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Influence of the pupil size on visual quality and spherical aberration after implantation of the Tecnis[®] 1-piece

Katrin Petermeier¹, MD, Charlotte Frank¹, Florian Gekeler¹, MD, Martin S. Spitzer¹, MD, Andre Messias¹, MD, Peter Szurman¹, MD

¹University Eye Hospital, Centre of Ophthalmology, Eberhard-Karls University, Tuebingen, Germany

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Corresponding author: Dr. Katrin Petermeier, Department of Ophthalmology, Eberhard-Karls University of Tuebingen, Schleichstr. 12, 72076 Tuebingen, Germany; Phone +49-7071-2984761, Fax +49-7071-294674; Katrin.Petermeier@med.uni-tuebingen.de

Abstract

Purpose: To evaluate the influence of the pupil size on clinical results and objective parameters of optical quality of the Tecnis[®] ZCB00.

Setting: Centre of Ophthalmology, Eberhard-Karls University Tübingen, Germany.

Methods: In this study 51 eyes were implanted with a Tecnis[®] ZCB00. Postoperatively, best-corrected (BCVA) and uncorrected visual acuity (UCVA) were assessed. Total spherical aberration and corneal spherical aberration for optical zones of 3, 4, 5, and 6 mm was measured. Contrast sensitivity and depth of focus were evaluated with a 3 mm and 5 mm pinhole (PH).

Results: Mean follow-up was 3.0 ± 0.4 months. Mean UCVA and BCVA were 20/25 \pm 8 letters and 20/18 \pm 4 letters, respectively. BCVA both with a 3 and a 5 mm PH was 20/18 \pm 4 letters. The corneal spherical aberration was 0.02 ± 0.01 μm , 0.06 ± 0.03 μm , 0.14 ± 0.09 μm and 0.27 ± 0.22 μm for 3, 4, 5 and 6 mm optical zone. Mean total spherical aberration was -0.01 ± 0.02 μm , 0.0 ± 0.03 μm , 0.0 ± 0.06 μm and 0.0 ± 0.08 μm , for 3, 4, 5 and 6 mm optical zone, respectively. Contrast sensitivity was not statistically significant different with a 5 mm or 3 mm PH. Also, the defocus curves with a 3 mm and a 5 mm PH were not statistically significant different.

Conclusion: The aspheric profile of the TECNIS[®] 1-Piece reduces total spherical aberration to virtually zero at all pupil sizes from 3-6 mm. Thus, visual acuity, contrast sensitivity, refraction and defocus curve show the same good results at large pupil sizes compared to small pupil sizes.

Key words: aspheric IOL; contrast sensitivity, depth of focus, spherical aberration, pupil size

Introduction

With refinements in surgical technique, intraocular lens design and biometry modern cataract surgery has advanced beyond mere restoration of visual acuity. After the introduction of the Tecnis® Z9000 in 2001 with a negative spherical aberration, the attention of cataract surgeons has been directed to optical aberrations, contrast sensitivity and visual quality. Aspheric IOLs compensate the positive spherical aberration of the cornea like the crystalline lens does in the young eye. They compensate the corneal spherical aberration even better than the natural lens in elderly people and thus lead to a total spherical aberration like in a young eye [1, 2].

In a recent review Montés-Micó et al. report on the advantages of aspheric IOLs like reduction of the total spherical aberration and improved contrast sensitivity [3]. But the pupil size is a crucial criterion for the comparison of functional results of spherical and aspheric lenses [3,4,5,6,7,8]. Most studies report that the reduction of total spherical aberration in eyes with aspheric IOLs compared to eyes with spherical IOLs is more evident at large pupil sizes [3,4,5,6,7,8,9]. Bellucci et al. could show that the reduction of spherical aberration leads to a refractive effect towards myopia at large optical zones [9]. Denoyer et al. found a change in refraction towards myopia at large pupil sizes [5]. Mrochen et al. showed that even in young phakic eyes the critical pupil size, at which the optical aberrations of the eye deteriorate the quality of the retinal image, is 3.3 mm for 50% and 4.5 mm for 89% of the eyes [10]. Finally, we know from clinical experience that medicamentous pupil dilation in older or pseudophakic patients leads to a blurred vision.

Until now the influence of the pupil size on quality of vision with an aspheric IOL has not been explicitly evaluated yet. In our study we evaluated this influence after implantation of the new Tecnis® ZCB00 IOL.

Patients and Methods

The presented study included 51 eyes of 51 consecutive patients who underwent phakoemulsification and injector implantation of a Tecnis[®] 1-piece (ZCB00) intraocular lens for cataract. This IOL is a one-piece IOL made from hydrophobic acrylic material with a modified anterior surface and a negative spherical aberration of $-0.27 \mu\text{m}$ at the 6 mm optical zone. Exclusion criteria were ocular disease other than cataract, previous ocular surgery and inflammation. Preoperative data included full ophthalmological examination and assessment of best-corrected visual acuity. Intraocular lens calculation was performed using an IOLMaster (Carl Zeiss Meditec AG, Jena, Germany) applying the SRK-T ($A=119.4$) formula. Phakoemulsification was performed through a 2.75 mm temporal clear cornea tunnel incision with a capsulorrhexis of 5-5.5 mm and in-the-bag injector implantation of the Tecnis[®] 1-piece intraocular lens.

Postoperatively, patients were evaluated for both uncorrected and best corrected visual acuity using ETDRS charts at a distance of 4 m. Corneal topography was performed with the C-scan (Technomed, Baesweiler, Germany) and Corneal spherical aberration was calculated for 3, 4, 5 and 6 mm pupil sizes.

Wavefront analysis was performed with dilated pupils with the Ocular Wavefront Analyzer (Schwind, Kleinostheim, Germany). This instrument measures total wavefront aberrations of the eye using the Hartmann-Shack principle. In order to evaluate not only the objective refraction but also the spherical aberration of the eye, the sphere, cylinder and the Zernike term Z4.0 was analyzed. Five measurements were obtained with a standard deviation not exceeding $0.05 \mu\text{m}$. Every measurement was then evaluated for a 3, 4, 5, and 6 mm optical zone. The spherical equivalent of each eye was calculated by adding half the cylinder to the sphere (sphere + cylinder/2).

After medicamentous pupil dilation contrast sensitivity was tested monocularly with F.A.C.T. Charts (Ginsburg CST-1500, Vision Science Research Corporation, San Ramon, CA) under

photopic (85 cd/m^2) and mesopic (6 cd/m^2) luminance levels at a spatial frequency of 6 cycles/degree.

The defocus profiles (visual acuity over imposed defocus) were registered by measuring monocular visual acuity at a distance of 4 m starting from best distance correction and then defocusing with added lenses in 0,25 dioptre steps from -1.5 D to +1.5 D. For statistical calculation, visual acuity was converted into logMAR. To simulate different pupil sizes, both the contrast sensitivity and the defocus profile were evaluated with a pinhole of 3 mm and 5 mm. Statistical analysis was performed using the paired T-Test. $P < 0.05$ was considered to indicate a statistically significant difference.

Results

The mean follow-up period was 3.0 ± 0.4 months. Patients' mean age was 71.0 ± 8.1 years (range 59 - 92). Mean intraocular lens power was 22.0 ± 3.0 D. (range 14.0-29.0).

Monocular uncorrected visual acuity was $20/25 \pm 8$ letters (LogMar 0.1 ± 0.16), best-corrected visual acuity was $20/18 \pm 4$ letters (LogMar -0.04 ± 0.08). The postoperative residual refractive error was -0.18 ± 0.5 D.

The residual refractive error (spherical equivalent) as measured with the wavefront analyzer was -0.5 ± 0.63 D, -0.53 ± 0.59 D, -0.53 ± 0.64 D and -0.56 ± 0.71 D for 3, 4, 5 and 6 mm optical zone, respectively. There was no statistically significant difference (figure 1).

In 8 eyes the corneal spherical aberration could not be evaluated for the 6 mm optical zone, so that these eyes were excluded from evaluation both for the corneal and the total spherical aberration. The corneal spherical aberration was 0.02 ± 0.01 μm , 0.06 ± 0.03 μm , 0.14 ± 0.09 μm and 0.27 ± 0.22 μm for 3, 4, 5 and 6 mm optical zone, respectively. Statistical analysis (paired T-Test) revealed a statistically significant difference between the spherical aberration of the 3 and 4 mm, 4 and 5 mm, 5 and 6 mm optical zone ($P < 0.05$) (figure 2). In contrast, the total spherical aberration of the different optical zones was not statistically significantly different: -0.01 ± 0.02 μm , 0.0 ± 0.03 μm , 0.0 ± 0.06 μm and 0.0 ± 0.08 μm , for 3, 4, 5 and 6 mm optical zone, respectively (figure 2). The total spherical aberration and the corneal aberration were highly significantly different for all optical zones ($P < 0.001$).

Contrast sensitivity under mesopic and photopic conditions with a simulated pupil size of 3 and 5 mm is shown in figure 3. The contrast sensitivity with a 5 mm pupil size remains at the same level as with a 3 mm pupil size under mesopic and photopic conditions ($P=0.91$ and 0.37 respectively).

The mean monocular defocus profiles with a 3 and a 5 mm simulated pupil size are shown in figure 4. In none of the 52 eyes, the defocus curves were statistically significantly different, nor were the mean values of all eyes ($P=0.19$). The best-corrected visual acuity was $20/18 \pm$

4 letters (LogMar -0.04 ± 0.08) with both a 3 and a 5 mm pupil size. Also, the refraction did not change with a 5 mm pupil size compared to 3 mm.

Discussion

We have shown that the aspheric design of the Tecnis[®] 1-piece compensates the positive corneal spherical aberration at all pupil sizes and thus leads to a high optical quality not only at a pupil size of 3 mm, but also at 5 mm.

Visual acuity and refraction

In our study we found no objective change in refraction at different optical zones measured with the wavefront analyzer. This is in accordance with the results of Bellucci and colleagues, who found a significant change in refraction towards myopia with spherical lenses, but not with an aspheric lens [9]. Denoyer et al. found a change in refraction of -0.56 D with a spherical IOL in mydriasis, while it was significantly smaller (-0.07 D) with the aspheric Tecnis[®] Z9000 [5]. We found no difference when measuring best corrected visual acuity at 3 and 5 mm pupil sizes. Neither the refraction nor the visual acuity were affected at 5 mm pupil size.

Spherical aberration

The spherical aberration of the cornea was higher at 6 mm than at 3 mm optical zone. At the 6 mm optical zone the mean spherical aberration was +0.27 μm and is thus perfectly compensated by the negative spherical aberration of -0.27 μm of the Tecnis[®] 1-piece. But even at the 3, 4 and 5 mm optical zones the positive corneal spherical aberration was significantly reduced by the aspheric lens (figure 2), since the spherical aberration of the lens is -0.02, -0.05 and -0.13 for the 3, 4, and 5 mm optical zones respectively (personal communication Henk Weeber, Abbott Medical Optics, Ettlingen Germany). Nevertheless, the standard deviation becomes larger with larger pupil sizes, both for the cornea and the total eye, which leads to the spherical aberration in some eyes being undercorrected or overcorrected. Thus, individual selection of the spherical aberration of the IOL based on the corneal spherical aberration may improve the results after aspheric IOL Implantation [3,6].

But even if the spherical aberration of the IOL was not individually selected in this study, the “standard” negative spherical aberration of the Tecnis® ZCB00 fits for the majority of patients, resulting in a mean total spherical aberration of 0.0 μm .

Contrast sensitivity

In this study contrast sensitivity was not related to the pupil size in patients with an aspheric IOL (figure3). At the spatial frequency of 6 cycl/deg the contrast sensitivity did not worsen with larger pupil sizes, demonstrating that quality of vision stays as good as at small pupil sizes. Although this has not been explicitly evaluated for spherical lenses, the fact that in most studies [3] the better contrast sensitivity of eyes with aspheric lenses is more evident under mesopic conditions may indicate a reduction of contrast sensitivity at large pupil sizes. The study is limited by the fact that only one spatial frequency was measured. We chose this spatial frequency, because some studies could not detect a difference between aspheric IOLs at high or low spatial frequencies but mostly at a spatial frequency of 6 cycl/deg [3].

Defocus profiles

Theoretically, one might assume that the depth of focus is compromised by aspheric lenses. In an eye model without any aberrations the image quality is higher at best focus than with additional spherical aberration, but the image quality deteriorates earlier with defocus [11]. But there are some important differences between a theoretical model and a clinically measured depth of focus: In a clinically measured defocus curve not only the spherical aberration, but also the other higher order aberrations have an impact on the depth of focus; also the pupil size does. Furthermore, a small pupil size may have an additional pinhole effect resulting in a higher depth of focus. In our study we could find such a pinhole effect at 3 mm pupil size, albeit faint: The depth of focus at 3 mm pupil size was only slightly broader than at 5 mm pupil size without statistically significant difference. At both pupil sizes the plateau in the defocus profiles of the Tecnis® 1-piece resulted in a visual acuity above 20/32 at a defocus of -1 D and above 20/50 at -1.5 D (figure 4). Rocha at al. found a lower

distance-corrected near visual acuity in patients with aspheric IOLs [12], but they did not perform a correlation with the spherical aberration and the pupil size of the eyes [13,14]. Since the theoretically compromised depth of focus of aspheric lenses is still under discussion, further comparisons with spherical IOLs at different simulated pupil sizes are needed.

In summary, we were able to show that after implantation of an aspheric Tecnis[®] 1-piece IOL visual acuity, contrast sensitivity, depth of focus and spherical aberration are not –in contrast to spherical IOLs– compromised at large pupil sizes. This should, however, not mislead to conclude that only patients with large pupil sizes profit from an aspheric Tecnis[®] 1-piece IOL. Certainly, miotic pupil states (e.g. senile) might limit the beneficial effect of aspheric IOLs [4,6], but one should take into account that the mean pupil size in the dark can still be 5 mm at the age of 60 and stay over 4 mm at the age of 80 [15].

In our study the compensation of the spherical corneal aberration by the Tecnis[®] 1-piece IOL was already statistically significant at a pupil size of 3 mm. Furthermore, two earlier studies could show that the total spherical aberration of the eye is significantly lower at 3 – 6 mm pupil sizes in eyes with an aspheric IOL (AcrySof SN60WF-IQ and Tecnis[®] Z9000) compared to a spherical IOL [16,17].

In fact, three studies found a better mesopic contrast sensitivity event though the pupil sizes highly varied from 3.2 to 5.1 mm [4,5,7,18]. Mester et al found a better mesopic contrast sensitivity for the aspheric Tecnis[®] Z9000 even at a mesopic pupil size of 3.2 ± 0.61 mm [18].

In conclusion, we were able to show that pupil size does not influence the quality of vision after implantation of an aspheric Tecnis[®] 1-piece IOL. Further evaluation, however, of optical parameters with standardized, simulated pupil sizes is needed to judge the influence of pupil sizes in eyes with spherical IOLs and also to assess the benefit of aspheric IOLs in eyes with small pupils.

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Figure legends:

Figure 1:

The residual refractive error (spherical equivalent) as measured with the wavefront analyzer for 3, 4, 5 and 6 mm optical zone. There was no statistically significant difference.

Figure 2:

Corneal spherical aberration (grey line) and total spherical aberration (black line) for 3, 4, 5 and 6 mm optical zones. The total spherical aberration and the corneal aberration are highly significantly different for all optical zones ($P < 0.001$). Thus, the negative spherical aberration of the Tecnis[®] ZCB00 corrects the positive corneal aberration in all optical zones.

Figure 3:

Monocular contrast sensitivity under mesopic (6 cd/m^2) and photopic (85 cd/m^2) conditions with a simulated pupil size of 3 and 5 mm. The contrast sensitivity with a 5 mm pupil size remains at the same level as with a 3 mm pupil size under mesopic and photopic conditions ($P=0.91$ and 0.37 respectively).

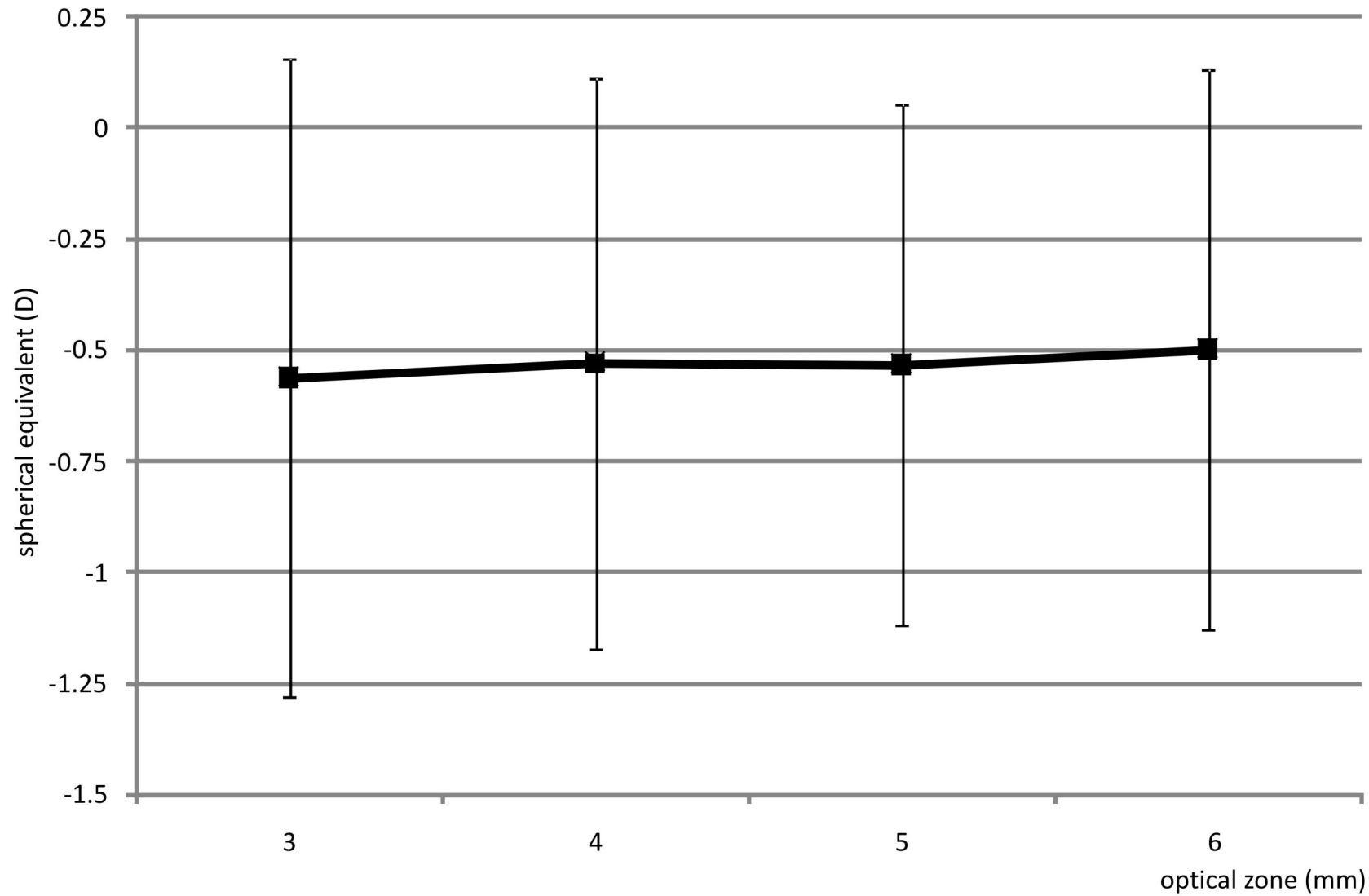
Figure 4:

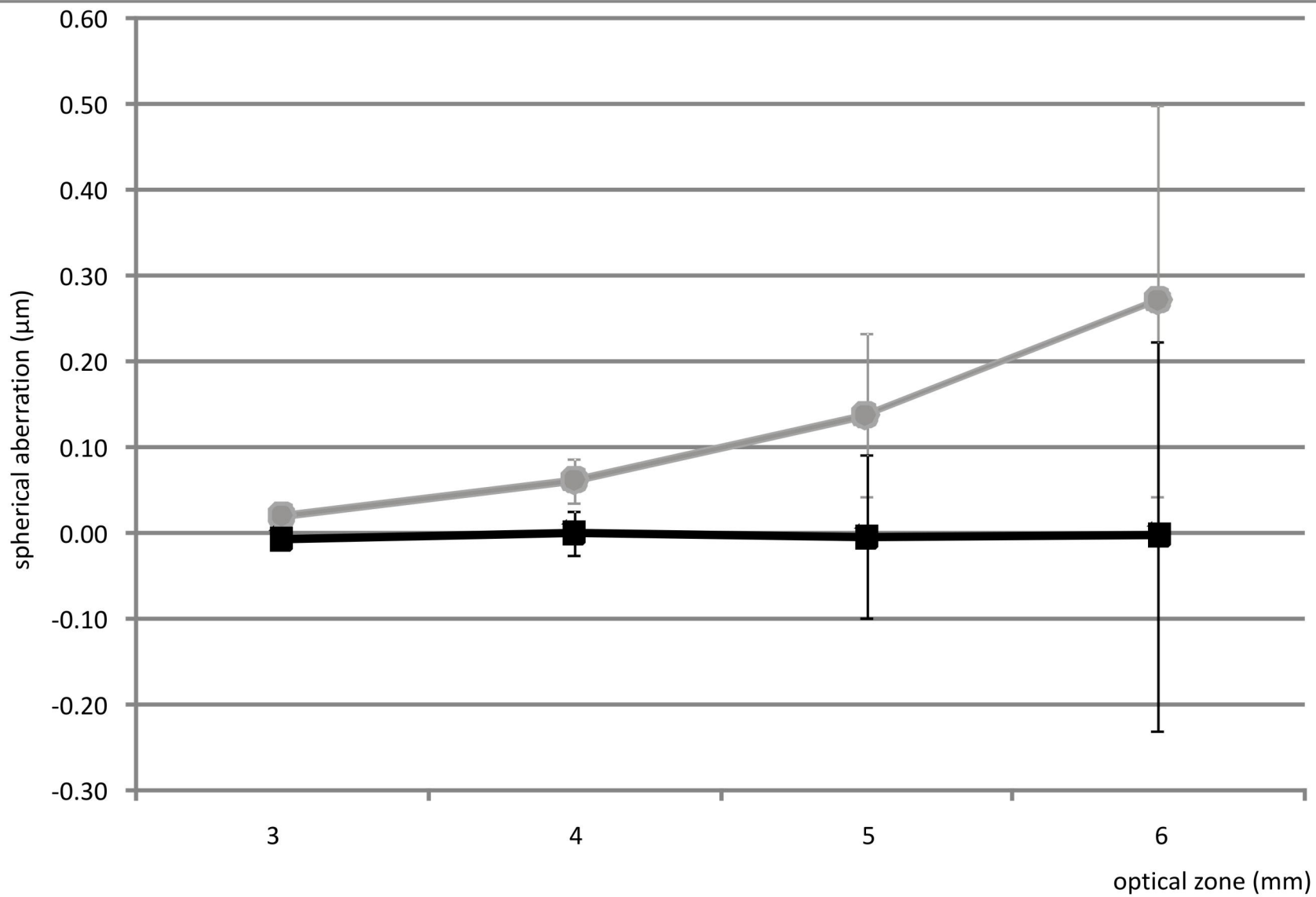
Mean monocular defocus profiles with a 3 (black line) and a 5 mm (grey line) simulated pupil size. Defocus curves were assessed by testing visual acuity with best distance correction by adding glasses from -1.5 D to $+1.5 \text{ D}$ in 0.25 diopters steps. The defocus curves were not statistically significantly different ($P=0.19$).

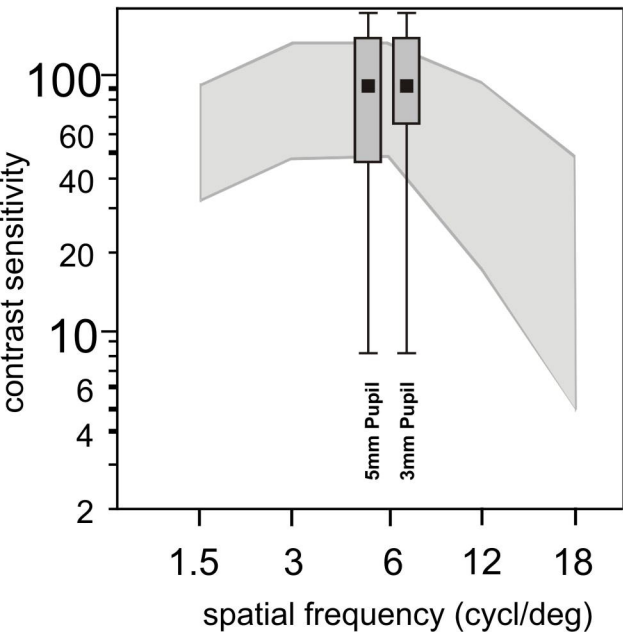
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All other authors have no competing interests.





photopic (85 cd/m²)**mesopic (85 cd/m²)**