Objective Measurement of Wavefront Aberrations With and Without Accommodation

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ABSTRACT

PURPOSE: The measurement of the refractive error profile is more useful than corneal topography in understanding the complexities of refractive surgery. We report on experimental studies of the spatially resolved refractometer Tracey-1, developed in Ukraine by IBME in medical cooperation with VEIC, Greece.

METHODS: Ten eyes were subjected to dynamic measurement of accommodation, in order to test the effectiveness of Tracey refractometry. Measurements were performed in zones 0 to 6 mm. The refractive aberrations were calculated and accommodation was evaluated.

RESULTS: Evaluation of data shows that the instrument can effectively follow the dynamic change of refractive aberrations through the accommodation process.

CONCLUSION: Clinical tests of Tracey technology demonstrated the ability to investigate accommodation using this instrument. [*J Refract Surg* 2001;17:S602-S607]

Wavefront aberration research has become important for many areas of ophthalmic investigation. We used information derived from the Tracey Wavefront Aberrometer to study accommodation of the human eye.

During accommodation, aberrations of the eye are changing. These changes are related to the crystalline lens and its performance over time during the aging process. The dynamic variable in accommodation is the lens, since the cornea curvature theoretically does not change. Nature has made our optical system in such a way that the lens and cornea complement each other, at least in the peripheral part of the optics. All aberrations and of most importance, higher order aberrations, change continuously both during the aging process and everyday vision.

The Tracey Wavefront Aberrometer (Fig 1) contains a CCD video camera and a special accommodation target for aligning the visual axis of the eye and the optical axis of the instrument (Fig 2). The target is observed through a positive lens. This lens moves in the area between the object and a distance equal to one focal length. This target is observed by the patient's eye to be examined. The virtual image can be moved from the object point to infinity by selectively positioning the lens. There is an indicator outside that translates the distance into diopters.

The accommodation target is adjustable in correspondence to any distance and enables examination of accommodative functions of the eye. The total time for scanning through the whole aperture of the eye is within 10 to 20 ms. Duration of scanning depends on the number of test points at the eye entrance and on the number of independent measurements in each point. Scanning pattern configuration can be chosen from the computer software, and contains 64 to 400 points, each checked one to five times with a default of 64 points, checked five times.

SUBJECTS AND METHODS

We present our first results of measuring accommodation with the Tracey Wavefront Aberrometer (Tracey Technologies Inc., Houston, TX).

We examined six eyes of six subjects in an accommodative and non-accommodative state. Patients were asked to concentrate their attention on the accommodation target. One observer, using the steps specified in the user manual, performed all measurements with the Tracey device.

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Dr. Pallikaris and Mr. Molebny have a proprietary interest in the technology mentioned herein.

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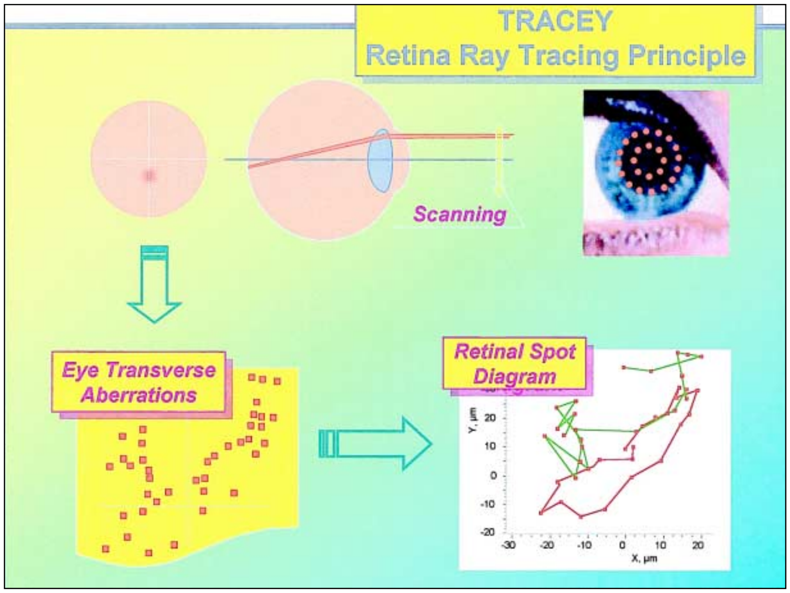

Figure 1. Schematic of the Tracey retina ray tracing principle.

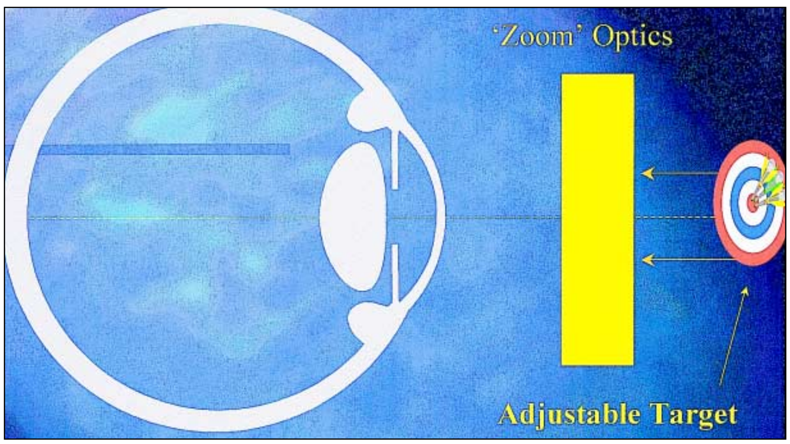

Figure 2. Tracey aberrometry schematic shows the accommodation target for aligning the visual axis of the eye and the optical axis of the instrument.

The subject was aligned and the diameter of the scanning pattern was chosen by the examiner according to the pupil size of the eye to be examined. We performed the examination in a dark room without any use of mydriatics. The accommodation target was initially set in the position for infinity. Using the joystick, the device was centered around the patient's pupil by superimposing the four images of the infrared light-emitting diodes reflecting from the cornea with the corresponding small computer-generated squares on a video monitor. When the eye was well aligned, a square indicator in the center of the video monitor changed from red to green. Pressing a button on the joystick then activated the scanning process. Then the accommodation target was adjusted to 20 cm. The examination procedure was repeated at the new accommodation level.

For case no. 1 (35-year-old subject), accommodation was measured under three accommodative conditions corresponding to the accommodative stimulus that ranged in 0 to -6.00 diopters (D) in steps of 3.00 D (Fig 4). For case nos 2, 3, 4, 5, and 6, accommodation was measured under two accommodative conditions, 0 and -6.00 D. For case no. 6, the accommodation process was measured with and without mydriatics.

RESULTS

For evaluation of the differences between the two states for each eye, we compared refractive maps for change in refraction as well as the root mean square (RMS) values for higher order aberration change during accommodation (Table).

Table
Refraction from Tracey and Higher Order Root Mean Square Values With and Without Accommodation in Eyes From Subjects of Different Ages

Case No.	Age) (yr)	Far Sphere (D)	Far Cylinder (D)	Far Higher Order RMS*	Near Sphere (D)	Near Cylinder (D)	Near Higher Order RMS
1	35	2.43	0.12	0.26	0.05	0.75	0.09
2	33	1.07	1.78	0.22	0.30	0.86	0.32
3	25	-0.23	0.37	0.57	-2.62	0.30	0.91
4	30	0.88	0.04	0.33	-1.85	0.21	0.48
5	40	-1.85	0.33	0.91	-3.64	0.07	0.39
6 no cycloplegia	46	-1.15	0.43	0.71	-1.94	0.32	0.71
6 cycloplegia	46	-0.95	0.23	0.91	-0.97	0.33	0.91

** Root mean square*

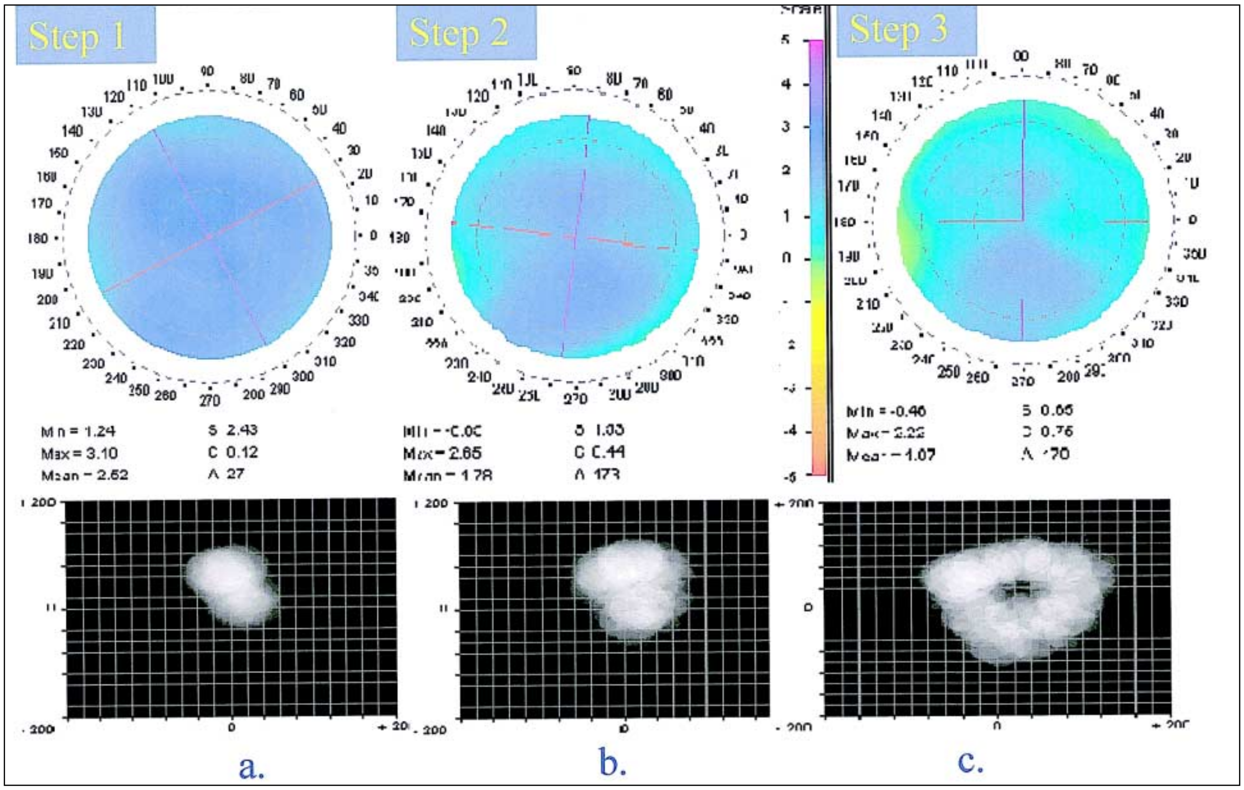

Figure 3. Refractive maps and retinal spot diagram maps for a 35-year-old subject (case no. 1) for three accommodative stimuli ranging from far for the first step (0 D) to -6.00 D (near), in steps of 2.00 D.

The RMS wavefront error provides a general estimate of the variation of the wavefront from the ideal. The higher the RMS wavefront error, the larger the wavefront aberration and the worse the image quality. We compared the change in RMS values when the eye was accommodating (Table).

In cases nos 2, 3, and 4, the higher order RMS decreased with accommodation; in case no. 1 it increased, perhaps because the subject was asked to accommodate slowly through three steps (not two); in case no. 6, the RMS value did not change due to the age of the subject, although the RMS value was different depending on whether cycloplegia was used (Figs 3-8). The RMS for case no. 5 was much

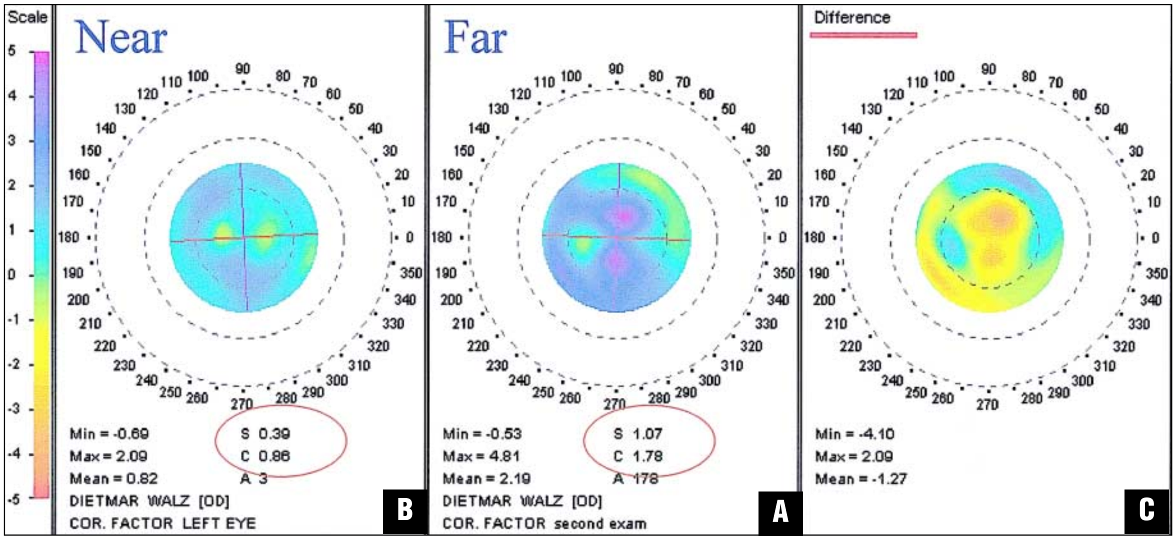

Figure 4. Refractive maps of case no. 2 (33 years old). **A)** The accommodation target is at infinity. Note the change in the distribution of refraction and the cause of astigmatism. **B)** Refraction distribution in the eye of the same subject after he concentrated on the accommodation target, adjusted to 20 cm. **C)** Difference map. (Original figure submitted with image B before image A.)

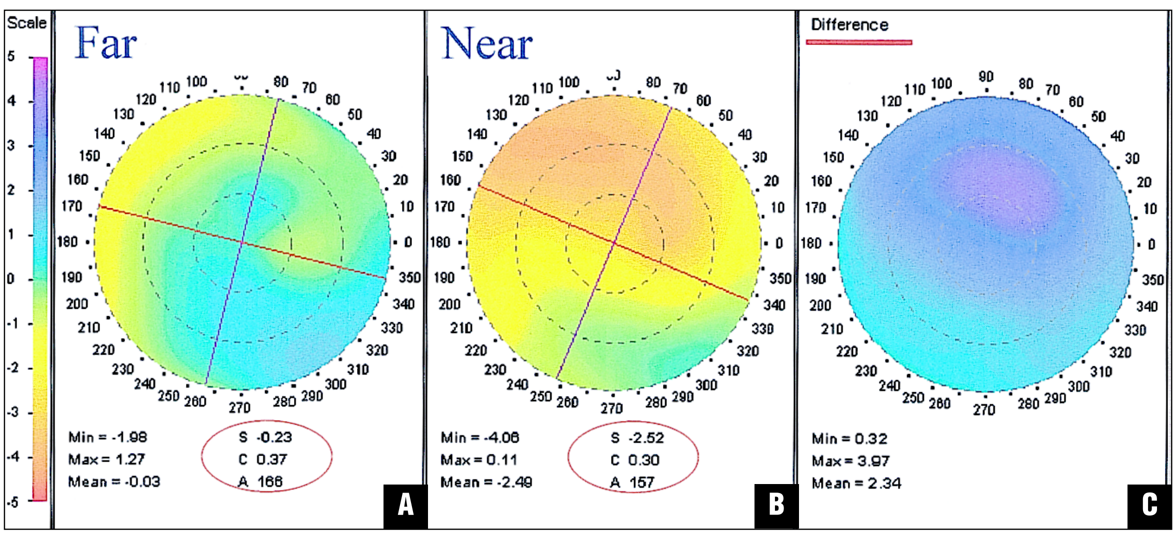

Figure 5. A,B) Refractive maps show a larger volume of accommodation for a 25-year-old subject (case no. 3). **C)** The difference map shows the difference between the two stages, far and near.

decreased for the accommodating stage because the pupil was smaller. In this case we see that the higher order aberrations are very dependent on pupil size.

DISCUSSION

In our study, the change in higher order aberrations with accommodation was variable. Case numbers 2, 3, and 4 showed increases in RMS value, and these patients were all 33 years old or younger. Case number 1 showed a decreased in higher order RMS (although the subject was 35 years old), probably due to the slow measurement of accommodation in three steps during which the subject was forced to "see" the target without immediate major differences in distance. In case number 6, where the patient was over 45 years old, there was no change in higher order RMS. Case number 6, with cycloplegia, showed no change, although the RMS values were different than with no cycloplegia. This may be due to intrinsic differences in wavefront

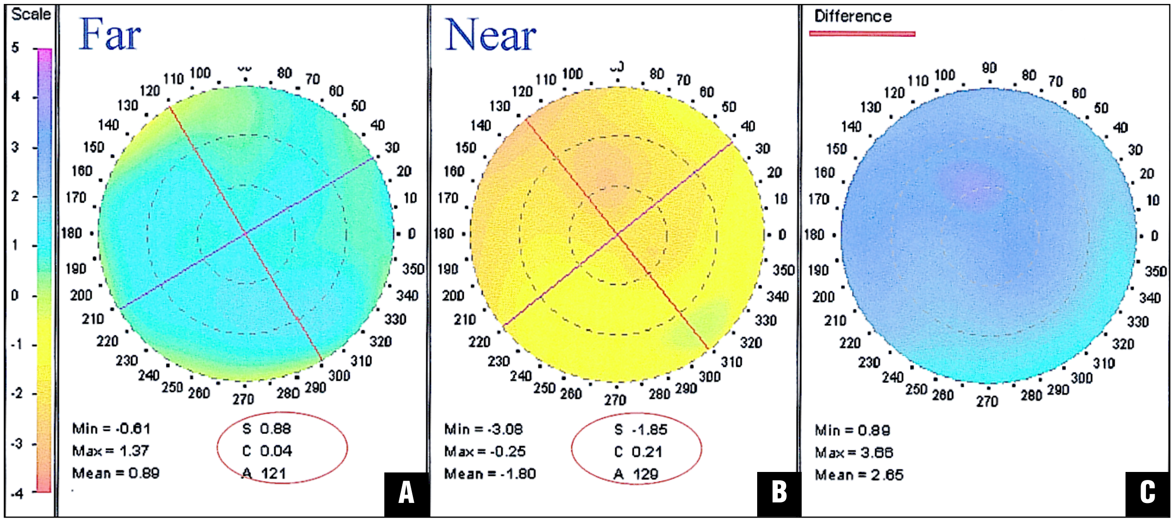

Figure 6. A,B) Refractive maps show the dynamic change of an eye of a 30-year-old (case no. 4), and C) difference map.

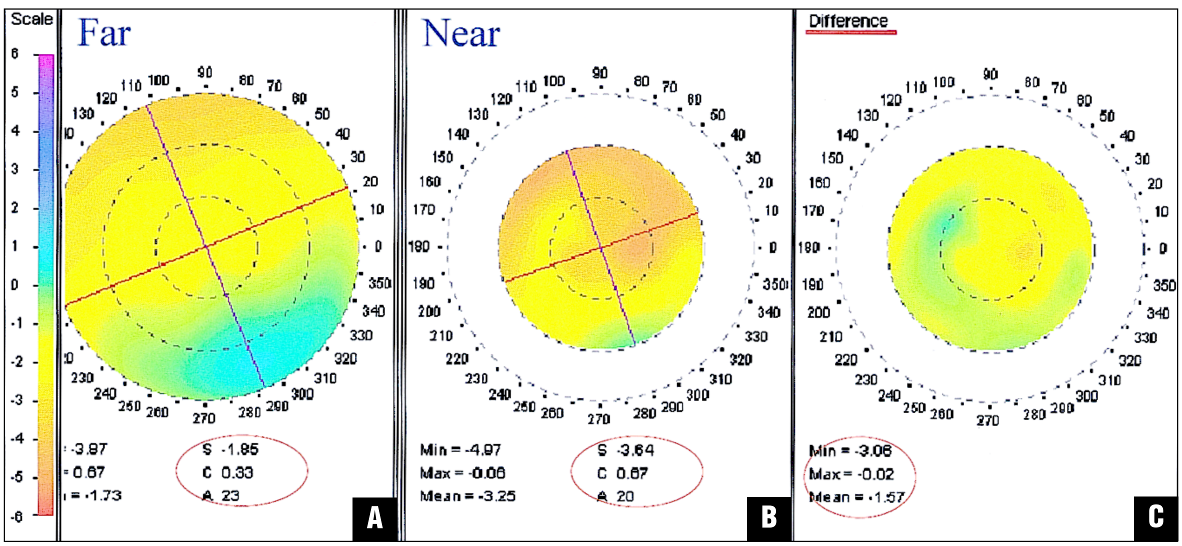

Figure 7. A,B) Refractive maps show the dynamic change of an eye of a 40-year-old (case no. 5) during accommodation and the change of the pupil diameter from 5 to 3 mm. C) Difference map for the 3-mm pupil.

error with cycloplegia. A decrease in RMS that was noted in case number 5 (40 years old) was due to the fact that the pupil size was decreased, accounting for the smaller RMS.

Our conclusion, based on this limited analysis, is that higher order aberrations seem to increase with rapid accommodation in younger patients and cycloplegia and show no change with older patients. Slow, stepwise accommodation seems to show decrease in higher order rms aberrations. However, an analysis of a larger number of eyes is required in order to draw more conclusions and substantiate these findings. The Tracey Wavefront Aberrometer can effectively “see” the accommodation process and give information about the dynamic vision range of an eye.

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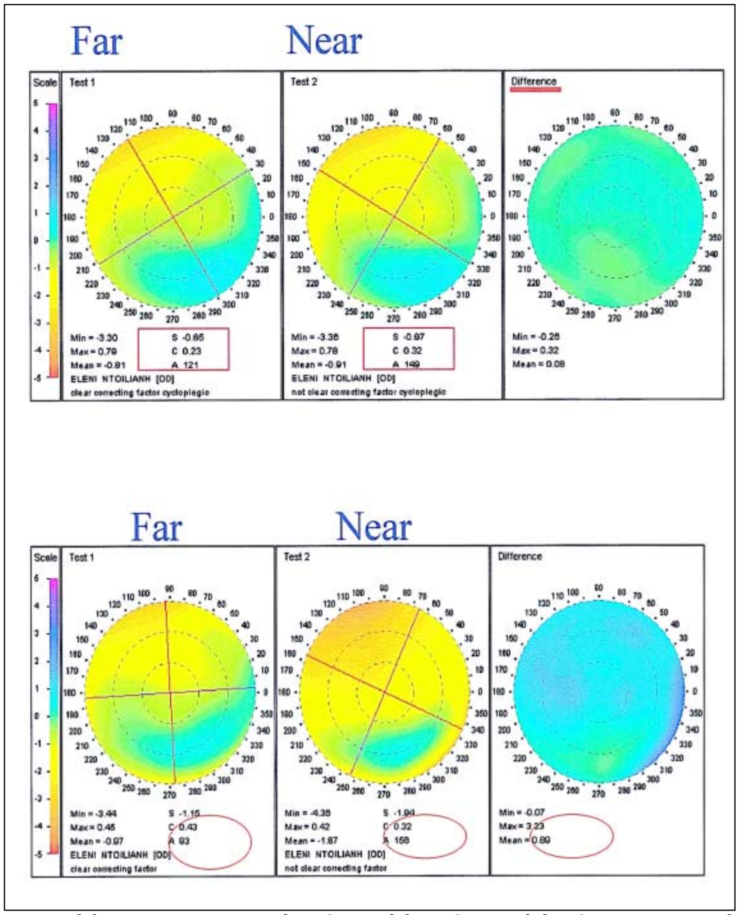

Figure 8. Eye of a 46-year-old (case no. 6) that did not accommodate (top, with cycloplegia; bottom, without cycloplegia). Note no difference was observed in the difference maps.

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