Depth of focus: Clinical manifestation

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PURPOSE. *To assess depth of focus on the basis of measurements of the point spread function, which involve Stiles and Crawford phenomenon.*
SETTING. *Department of Ophthalmology of National Academy of Postgraduate Education.*
METHODS. *Gullstrand's schematic eye parameters and data of subjective measurement of size of diffusion circles were used for calculation of depth of focus. Data of 1171 eyes with visual acuity 1.0–2.0 were included in the study.*
RESULTS. *Under condition of visual acuity 1.5 data of the depth of focus were 0.38 D, 0.64 D, and 1.92 D for pupil diameter 5.0 mm, 3.0 mm, and 1.0 mm, respectively. Visual acuity 1.0 is characterized by larger value and visual acuity 2.0 by lesser value of the depth of focus.*
CONCLUSIONS. *Depth of focus and normal levels of visual acuity have a close relation: the higher the visual acuity, the smaller the depth of focus. (Eur J Ophthalmol 2007; 17: 836-40)*

KEY WORDS. *Depth of focus, Apparent accommodation, Amplitude of accommodation, Pseudoaccommodation, Visual acuity*

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INTRODUCTION

The physiology of the human eye has been extensively studied using the model of the schematic eye having ideal optic and negligible depth of focus. It is understandable why until two recent decades the term depth of focus was not often encountered in ophthalmic literature. Modern technologies provide explicit data regarding physiologic optical aberrations and stimulate study of the depth of focus. Depth of focus appears to be useful for practical applications, for instance, for clinical assessment of accommodative intraocular lenses (IOLs).

Measurements of the depth of focus have resulted in contradictory data from 0.7 D to 3.2 D for 2–3 mm pupil diameter (1-4). A similar disparity was found for other pupil sizes.

Amid factors contributing disagreement in assessment of the depth of focus is the Stiles and Crawford phenomenon (5). The ability of the retina to neutralize a part of the optical aberrations may correct results of evaluation of the depth of focus made only on the optical basis.

In a previous study (6) we performed experimental measurement of the point-spread function (PSF) for different levels of normal visual acuity. This article presents an effort to use the PSF measurements involving the retinal factor for estimation of the depth of focus.

METHODS

Calculation of the depth of focus was made by using Gullstrand's schematic eye parameters (Fig. 1). In ideal optics the light rays pass the exit pupil PP' and converge on the retina in the point F. In reality, optical aberrations determine the formation of diffusion circles with a diameter CC' = DD'. Therefore, the retinal

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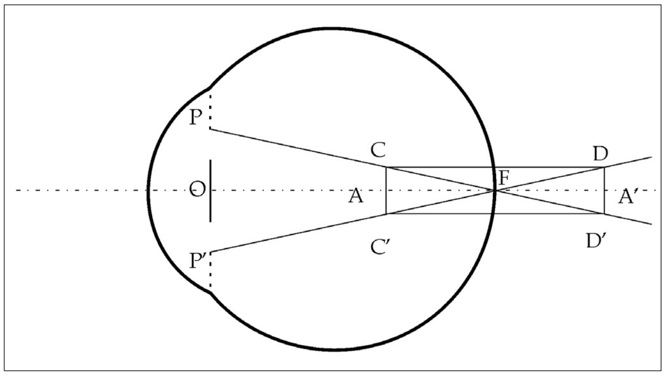

Fig. 1 - *Formation of the depth of focus on the basis of the Gullstrand's schematic eye.*

image is always slightly blurred. The interval AA' along the visual axis has a very similar degree of fogging of the retinal image. This interval is the depth of focus.

For calculations, we used the following equation:

$$\frac{PP'}{CC'} = \frac{OF}{AF} \qquad AF = \frac{CC' \quad OF}{PP'}$$

Where AF is 0.5 depth of focus, CC' is the diameter of diffusion circles, OF is the distance from the exit pupil plane to the retina (20.33 mm), PP' is the pupil diameter (1, 3, and 5 mm).

This study uses the diameters of the diffusion circles. Data from our previous article (6) on investigating the relationship between visual acuity and diameter of the diffusion circles were used. The research was carried out on 1,171 eyes with different levels of normal visual acuity (1.0, 763; 1.5, 391; and 2.0, 17 eyes).

A tenet of the subjective measurement of diffusion figures was based on the following principle. If two-point light sources are placed in front of an eye two diffusion circles are formed on the retina. We used 5 meters distance between eye and light sources. At the moment when two diffusion circles seem to touch the distance between the centers of diffusion circles is equal to diameter of each perceived diffusion circle. Practically, such measurement is easier if the device is supplied not by two light points by the two curved light slits (Fig. 2). Distance between edges of the light slits is equal to the diameter of diffusion circles. Often diffusion circles are oval, which is one reason why two measurements in horizontal and vertical meridian were performed. The mean of two measurements was recorded.

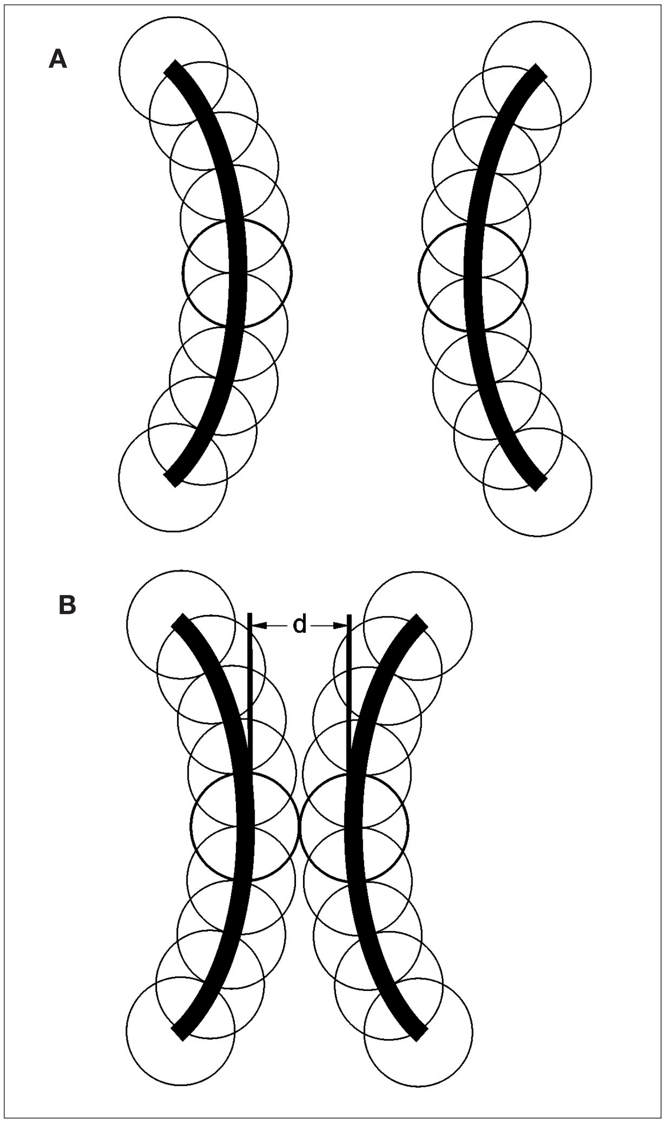

Fig. 2 - *Tenet of a measurement of size of the diffusion circles:* **(A)** *Initial position of the light slits,* **(B)** *distance between edges of the slits corresponds to d-2 radiuses or a diameter of the diffusion circles.*

Using parameters of Gullstrand's schematic eye data of measurements are as follows: 27.6±6.9 µm, 18.4±4.9 µm, and 10.9±2.5 µm for visual acuity 1.0, 1.5, and 2.0, respectively.

RESULTS

Amplitudes of the depth of focus for different pupil diameters (5.0 mm, 3 mm, and 1 mm) and normal degrees of visual acuity (2.0, 1.5, and 1.0) are presented in Table I. Val-

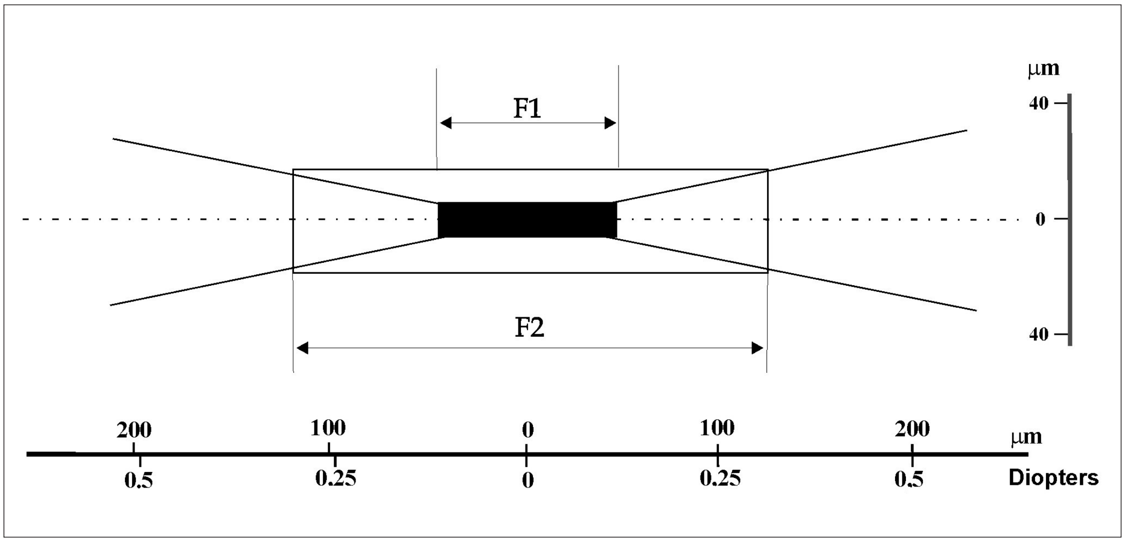

Fig. 3 - *Depth of focus in eyes with visual acuity 1.0 and 2.0.*

TABLE I - VALUES OF DEPTH OF FOCUS IN EYES WITH VISUAL ACUITY (VA) 1.0, 1.5, AND 2.0

Pupil diameter (mm)	Depth of focus (diopters/µm)		
	VA 1.0	VA 1.5	VA 2.0
5.0	0.64/243	0.43/164	0.23/54
3.0	1.1/409	0.71/273	0.39/148
1.0	3.2/1215	2.15/820	1.16/445

ues of the depth of focus are expressed in diopters as well as in micrometers (µm). Statistical analysis was performed by Statistica for Windows 5.0 (Stat Soft Inc.). Data are presented as means and standard deviations. The difference was significant between groups 1.0 and 1.5, $p<0.05$, and 1.5 and 2.0, $p<0.05$. Figure 3 shows a comparative representation of the depth of focus in eyes with visual acuity 1.0 and 2.0 (pupil diameter 5 mm).

DISCUSSION

The results of our study are shown in comparison with previous experimental measurements of the depth of focus (Fig. 4). Data published by Campbell (2) and Charman and Whitefoot (3) are in agreement with our computed depth of focus for visual acuity 1.5.

Dependence of depth of focus on pupil diameter is most often discussed in the literature. Green et al (7) made emphasis on such factors as visual acuity and the just-detectable retinal blur circles. Difference in size of perceivable and physically existing blur circles may be substantial due to Stiles and Crawford phenomena. Directional effect of cones has perceptual consequences (5).

The terms “blur circles” or “circular disc of light” are conventional but not accurate. The living human eye possesses significant optical aberrations which create basis for formation of irregular, eccentric blur figures. In our study we have used the detectable size of the blur figures measured by subjective method (6).

Modern aberrometers make it possible to produce a range of transverse sections of the focus zone, a number of asymmetric figures which are the PSF. The aberrometer calculates PSF based on analysis of the wave front. A series of asymmetric figures present shape of not perceived, but physically existing light distribution.

Helmholtz (8) was probably the first to demonstrate the subjectively detected blur figures in his own eyes under condition of dynamic accommodation (Fig. 5). The asymmetric diffusion figures have globe patterns as a consequence of the anatomic structure of the human lens. Helmholtz discovered that an accommodative tonus shift causes an alteration of both the outer shape and inner structure of the diffusion figures. Recent investigations

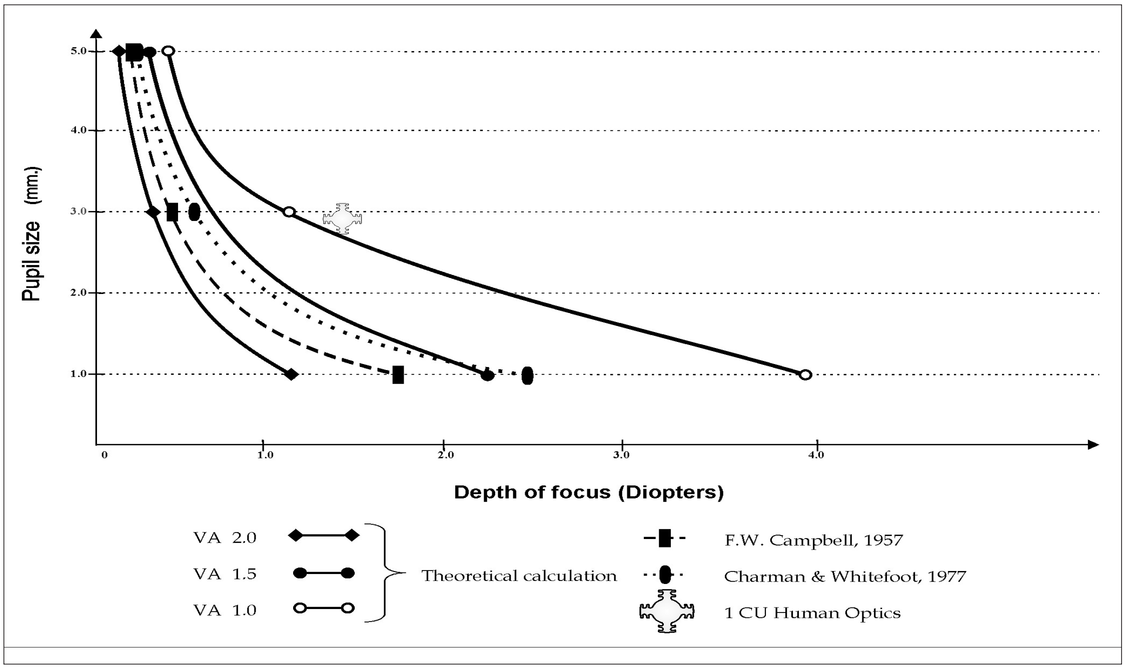

Fig. 4 - *Comparative representation of a theoretical calculation and experimental measurements of the depth of focus, and accommodative ability of pseudophakic eyes.*

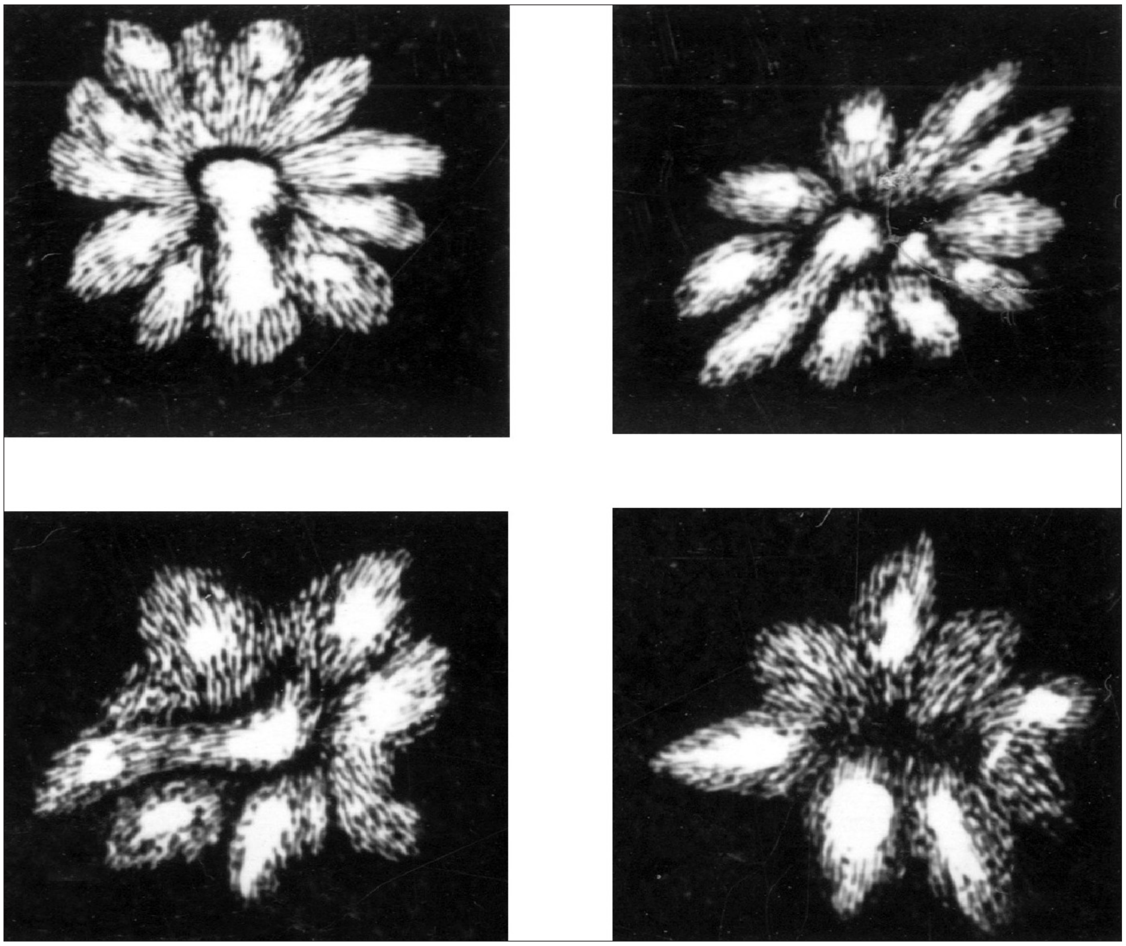

Fig. 5 - *Helmholtz's drawing of diffusion figures in his own eyes during dynamic accommodation.*

confirm that the amount of aberrations changes during dynamic accommodation (9).
Hypothetically, it may be assumed that any individual's optical system is close to the optical system of the schematic eye. In such cases depth of focus may be about 0.14 to 0.17 D, which is a characteristic of the perfect optical system of the schematic eye.
Clinically, depth of focus is the passive ability to obtain clear vision at one specific distance in the absence of natural accommodative activity. This ability is named depth of field, apparent accommodation, or pseudoaccommodation. Measurement of amplitude of the pseudoaccommodation depends on the size of visual objects.
Currently, investigation of the accommodative ability after implantation of the accommodating IOLs acquires a special significance. Amplitude of accommodation of the pseudophakic eye, which exceeds pseudoaccommodation, proves the presence of artificial accommodation.
Analyzing data about accommodative IOLs 1 CU (10), the accommodation amplitude in late postoperative follow-up (6 months) of 1.9 D exceeds pseudoaccommodation for all levels of normal visual acuity and pupil diameters (Fig. 4). It indicates the presence of artificial accommodation. However, it is difficult to determine the precise level of artificial accommodation.
In conclusion, a calculation of depth of focus was performed on the basis of size of detectable retinal blur circles. A relationship between depth of focus and normal levels of visual acuity 1.0, 1.5, and 2.0 was noted.

Proprietary interest: None.

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