

Objective assessment of the effect of pupil size upon the power distribution of multifocal contact lenses

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Abstract

• **AIM:** To analytically assess the effect of pupil size upon the refractive power distributions of different designs of multifocal contact lenses.

• **METHODS:** Two multifocal contact lenses of center-near design and one multifocal contact lens of center-distance design were used in this study. Their power profiles were measured using the NIMO TR1504 device (LAMBDA-X, Belgium). Based on their power profiles, the power distribution was assessed as a function of pupil size. For the high addition lenses, the resulting refractive power as a function of viewing distance (far, intermediate, and near) and pupil size was also analyzed.

• **RESULTS:** The power distribution of the lenses was affected by pupil size differently. One of the lenses showed a significant spread in refractive power distribution, from about -3 D to 0 D. Generally, the power distribution of the lenses expanded as the pupil diameter became greater. The surface of the lens dedicated for each distance varied substantially with the design of the lens.

• **CONCLUSION:** In an experimental basis, our results show how the lenses power distribution is affected by the pupil size and underlined the necessity of careful evaluation of the patient's visual needs and the optical properties of a multifocal contact lens for achieving the optimal visual outcome.

• **KEYWORDS:** multifocal contact lenses; pupil size; power profiles; refractive power distribution

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INTRODUCTION

Starting as early as in puberty, human's eye accommodative ability decreases almost linearly with age^[1-3]. The consequences of this irreversible loss are noticeable around mid-forties, where the amplitude of accommodation falls below 3 D^[1]. This condition, known as presbyopia, occurs naturally in people as they age.

Several strategies^[1-4] are available for compensating presbyopia symptoms, including spectacles for correcting near vision, progressive ophthalmic lenses, contact lenses (CLs) and surgical approaches (e.g. implantation of intraocular lenses). Although spectacle wearing is the most common solution for presbyopia correction, social and practical reasons drive new presbyopes to seek alternative correcting methods^[1-4]. The CLs industry has been evolving during the past decades in order to offer multifocal solutions for reducing spectacle dependence^[1,5-6].

Nowadays, the majority of the commercially available multifocal CLs are following simultaneous vision strategies^[1,5]. Simultaneous vision^[1] is based on the superimposed projection of different images on the retina at the same time. Each projected image corresponds to a different vergence and the human brain has to choose among them for a sharp image (in-focus) and suppress the blurred images (out-of-focus)^[1,5-7]. The problem with simultaneous vision is the ability or not of the human brain to suppress the out-of-focus images; if not able to suppress, the superimposed out-of-focus images will reduce the contrast of the in-focus image^[7]. Simultaneous vision CLs can be of concentric design (consisting of two circular zones) or of annular design (consisting of several concentric circular zones), and they also incorporate certain amounts of spherical aberration (SA) for expanding the depth-of-focus (DoF)^[1,5-6,8-10]. In both designs, the center of the CLs can be dedicated either for the distance correction (center-distance) or for the near correction (center-near)^[1].

Despite the availability of several simultaneous vision CLs, the proportion of presbyopic population fitted with those lenses is still relatively low^[6]. Several studies^[10-13] have evaluated the visual and optical performance of multifocal CLs and the impact of several factors. These factors range from fitting techniques followed by the practitioners to ocular changes (e.g. pupil size). Previous studies^[10,14-18] assessed the importance of

Table 1 Technical specifications of the contact lenses under study

Parameters	Acuvue Oasys for presbyopia	Fusion 1d Presbyo	Biofinity multifocal
Replacement	2wk	Daily	Monthly
Water content (%)	38	60	48
Refractive index	1.42	1.42	1.40
BOZR (mm)	8.40	8.60	8.60
TD (mm)	14.30	14.10	14.00
DK/t (@ -3 D)	147	29	142
CT(mm) (@ -3 D)	0.07	0.07	0.09
Lens design	Concentric rings	Afocal	Asymmetric D and N
Manufacturer	Johnson & Johnson	Safilens	Cooper Vision

BOZR: Back optic zone radius; TD: Total diameter; DK/t: Oxygen transmissibility; CT: Central thickness.

pupil size in the refractive power provided by simultaneous vision CLs as a function of beam vergence in order to gain a better understanding of the lens designs.

In this context, we aimed to evaluate *in vitro* three models of simultaneous vision multifocal CLs of different designs and addition powers and to assess the effect of pupil size upon their refractive power distributions.

MATERIALS AND METHODS

Multifocal Contact Lenses Designs Three rotationally symmetrical simultaneous vision CLs for presbyopia correction were included in this study (see Table 1 for specific characteristics): the first CL was the Acuvue Oasys for presbyopia (Vistakon, Inc., Jacksonville, FL, USA), which is a multifocal CL consisting of concentric aspheric zones alternating between distance and near vision. Its central zone is dedicated to far vision (this center-distance design will be referred to as CD). The lens is available in powers ranging from +6.00 D to -9.00 D in steps of 0.25 D and it comes with three different addition powers (commonly known as "add"), namely, "Low", "Mid" and "High".

The second CL was the Fusion 1d Presbyo (Safilens S.R.L., Staranzano, GO, Italy). This lens has an optical design which, according to the manufacturer, aims to provide clear vision at any distance. The lens has a continuous power gradient and center-near (CN) design. It is available in powers ranging from +6.00 D to -6.00 D in steps of 0.25 D and from -6.00 D to -10.00 D, and from +6.00 D to +8.00 D, in steps of 0.50 D.

The third lens was the Biofinity multifocal (Cooper Vision, Fairport, NY, USA), available in both CN and CD designs for monovision^[1] correction. The power range of this lens is from +6.00 D to -6.00 D in steps of 0.25 D and from -6.00 to -10.00 D in steps of 0.50 D. It comes with addition powers of +1.00 D, +1.50 D, +2.00 D and +2.50 D. In this study only CD lenses were evaluated.

Instrument for *in Vitro* Measurements The power profiles of the multifocal CLs were measured by the NIMO TR1504

(LAMBDA-X, Nivelles, Belgium) device. This instrument is based on a quantitative deflectometry technique which combines the Schlieren principle with a phase-shifting method. The phase-shifting Schlieren technique makes possible to calculate the power distribution of lenses by measuring light deviations. According to Joannes *et al*^[19], the phase-shifting Schlieren technique prevails over any current ISO-referenced technique in terms of accuracy and repeatability. Previous studies^[15,17,20-21] have described in detail the functioning of the device.

Experimental Procedure Three -3.00 D new lenses were measured for each lens design and addition power. Before the measurements, each lens was removed from its blister, submerged in saline solution (refractive index of 1.335) and left at room temperature for at least 12h. The lens was then inserted into a cell, which was filled with the same saline solution. Then, the wet-cell was placed on NIMO's translation table and the required measuring parameters were adjusted: the refractive index of the saline solution, the refractive index of the lens, the lens diameter, the back optic zone radius of the lens, the lens optical zone diameter and the central thickness of the lens.

For each lens, five consecutive measurements were performed using the multifocal measuring mode and the auto-centration mode for aligning the optical axis of the lens with the optical axis of the system. The power profiles of each lens were measured over a 6 mm aperture, which was manually adjusted using the device's software.

Data Analysis The power profiles of the lenses were manipulated in two different ways using custom software developed in MatLab (Mathworks, Inc., Natic, MA, USA). First, the power distribution of each lens (as in a histogram) was calculated over different pupil diameters. For each pupil diameter, the power profile of the lens was divided into regions of 0.25 D and then the proportion of the profile, which was devoted to provide a certain refractive power, was calculated.

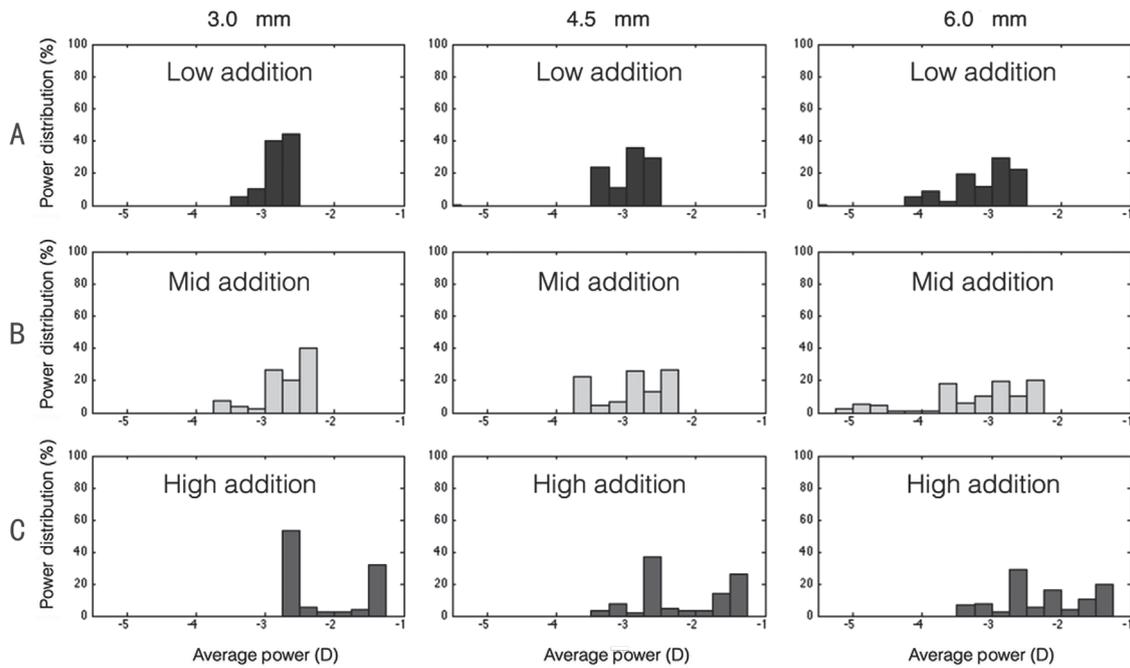


Figure 1 Power distribution (%) as function of pupil size (3.00 mm, 4.50 mm and 6.00 mm) for each available addition power of the Acuvue Oasys for presbyopia lens. A: Low-addition lens; B: Mid-addition lens; C: High-addition lens.

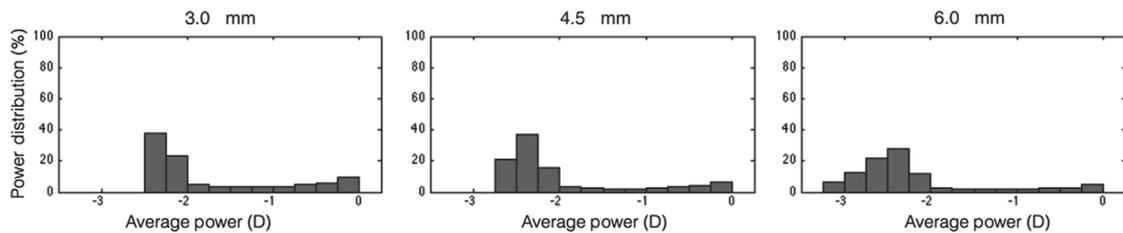


Figure 2 Power distribution (%) as function of pupil size (3.0 mm, 4.5 mm and 6.0 mm) for the Fusion 1d Presbyo lens.

Secondly, for the high addition lenses, we calculated the proportion of the power profile of the lens which was dedicated for vision at different distances (far, intermediate and near) as a function of pupil size. For this purpose, three standard distances were considered. The vergence threshold between far and intermediate vision was set at 1.00 m (1.00 D with respect to the lens' nominal power), whereas the threshold separating intermediate and near vision was set at 40 cm (2.50 D with respect to the lens' nominal power).

RESULTS

Power Distributions as a Function of Pupil Size Figures 1 to 3 show the power distributions of the lenses as function of pupil size (for 3.00, 4.50 and 6.00 mm pupil diameters).

Figure 1 corresponds to the Acuvue Oasys for presbyopia lenses. For the low-addition (Figure 1A), the main power contributors were located between -2.50 D and -3.50 D. The power distribution of the mid-addition lens (Figure 1B) slightly spread over more refractive powers, more pronouncedly at greater pupil sizes. For those lenses, minor power contributors (around 10%) of more negative values were present at 6.00 mm pupil size. For the high-addition lens (Figure 1C), there was a small shift towards less negative refractive powers at the three

pupil sizes; two regions gathering the main power contribution were spotted: from -1.25 D to -1.75 D (around 30% of the power at 3.00 mm) and from -2.50 D to -2.75 D (around 60% of the power at 3.00 mm). As the pupil size increased, the power distribution between those areas changed: at 6.00 mm pupil a low contribution (around 10%) of more negative values appeared.

Similarly, Figure 2 corresponds to the Fusion 1d Presbyo lens. At 3.00 mm, the main power contributor (more than 60%) was found between -2.00 D and -2.50 D interval. However, as the pupil size increased, the distribution shifted towards more negative power values.

Figure 3 shows the power distribution graphs of the Biofinity CN lenses. The +1.50 D addition lens (Figure 3A), had a main power contributor (around 80% of the total power) between -1.50 D and -1.75 D at 3.00 mm pupil. As the pupil increased, another power contributor appeared between -2.75 D and -3.25 D (around 20% at 4.5 mm and around 40% at 6.00 mm pupil). The +2.00 D addition lens (Figure 3B) yielded similar distributions: a power contributor of more than 80% emerged at -1.00 D at 3.00 mm pupil size. The distribution spread out and shifted towards more negative values as the pupil size

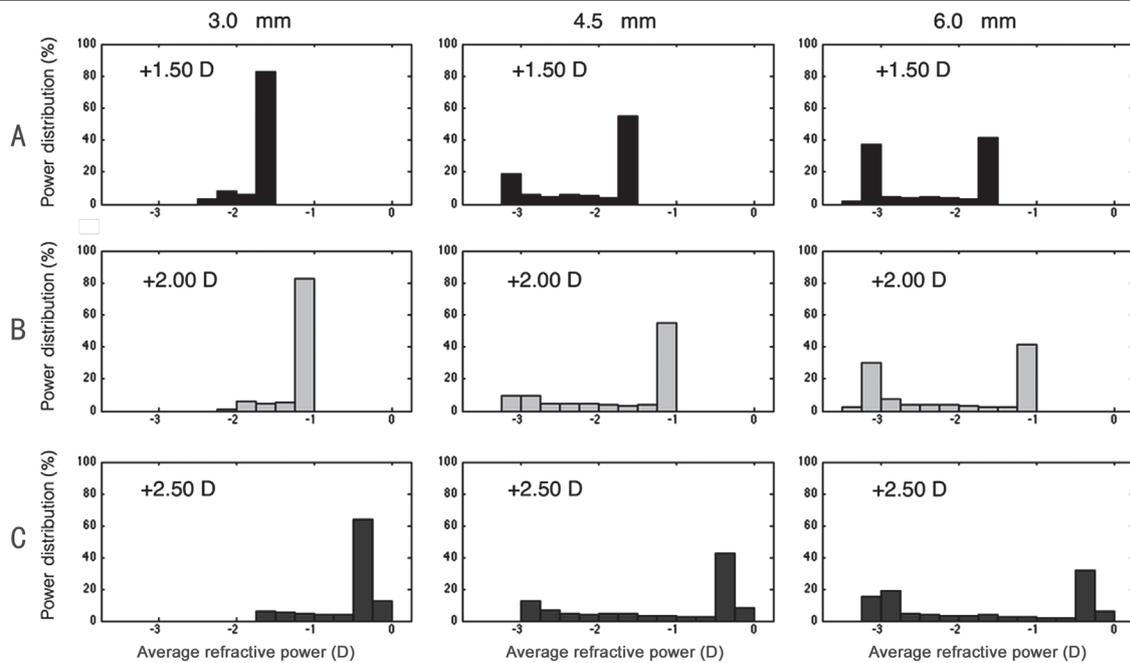


Figure 3 Power distribution (%) as function of pupil size (3.00 mm, 4.50 mm and 6.00 mm) for three addition powers of the Biofinity CN lenses A: +1.50 D; B: +2.00 D; C: +2.50 D.

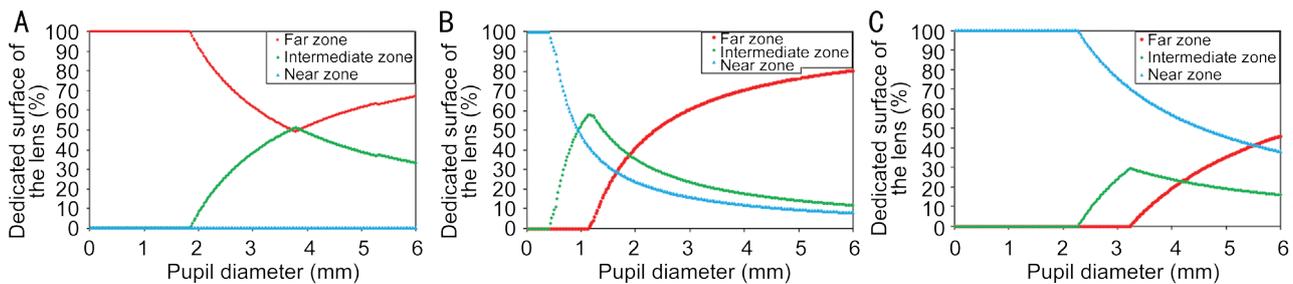


Figure 4 Proportion of the lens surface dedicated to different distances (far, intermediate and near vision) as a function of pupil size A: Acuvue Oasys for presbyopia (high addition); B: Fusion 1d Presbyo; C: Biofinity CN multifocal (+2.50 D addition power).

increased: at 6.00 mm pupil, 40% of the power was located at -1.00 D and 60% between -1.25 D and -3.25 D. The +2.50 addition lens (Figure 3C) followed a similar pattern of power distribution. At 3.00 mm, more than 80% of the power was concentrated between 0.00 D and -0.50 D, whereas at 4.50 mm and up to 6.00 mm pupil size, the power distribution spread out and shifted towards more negative values.

Proportion of the Lens Surface Dedicated to Different Distances as a Function of Pupil Size Figure 4 shows the proportions of the lens surface (proportion of power profile) for the high addition lenses dedicated to different distances and how they change with pupil size. The high addition Acuvue Oasys lens (Figure 4A) enhanced the far vision for small pupil sizes (100% dedicated to far vision at pupils less than 2 mm), opposed to the Fusion 1d Presbyo (Figure 4B) and the +2.50 D addition Biofinity (Figure 4C) lenses, which enhanced near vision at smaller pupil sizes. From the graph, it is evident that all the three lenses enhanced intermediate vision. The highest enhancement for intermediate vision came from the Presbyo lens (around 60% of the lens surface at 1.2 mm), followed by the Acuvue lens (around 50% at 3.5 mm) and the Biofinity lens

(around 30% at 3.2 mm). The lack of near vision zone of the Acuvue Oasys lens is due to the fact that the lens did not reach the selected threshold for near vision (*i.e.* +2.50 D from the nominal power of the lens).

DISCUSSION

The aim of this work was to assess objectively the power distribution of different designs of multifocal CLs, as a function of pupil size, based on power profiles measurements. Due to the complexity of multifocal CLs designs, it is important to obtain information about the potential correction they can provide at given pupil sizes and vergences.

Figures 1 to 3 represent the power distribution of the multifocal CLs at different pupil sizes. The figures show the differences in power distribution with pupil size among the different lens types and also among the different addition powers. All the lenses in this study had a nominal power of -3.00 D. The pupil size where each lens reached the nominal power was different due to the addition power. For instance, the low- and mid addition CD Acuvue lenses required a pupil size of at least 3 mm to reach the nominal power, whereas the high addition lens needed a greater pupil size. The CN Fusion lens required

a pupil above 5 mm and as for the CN Biofinity lenses, the differences among the three addition powers were marginal. Note that this lens comes to CN and CD design for monovision correction, hence, this combination is expected to compensate for pupil size changes.

Evaluation of multifocal CLs based on power profile analysis has been presented before. In these previous studies^[10,14-18], the role of pupil size has been discussed and has been concluded that the pupil dynamics have a significant role in multifocal CLs performance. Although power profile data show the power distribution as a function of radial distance, it is however difficult to predict the impact of given pupil sizes on power distribution and how this may affect the optical performance of the lens and therefore, the subject's visual performance. The motivation of the analysis in our study was precisely this; to provide an analytical and easy-to-understand approach about the interaction between pupil size and power distribution of multifocal CLs and give some evidence about potential visual performance with these lenses.

In a study of Koch *et al*^[22], pupil size data corresponding to different visual tasks and illumination levels were presented for different age groups. Those data showed the dependence of pupil size regarding different visual tasks and illumination levels, and also, the variance of pupil size among individuals. The results of that study and of a previous one by Montés-Micó *et al*^[17], showed that the refractive power provided by a multifocal CL not only varies with pupil size, but also across individuals. This observation is crucial because it means that subjects with the exact same visual demands can have different visual performance when they are fitted with the same multifocal CL type as a consequence of pupil size variation. Taking the latter into account, choosing between CD and CN designs can be difficult if there is no sufficient information about the pupil dynamics. For instance, if the pupil size is small under bright illumination, the amount of light which enters through the periphery of the lens will decrease; hence the contribution of the refractive power corresponding to the lens' periphery will diminish too.

Similar to previous studies^[10,23], we show in Figure 4 the proportions of the lens surface dedicated to different distances (far, intermediate and near vision), and how these proportions change with pupil size. Since all the lenses were characterized by rotational symmetry, the proportions of profile calculated can be directly related to proportions of the lens surface. The reason of presenting only the higher addition lenses was because these lenses are conceived for people whose amplitude of accommodation is practically zero. The lower addition lenses are conceived for younger presbyopes where some amplitude of accommodation still exists in the fitted eye and it helps the subject to achieve satisfactory near vision.

Regarding pupil size, the findings of our study can provide

useful information to the practitioner in selecting the appropriate lens design depending on the task that is more important to the subject. For example, according to Koch *et al*^[22], the typical pupil diameter for reading under low illumination (215 lx) in subjects between 50 and 59 years old is around 3 mm. Subjects with more than 55 years of age are considered to have almost zero amplitude of accommodation, hence they require lenses with high addition value^[24]. In Figure 4 we can easily see that for this pupil size, Acuvue Oasys has around 60% of its surface dedicated to far vision and 40% to intermediate vision. Subsequently, at 3.00 mm the Fusion offers approximately 60% of its surface for far vision, 25% for intermediate vision and 15% for near vision, whereas the Biofinity has approximately 25% of its surface for intermediate vision and 75% for near vision.

All the *in vitro* measurements in this study were performed assuming the lenses were perfectly centered. Nevertheless, when a CL is fitted on the eye factors such as eye movements or irregularities of corneal surface can displace the lens. For soft CLs the estimated movement ranges between 0.5 mm and 1.0 mm^[25]. As we showed in our findings the pupil size changes the resulting provided refractive power with a multifocal CL. Subsequently, for a given pupil size a displacement of a multifocal CL could result refractive power that does not cover sufficiently the visual demands of the subject (*i.e.* the subject can be over- or under-corrected). Further investigation for the effect of decentration^[26] upon the power profiles of different designs of multifocal CLs will increase the insight about their optical behavior and to estimate the impact on visual performance.

In conclusion, although previous works^[10,15] have already shown the power profiles for some of the lenses presented here, in this work we aimed to objectively assess the impact of pupil size upon the power profiles of multifocal CLs. To achieve this, we calculated the proportion of power distribution at different pupil sizes (Figures 1 to 3) and we also divided the power profile of the high addition lenses into different vision zones (Figure 4) to show how the power distribution at each zone changed with pupil size. Our results, combined with the ones of previous studies^[10,15,17-18], can enhance the present understanding of the optical behavior of multifocal CLs. Finally, the analytical approach presented here can be helpful in facilitating the proper fitting of multifocal CLs, depending on the pupil dynamics of the subjects.

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