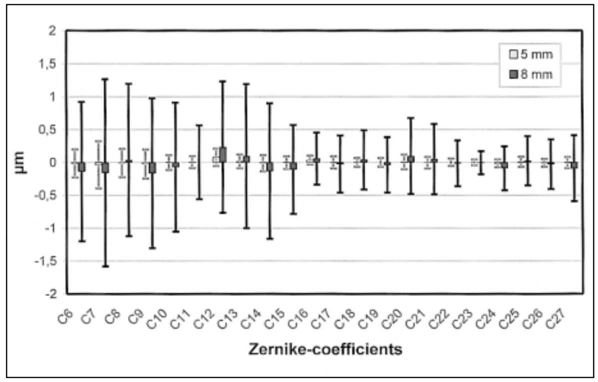

Figure 2. Mean Zernike coefficients of the investigated population (pupil size: 5 and 8 mm; single-index scheme, third to sixth order coefficients). Only vertical coma C7 (P = .015) and spherical aberration C12 were significantly different from zero (P = .01).

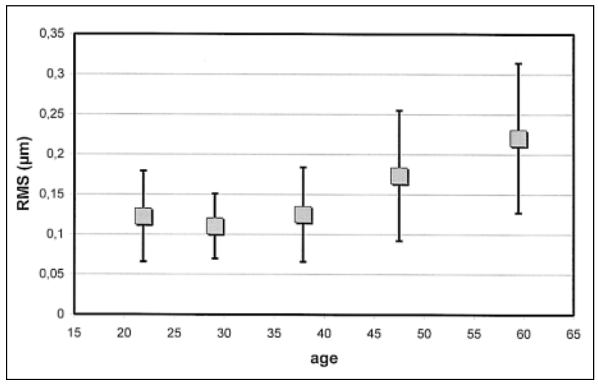

Figure 3. Comparison between the mean root mean square values of the five age groups calculated only from higher-order aberrations (pupil size: 5 mm). Significant change was only found between groups III and IV (P = .01) and IV and V (P = .022).

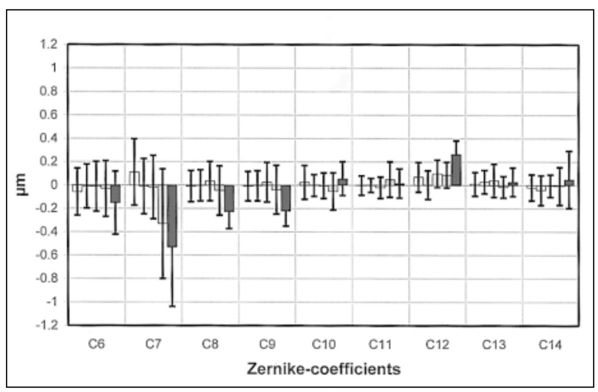

Figure 4. Comparison between the mean Zernike coefficients of the five age groups (pupil size: 5 mm, single-index scheme, third and fourth order coefficients). The number of the age group increases from left to right for each coefficient. Significant changes of third order terms C6 to C9 and spherical aberration C12 were found.

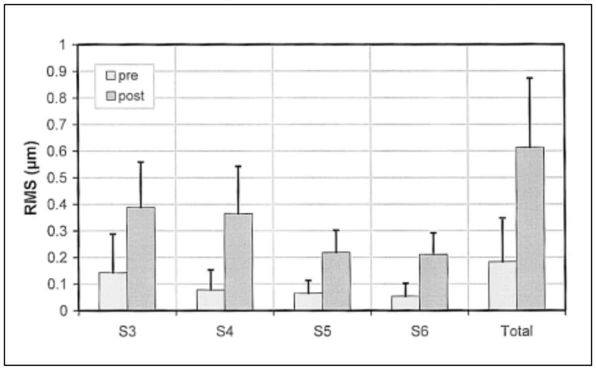

Figure 5. Comparison between preoperative and postoperative higher order root mean square values (pupil size: 5 mm). S3: root mean square calculated from third order Zernike coefficients (C6 to C9); S4: root mean square calculated from fourth order Zernike coefficients (C10 to C14); S5: root mean square calculated from fifth order Zernike coefficients (C15 to C20); S6: root mean square calculated from sixth order Zernike coefficients (C21 to 27); Total: root mean square calculated from all higher order Zernike coefficients (C6 to C27).

root mean square values after surgery was a large amount of positive spherical aberration induced by the surgery and an increased coma-like aberration resulting from small decentrations of the ablation zone. The main result of this study, however, was that the increase in ocular optical aberrations correlated significantly with the decrease of low contrast visual acuity (r = 0.85, P = .01), which indicates that the induced wavefront aberrations are one reason for the complaints of patients after refractive surgery.

DISCUSSION

All studies that we performed over the last few years showed that the Tscherning aberrometer is appropriate for routine clinical investigations on optical aberrations of the human eye. In cases of opacities in the central region of the optical system of the eye, or large higher order ocular aberrations (which cause crossing over effects in retinal images), it is difficult and in some cases impossible to perform a correct measurement. This is a general problem of all raytracing-based methods and is an object of further investigation. However, this new device will be used in our attempts to improve refractive surgery by performing wavefront-guided treatments based on aberration measurements.

REFERENCES

1. Tscherning M. Die monochromatischen Aberrationen des menschlichen Auges. Z Psychol Physiol Sinne 1894;6; 456-471.
2. Mierdel P, Krinke HE, Wiegand W, Kaemmerer M, Seiler T. Ein Mebplatz zur Bestimmung der monochromatischen Aberrationen des menschlichen Auges. Ophthalmologe 1997;94:441-445.
3. Mrochen M, Kaemmerer P, Mierdel P, Krinke HE, Seiler T. Principle of Tscherning Aberrometry. J Refract Surg 2000;16:S570-S571.
4. Mrochen M, Kaemmerer M, Seiler T, Mierdel P. Wavefront-guided LASIK—a brief report on feasibility and first results. J Refract Surg, in press.
5. Howland HC, Howland B. A subjective method for measurements of monochromatic aberrations of the eye. J Opt Soc Am 1977;67:1508-1518.
6. Seiler T, Kaemmerer M, Mierdel P, Krinke HE. Ocular optical aberrations after photorefractive keratectomy for myopia and myopic astigmatism. Arch Ophthalmol 2000;118:17-21.