Ocular straylight with different multifocal contact lenses

Łabuz G, López-Gil N, van den Berg TJTP, Vargas-Martín F.

Optom Vis Sci. 94.4 (2017):496-504

ABSTRACT

Purpose

Multifocal contact lenses have been growing in popularity as a modality to correct presbyopic eyes, although visual side effects such as disability glare have been reported. The objective of this study was to investigate the effect of multifocal contact lenses on disability glare by means of ocular straylight.

Methods

A prospective randomized, comparative study was performed that included 16 subjects free of ocular pathology. Straylight was measured using a commercial straylight meter with the natural and dilated pupil. Participants were fitted with Proclear Multifocal (Distance/Near), ACUVUE Oasys for Presbyopia, and Air Optix Aqua Multifocal randomized to the left or right eye. Straylight measurements were repeated with the contact lens in situ after the pupil dilation. Results obtained with the dilated pupil without contact lens acted as a control.

Results

Diameter of the natural and dilated pupil was 2.87 ± 0.40 mm and 7.45 ± 0.86 mm, respectively ($P < .001$). After pupil dilation, straylight increased from 0.92 ± 0.13 log(s) to 1.04 ± 0.11 log(s) ($P < .001$). Of the four studied lenses, a significant difference was only found between Air Optix and the control group ($P = .006$). The latter showed also slightly increased light scatter.

Conclusions

A difference in measured straylight was found between the studied multifocal lenses. The observed variability and the straylight-pupil size dependency should be taken into account to avoid elevated straylight in multifocal contact lens wearers. The reason for the observed differences in straylight must be the subject of future studies.

INTRODUCTION

According to the World Population Ageing 1950-2050 report,[1] issued by the United Nations, the ongoing process of population aging is a well-recognized global phenomenon. If the current trend continues, the percentage of older persons in the developed countries will exceed the proportion of young people by 2050.[1] This demographic shift has an important effect on the prevalence of age-related changes in the eye and will cause increasing demands of patients to maintain good quality of vision. The inability to change the focus of the eye becomes noticeable to the patient at around 45 years.[2] Spectacle lenses are commonly utilized to provide near vision in presbyopia.[3,4] However, for presbyopic patients who wish to have spectacle independence without undergoing a surgical procedure, multifocal contact lenses emerged as an alternative and have grown in popularity when compared to monovision correction.[5] The optical principle of these contact lenses is based on the projection of multiple images with different foci. As a result, a concern arose whether this could be a reason for elevated sensitivity to disability glare, particularly under low-light conditions because of the resulting increase in pupil size.[6]

Straylight is a visual handicap caused by inhomogeneities in the eye's optical media that scatter light in the forward direction.[7] The Commission Internationale de l'Éclairage reported that disability glare is defined as straylight and as the outer part of the functional Point Spread Function.[8] Straylight is quantified by means of its equivalent luminance, where the amount of light scattered over some angular distance toward the retina is compared to the intensity of a comparison light. This gives a functional straylight parameter presented logarithmically as log(s). In comparison to logMAR, an increase of 0.1 log(s) is comparable in visual quality to the loss of 1 line.[9] Straylight and visual acuity (VA) are quite independent aspects of quality of vision. Several studies have reported increased straylight in patients with good VA, but the reverse can also occur.[9-12] However, the importance to quality of vision is comparable.[9] Also quite independent from straylight is contrast sensitivity (CS).[7] This lack of correlation indicates that standard ophthalmic techniques cannot be used to assess ocular straylight. The concept of equivalent luminance has been developed and is now used instead. This has led to extensive studies on straylight and its relation to visual quality.[12]

It has been found that, in absence of ocular pathologies, approximately 10% of light is scattered in the normal eye.[13] The main sources of light scattering in the eye are the crystalline lens, the cornea, fundus reflectance, and light transmittance by sclera and iris.[13] In youth, the straylight value is on average 0.90 log(s), but as the eye ages, this increases 2-fold, to an average of 1.20 log(s), at 65 years of age.[10] Aging of the eye causes straylight increase in the normal eye, but log(s) elevation can be found in several other pathologies as well. Clinical conditions, such as cataract, vitreous turbidity, and corneal dystrophies, may lead to serious straylight-related visual difficulties.[12,14] Moreover, the literature has shown that corneal edema causes a significant increase of straylight, which may be caused by contact lens-related complications.[15] Because contact lenses alter the normal corneal shape and physiology of established users,[16] it is of importance to study how these changes affect the quality of vision in terms of ocular straylight. Increased straylight, which causes disability glare, is a real hindrance when performing everyday tasks and may occur under different light conditions, *e.g.* while driving. The typical problems are being blinded by the headlights of approaching cars and excessive irritation while driving towards a low sun.[12,14] However, other patient's symptoms may occur, such as hazy vision (typically described as looking through a fog), decrease in color discrimination, or elongation of light adaptation.[12,14] Because contact lens wearers are exposed to different light conditions on a daily basis, it is of particular importance to study how administration of a contact lens correction affects their ocular straylight and consequently their quality of vision.

In contrast to optical aberrations, such as defocus and astigmatism, straylight from different parts of the eye is additive and cannot be reduced with artificial optical devices. Thus, the use of the contact lens for refraction or presbyopia correction may increase ocular straylight. This has been studied in the past, though with variable results. In 1987, Applegate and Wolf[17] compared straylight of hydrogel contact lenses using eyeglasses as control. A significant difference in favor of the spectacles correction was found when a lower straylight value was observed in this group. However, this finding could not be verified.[18] Elliott et al.[19] evaluated hydrophilic and rigid gas permeable (RGP) contact lenses. In this study, no effect was observed for hydrophilic contact lens wearers. The RGP group performed worse, which resulted in a higher straylight value. When the lens was removed, straylight returned to a normal level. It was concluded that optical properties might be a factor affecting ocular straylight.[19] In contrast, a later study by Lohmann et al.[20] suggested that less straylight was associated with hard contact lenses as compared to soft ones used for correction of myopia. Nio et al. made a comparison of various modalities for myopia as well.[21] They found that spectacle correction and laser eye surgery outperform soft and RGP lenses when ocular straylight is concerned. However, differences were also found between the contact lens groups, as more (0.07 log(s)) straylight was observed in the RGP group than among soft contact lens wearers.[21]

One potential explanation for these variations between studies may be the differences in lens characteristics; another explanation could be the methodology used for straylight assessment. The Direct Comparison method, which was applied in these studies, has been considered reliable and discriminative,[22] but its accuracy varied when used clinically.[12] The new Compensation Comparison (CC) methodology, applied in a commercially available straylight meter (C-Quant; Oculus), provided a step forward by giving control over the reliability of the measurements.[12,23] This was improved by adding quality parameters to eliminate erroneous results. The appearance of the CC technique has led to a large number of clinical studies on straylight with documented reliability. With respect to contact lens studies, Cerviño et al.[24] employed the new instrument to investigate sensitivity to glare of subjects after fitting them with tinted and standard contact lenses. These lenses were made of the same material, and the only difference was the presence of an amber/gray-green tint in one group. A statistically significant straylight increase was reported with respect to the grey-green correction. In a previous study, no difference was found in straylight measured with/without monovision soft contact lenses.[25] Only established contact lens wearers were enrolled in that study and measured with their habitual correction. In addition, RGP contact lens users were investigated.[25] The findings of that study were in line with Fortuin et al.,[26] as straylight decreased after RGP lenses removal, albeit without reaching the level of the age-matched control group. It was suggested that corneal integrity could be affected by subclinical changes caused by long-time use of the RGP lenses because the straylight value remained elevated even after 24 hours of discontinuation of contact lenses.[25] Therefore, to avoid a potential confounding effect of the post-RGP contact lens use complication, the RGP contact lens wearers were excluded from the current study.

Several studies have been done to obtain straylight values of monofocal contact lenses,[17-21,24-26] but to the best of our knowledge, no report has been published to date on the relation between multifocal contact lenses and straylight. Although multifocal contact lenses have shown to give good VA and CS,[27] unwanted visual phenomena such as glare, which may result in patient dissatisfaction, have been reported.[28] The visual handicaps that subjects may experience raises the important question in how far the use of multifocal contact lenses may be a tradeoff between a near vision problem and a straylight problem. Taking this into consideration, discontinuity between different zones of a multifocal contact lens may scatter light beyond 1°.[7] Also, multiple abrupt changes in a power profile may contribute significantly to light scattering[29] because each transition might act as an independent source of straylight.

In the current study, straylight of four different present-day multifocal contact lenses were compared. Multifocal contact lens wearers most often complain about their night vision, and this can be related to scotopic pupil size. For this reason, the evaluation was performed after pupil dilation.

METHODS

Participants

Sixteen subjects (11 males and 5 females) were enrolled in this study. Their mean age ± SD (range) was 31 ± 8 (21-48) years. The mean spherical equivalent wasj1.53 ± 3.71D, with cylinder power ranging from -0.75 to +3.50D and best-corrected monocular VA of the studied eyes was 20/20 or better. Participants were mostly recruited among students and employees of the Optometry School of the University of Murcia. Only subjects without any ocular pathology, systematic disease, or history of eye surgery were included. There was no limitation regarding age, refractive error, or race of the participants. RGP contact lens wearers were excluded because of the potential confounding effect of subclinical corneal changes to straylight.[25] The habitual soft contact lens users were asked to abstain from contact lens use for 1 day before participation in the study.

The study was designed according to the tenets of the Declaration of Helsinki and was approved by the independent Ethics Committee of the University of Murcia. A written informed consent was obtained from each participant after thorough explanation of the purpose and nature of the study.

Contact Lenses

The study included four multifocal contact lenses that are currently available on the market. The distance (+0.25D) and addition power (2.50D) were equal among all lenses. This allowed exclusion of potential confounding factors related to lens geometry. For more details about technical parameters of each contact lens, please refer to **Table 1**.

Proclear Multifocal contact lens (Cooper Vision, Fairport, NY) is offered in two different optical designs, with the center dedicated to near (N) or distance (D) vision. The center and the surrounding area have spherical and aspherical designs, respectively, with a progressive power profile. The ACUVUE Oasys contact lens for Presbyopia (Vistakon, Division of Johnson & Johnson Vision Care, Jacksonville, FL) consists of five alternating distance and near rings with an aspheric progressive profile. The center of the lens is set for distance vision. AirOptix Aqua Multifocal (Alcon Laboratories, Fort Worth, USA) is a near-center contact lens with a surrounding intermediate zone and with the distance power situated at the outer part of the lens. This lens has an aspheric back surface design.

All included lenses were stored under the same conditions. The Ever Clean (Avizor S.A., Spain) solution was used to clean and sterilize the contact lenses.

Table 1. Descriptive characteristic of the included multifocal contact lenses.

CL Model	Material	CW [%]	BC [mm]	DA [mm]	RI	CT [mm]	Tint	Center	No. Rings
Proclear Multifocal	omafilcon A	62	8.7	14.4	1.39	0.16	Lightly blue	Near	2
Proclear Multifocal	omafilcon A	62	8.7	14.4	1.39	0.16	Lightly blue	Distance	2
ACUVUE OASYS for Presbyopia	senofilcon A	38	8.4	14.3	1.42	0.07	Lightly blue	Distance	5
AIR OPTIX Aqua Multifocal	lotrafilcon B	33	8.6	14.2	1.42	0.08	Blue	Near	3

CW, content of water; BC, base curvature; DA, total diameter; RI, refractive index; CT, center thickens (at -3.00 D)

Straylight Measurements

The evaluation of ocular straylight was performed using a commercial straylight meter (C-Quant; Oculus). The measurement principle is based on the psychophysical CC method,[23] which works as follows. A subject fixates on a central test field, which is surrounded by a flickering straylight source (alternating on- and off-phase, **Figure 1**). As a small part of the light entering the eye is scattered and falls onto the fovea, the subject perceives a faint flickering at the test field if the test field is dark. The test field is subdivided into two halves (left and right, **Figure 1**). One, randomly chosen, half is dark, and in the other half a counter-phase light is given, compensating straylight. The first half shows unmodified ocular straylight of the subject. While the subject fixates on the central field, short-lasting flickering stimuli (alternating on- and off-phase, **Figure 1**) are presented throughout the test. At each stimulus, the subject must decide which half (left or right, **Figure 1**) flickers stronger by pressing a button. Based on the subject's responses and the known value of the compensation light, a psychometric curve is plotted and used to determine the individual straylight parameter.[23] To estimate reliability of results, the instrument gives ''expected standard deviation'' (ESD). ESD is calculated based on a maximum likelihood fit of the psychometric function as the average width of the likelihood function.[30] As ESD closely corresponds to the actual accuracy of an individual value, it is used as a criterion of reliability.[30] Only results with ESD of 0.12 log units or less were accepted and included in the data analysis.[30] Independent studies have shown good reliability and repeatability of the C-Quant instrument.[31,32]

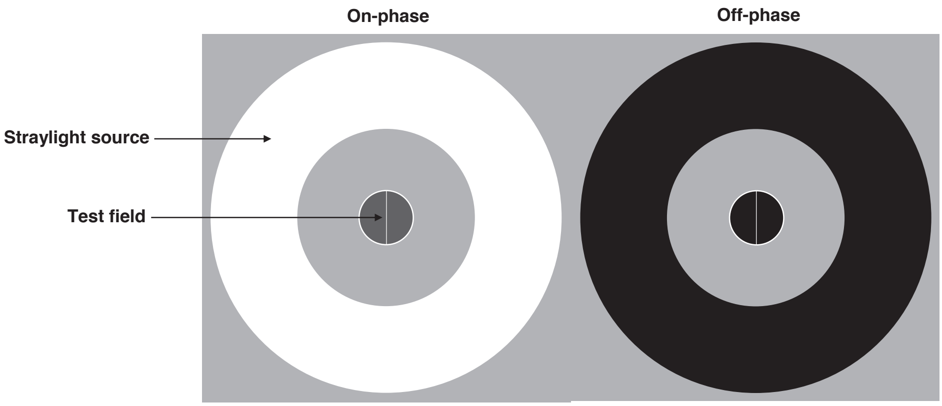

Figure 1. Test screen of the C-Quant. Please refer to the Methods section for more details.

Study Protocol

All participants underwent a complete ocular examination performed by an experienced optometrist. The flowchart of the data collection process is presented in **Figure 2**. An initial examination included refraction, best-corrected monocular visual acuity (VA) on a

Snellen chart, evaluation of the anterior segment of the eye with a slit-lamp biomicroscope, and straylight measurements (two times for each eye) using the C-Quant device. The eyes were photographed using a standard CCD camera attached to the slit-lamp unit. After preliminary evaluation including a first set of straylight measurements, subjects received two drops of tropicamide agent (1%; Alcon Cusi, Spain) to both eyes with an interval of 10 minutes. Thirty minutes after administration of the second drop, the straylight measurements were again performed. If necessary, refractive error was corrected using trial lenses inserted into the C-Quant ocular. The same correction was applied for the contact lens evaluation, as all studied contact lenses hold the same distance power of +0.25D and did not differ between subjects. Because even a single fingerprint on a spectacle lens might cause straylight increase,[33] trial lenses were thoroughly cleaned to exclude this potential effect. Pupil size was measured before and after pupil dilation based on analysis of the recorded photographs. Slit-lamp photographs of the studied lenses, with the reverse illumination, were taken as well. For this purpose, the contact lenses were placed into a wet cell and immersed in saline solution.

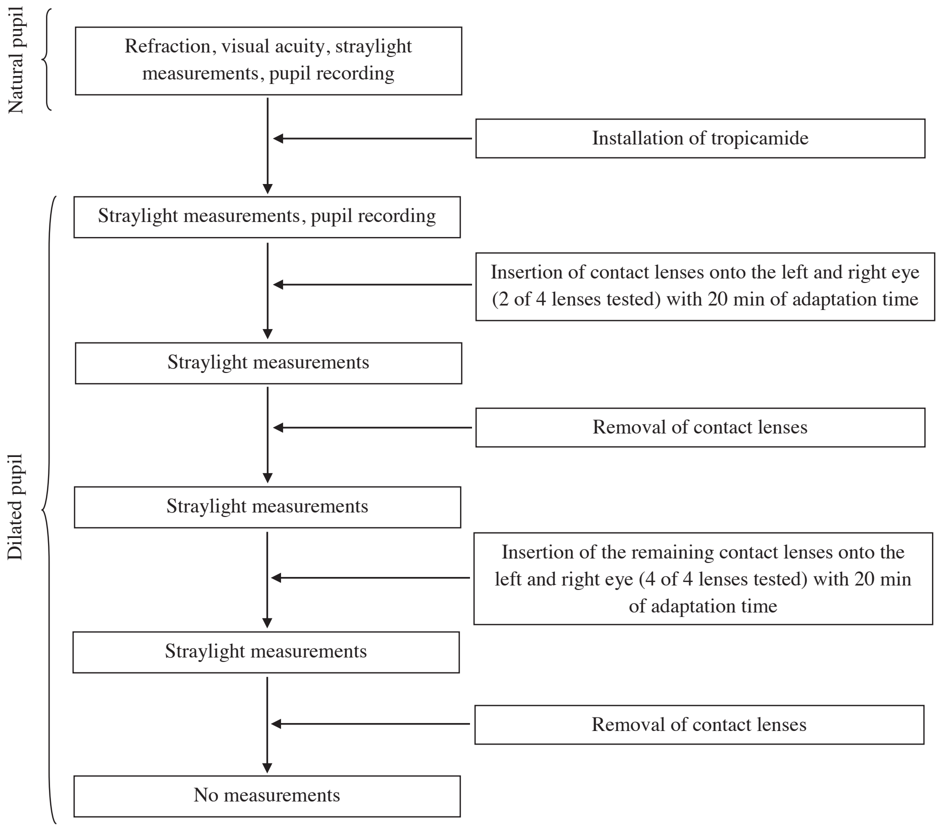

Figure 2. Flowchart of data collection.

Subjects were fitted with four different multifocal contact lenses, and each eye was evaluated with two randomly chosen lenses; therefore, the trial was divided into two parts. In the first part, two lenses were applied and tested monocularly, *i.e.* the left and right eye were always evaluated with different contact lenses present. The quality of a contact lens fit was assessed with the slit-lamp biomicroscope after the 20-minute adaptation time. The straylight measurements were performed with and without contact lenses. In the second part, the remaining two contact lenses were examined following the same protocol. Allocation was randomized by assignment of a random number generated by a computer to an individual contact lens. Subjects were not aware of the type of contact lens being tested. Both eyes of each subject were included in this comparative study because straylight values have been found to differ between fellow eyes by not much more than can be expected on the basis of the repeated measures standard deviation of 0.072 log(s).[34] The straylight values during multifocal contact lens wear were compared to those of a naked eye as controls. Earlier study has shown that soft contact lens wear (monofocal) does not affect straylight.[25]

Data Analysis

Straylight obtained with the natural and dilated pupil was compared. Because of the potential influence of pupil size on ocular straylight,[35] values measured after administration of tropicamide were considered to be a control. To exclude differences in preexisting straylight levels of the enrolled subjects, and (potentially) between the left and right eye, an analysis of residuals was performed. The residuals are defined as straylight of the eye with a contact lens minus straylight of the control value. The negative and positive sign of residuals refers to a decrease and increase of straylight, respectively, after a contact lens insertion.

Descriptive statistics were determined by calculation of mean, standard deviation (SD), and repeated measures standard deviation (RMSD) as based on the repetition of each measurement. Normality was assessed by the Shapiro-Wilk test and visual inspection of Q-Q plots. The paired double-side t-test was applied for statistical comparison of data. One-way analysis of variance ANOVA was used to evaluate significance of differences between groups, including the multifocal contact lenses and the control group. Tukey's HSD multiple comparison was performed as a post hoc test. Differences were deemed statistically significant if a p value was less than 0.05. Data were analyzed with the statistical packages STATISTICA 10 (StatSoft Inc., 2011) and Excel 2013 (Microsoft Corp.).

RESULTS

No significant difference was found between VA of the left and right eye (P = .94). The mean pupil diameter before and after dilation was 2.87 ± 0.40 mm and 7.45 ± 0.86 mm, respectively (P < .001). The mean straylight before administration of tropicamide was 0.92 ± 0.13 log(s). In mydriasis, the straylight value increased to 1.04 ± 0.11 log(s), and this difference was found to be statistically significant (P < .001). There was no significant difference between straylight of the left and right eye before (0.93 ± 0.14 log(s) vs. 0.91 ± 0.11 log(s), P = .58) and after (1.04 ± 0.11 log(s) vs. 1.04 ± 0.10 log(s), P = .85) pupil dilation. The mean log(s) results of the left and right eye before and after pupil dilation are presented in **Figure 3**.

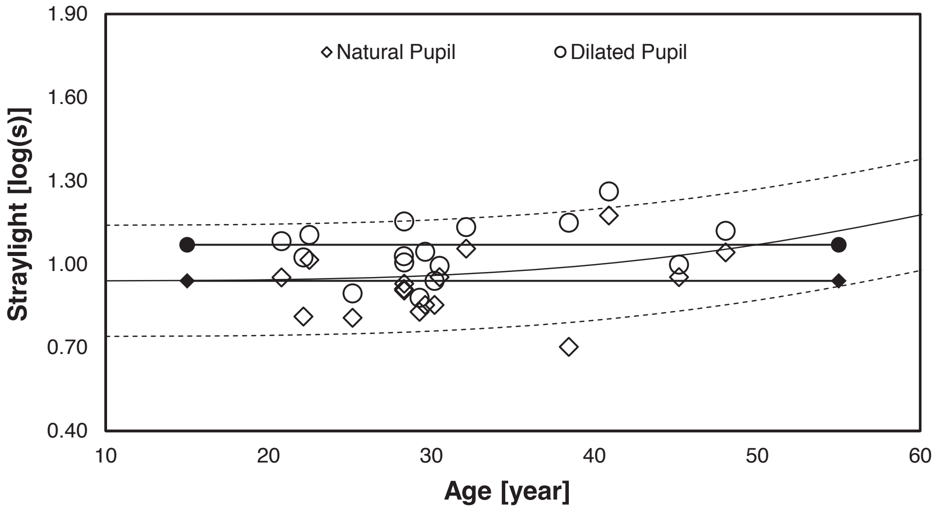

Figure 3. Individual straylight values before (diamonds) and after (circles) pupil dilation as a function of age. The lines with filled diamonds and round markers at their ends indicate the mean straylight level of the eye with the natural and dilated pupil respectively. The results were averaged over the left and right eye. Note that each data point for the natural pupil was based on 4 measurements (2 per eye; overall RMSD = 0.05 log); for the dilated pupil it was 8 measurements (4 per eye; overall RMSD = 0.06 log) as straylight before (2 per eye) and after (2 per eye) application of the first contact lenses was included. The black solid line gives the normal straylight function for phakic eyes with the 95% confidence interval (dashed lines).

The straylight level measured after removal of the first contact lens fitted was 1.06 ± 0.11 log(s). This difference did not reach the significance level (P = .13) when compared to straylight of the eyes before the first application. Therefore, these results (four measurements for each eye) were averaged and used as control.

One-way ANOVA indicated that a significant difference exists between the studied groups (P = .02). Tukey's HSD post hoc test showed that only the Air Optix straylight results differ significantly from the control (P = .006).

The calculation of residuals after the application of Oasys, Air Optix, Proclear (D), and Proclear (N) resulted on average in higher straylight by 0.02 ± 0.04 log(s), 0.11 ± 0.07 log(s), 0.05 ± 0.08 log(s), and 0.03 ± 0.07 log(s), respectively (**Figure 4**). One-way ANOVA showed a significant difference between residuals of the included multifocal lenses (P < .001). The post hoc analysis revealed statistically significant differences for the comparison of Air Optix with Oasys (P = .001) and Proclear (N) (P = .003). The remaining comparisons did not reach the significance level. The individual residuals are presented in **Figure 5** showing a larger number of the Air Optix results in the upper part of the graph (*i.e.* more straylight).

The slit-lamp images obtained with reverse illumination (**Figure 6**) show an increased intensity of scatter light from the Air Optix bulk (**Figure 6B**), dissimilar to that of the other studied contact lenses (please disregard the bright spots caused by dust particles). None of the analyzed multifocal designs showed increased scattering from the transition zones.

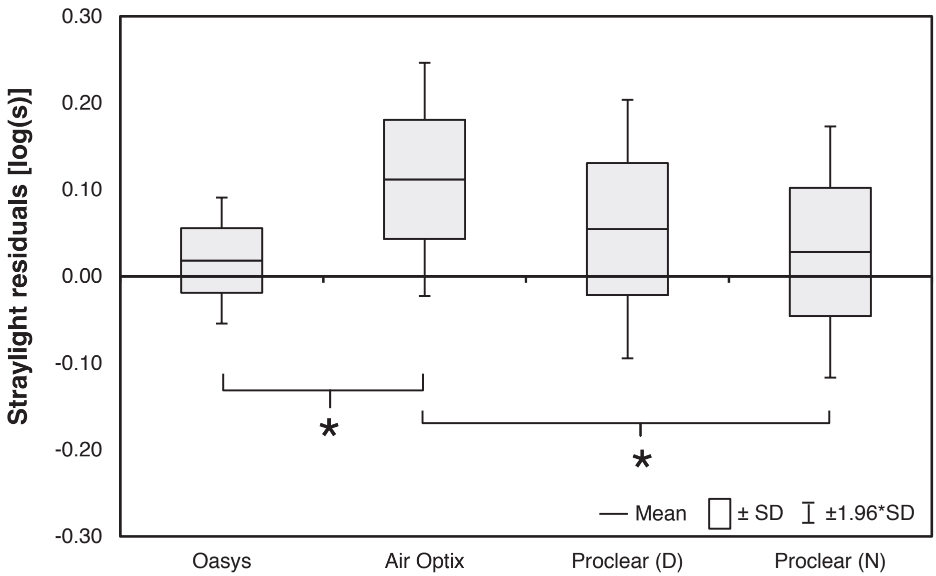

Figure 4. Straylight difference (residuals) following contact lens application. The straylight residuals are defined as a subtraction of straylight of the eye with a contact lens present and the control (base) value. Note positive residuals indicate straylight increase following the lens fitting. *, statistically significant.

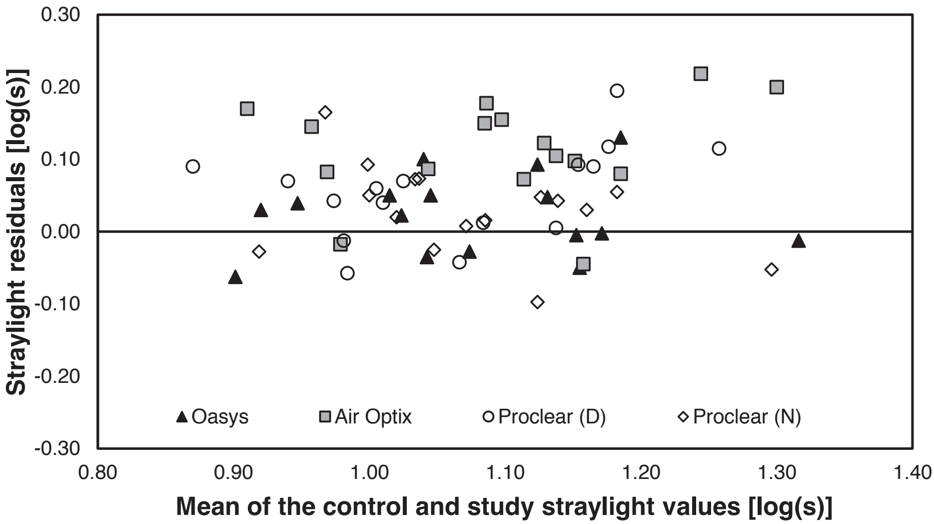

Figure 5. Bland-Altman plot of straylight residuals as a function of the mean straylight values. The residuals are defined as a subtraction of straylight of the eye with a contact lens present and the control (base) value. Note positive residuals indicate straylight increase following the lens fitting.

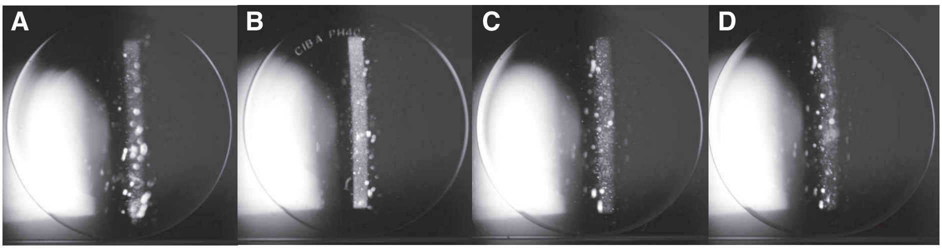

Figure 6. Slit-lamp photographs of the contact lenses used with reverse illumination. A, Oasys; B, Air Optix; C, Proclear (D); D, Proclear (N). AirOptix (B) shows a fine-grainy intensity pattern of the scattered light that cannot be found in the other studied lenses. Note uniform scattering from the AirOptix bulk irrespective of the different refractive zones.

DISCUSSION

As mentioned in the introduction, multifocal contact lenses are particularly prone to glare problems, but straylight has not yet been reported. To address this issue, four different types of present-day multifocal contact lenses were compared in the current study. The results varied significantly across the studied groups (P = .02), but the subsequent post hoc analysis revealed that, except for Air Optix (P = .006), straylight of the studied contact lenses did not differ significantly from the control. Oasys showed the lowest level of straylight increase by 0.02 log(s) whereas Air Optix caused the highest, 0.11 log(s) elevation. This difference was also found to be statistically significant (P = .001).

In this study, the lowest straylight was found in the multifocal with the highest number of optical zones. According to the manufacturer, this multiple-zones configuration cuts down visual side effects that are typically encountered by simultaneous-vision contact lens wearers, but no further explanation is given. Although complete information on optical designs of contact lenses is not available because of commercial confidentiality, some papers emerged that studied this issue, particularly in terms of power profiles. Various multifocal lenses were analyzed in the past and revealed considerable differences in their power profiles.[36,37] Interestingly, an analysis of AirOptix high addition showed a very smooth progression of optical power throughout the lens.[36,37] The power profile of Oasys with the same addition resulted in several abrupt changes,[36,37] and this could be considered as a potential source of light scattering.[29] However, the results of the current study rather contradict this hypothesis, as the lowest straylight was found in the Oasys group. The slit-lamp images did not reveal increased light scattering at the transition zones either. The optical power distributions themselves are unlikely reasons for the differences found because straylight and refractive errors affect separated aspects of visual performance.[7] The very close results of Proclear (N) and Oasys seem to confirm the validity of this assertion. Therefore, differences in optical design of the studied multifocals do not have an important effect on straylight. Moreover, the results of Oasys indicate that, despite its multifocal properties, straylight remains close to the level of the naked eye. Although the center thickness (at -3.00D) of the Proclear (D/N) lenses is twice as high as of Air Optix, straylight was lower in the Proclear group. This points to material characteristics as the suspect for increased straylight in Air Optix. Examination of the studied lenses with the reverse slit illumination (**Figure 6**) may also support this suggestion, as clearly there is some rather uniform light scattering taking place from the Air Optix bulk (**Figure 6B**). Thus, material properties may have important implications, and one would expect this to hold not only for multifocal but for soft contact lenses in general. However, Van der Meulen at al.[25] found no significant straylight effects for monofocal soft contact lenses. This seeming discrepancy might be caused by a difference in analyzed materials, as a random selection of various contact lenses was included in the Van der Meulen study.[25]

With respect to material properties, the literature has shown only small differences in surface roughness between analyzed contact lens materials. A microscopic examination of omafilcon A, senofilcon A, and lotrafilcon revealed average roughness values (mean ± SD) of 1.90 ± 0.39 nm,[38] 3.34 ± 0.28 nm,[38] and 4.50 ± 2.3 nm,[39] respectively. These values are much smaller than wavelength; hence, the potential effect of surface roughness on functional light scattering can rather be ruled out. It is also of interest to note that hydrophobicity has been suggested to affect ocular straylight when monofocal intraocular lenses are used.[40] However, the similarity between Oasys and Proclear (D/N) rather contradicts this for the case of contact lenses. In the current study, all investigated lenses were blue-tinted, and a possible confounder of contact lens tint[24] thus seems to be a nonfactor as well. However, the proposed potential relation of differences in material properties and straylight remains to be studied. Besides clinical studies, *in vitro* measurements with an optical bench set-up might be desirable to address these problems.

Only a small effect of pupil size on straylight has been found in the normal eye.[35] If light scattering is more or less uniform over the entire pupil, the proportion between the wanted and unwanted (scattered) light remains the same, regardless of pupil size. Hence, the straylight parameter is expected to remain at the same level as well. Franssen et al.[35] proposed a detailed model of straylight dependency on pupil size as the authors realized that not only light scattering in pupil opening contributes to straylight but also eye wall translucency. This second effect becomes more important for small pupils, especially below 2 mm. For large pupils, a small linear increase with pupil size was found.[35] In the present study, the mean pupil diameter changed from 2.87 to 7.45 mm resulting in 0.12 log(s) straylight elevation. According to the linear model, a 0.025 log(s) increase per 1 mm of pupil diameter may be expected,[35] hence, the difference of 4.58 mm in pupil diameter leads to the 0.11 log(s) theoretical straylight increase, which is very close to what the linear model predicts. In clinical practice, this finding can also be used as a reminder that patients with dilated pupils after, *e.g.*, eye examinations should avoid driving as their sensitivity to glare will be significantly increased.

LIMITATIONS

Inclusion of young subjects in the current study might be considered as a limitation despite the use of the cycloplegic agent as a presbyopia simulation because a multifocal correction is predominantly prescribed at an age that is older than the majority of the subjects enrolled in this study. The residual analysis, however, accounted for the straylight-age difference and other intersubject variabilities.

On the one hand, a refractive error correction using an ophthalmic lens instead of a dedicated contact lens correction might be seen as a deviation from the real-world situation. On the other hand, this approach enabled the researchers to maintain similarity among geometrical parameters of the studied lenses and, therefore, to exclude other potential confounders. One of the geometrical parameters associated with refractive power is lens thickness. **Table 1** presents the center thickness for the -3.00D lens, but one may wonder how this changes with increasing power.

Mydriasis was used to mimic night vision, so as to maximize potential effects of the multifocal designs on ocular straylight. Because it was shown that the bulk scattering (which is irrespective of pupil size) rather predominates over scattering from the optical (multifocal) design, the presented results could also be considered as a good approximation for straylight under daylight conditions.

In conclusion, we studied and compared ocular straylight of four multifocal contact lenses. Most of the studied multifocal designs showed a rather weak scattering effect. Thus, the observed increased straylight of Air Optix is more likely to be related to its material than to the optical design. More research is needed to determine the importance of material properties to ocular straylight. The results of this study could advise which type of multifocal contact lens might be more beneficial for a specific group of people, *e.g.* professional drivers, when straylight is taken into account.

REFERENCES

1. Economic UNDo. World Population Ageing, 1950-2050: New York: United Nations; 2002.
2. Oyster CW. The human eye: structure and function. In: Time and Change. Sunderland: Sinauer Associates; 1999:753-66.
3. Callina T, Reynolds TP. Traditional methods for the treatment of presbyopia: spectacles, contact lenses, bifocal contact lenses. Ophthalmol Clin North Am 2006;19:25-33, v.
4. Glasser A. Restoration of accommodation: surgical options for correction of presbyopia. Clin Exp Optom 2008;91:279-95.
5. Morgan PB, Efron N, Woods CA. An international survey of contact lens prescribing for presbyopia. Clin Exp Optom 2011;94:87-92.
6. Borish IM. Pupil dependency of bifocal contact lenses. Am J Optom Physiol Opt 1988;65:417-23.
7. Van den Berg T, Franssen L, Coppens J. Ocular media clarity and straylight. Encyclopedia of the Eye 2010;3:173-83.
8. Vos JJ. Disability glare - a state of the art report. Commission International de l'Eclairage Journal 1984;3:39-53.
9. van der Meulen IJ, Gjertsen J, Kruijt B, Witmer JP, Rulo A, Schlingemann RO, van den Berg TJ. Straylight measurements as an indication for cataract surgery. J Cataract Refract Surg 2012;38:840-8.
10. Van Den Berg TJ, Van Rijn LJ, Michael R, Heine C, Coeckelbergh T, Nischler C, Wilhelm H, Grabner G, Emesz M, Barraquer RI, Coppens JE, Franssen L. Straylight effects with aging and lens extraction. Am J Ophthalmol 2007;144:358-63.
11. Michael R, van Rijn LJ, van den Berg TJ, Barraquer RI, Grabner G, Wilhelm H, Coeckelbergh T, Emesz M, Marvan P, Nischler C. Association of lens opacities, intraocular straylight, contrast sensitivity and visual acuity in European drivers. Acta Ophthalmol 2009;87:666-71.
12. Van den Berg TJ, Franssen L, Kruijt B, Coppens JE. History of ocular straylight measurement: A review. Z Med Phys 2013;23:6-20.
13. van den Berg TJ. Analysis of intraocular straylight, especially in relation to age. Optom Vis Sci 1995;72:52-9.
14. Van den Berg TJ. On the relation between glare and straylight. Doc Ophthalmol 1991;78:177-81.
15. Elliott DB, Fonn D, Flanagan J, Doughty M. Relative sensitivity of clinical tests to hydrophilic lens-induced corneal thickness changes. Optom Vis Sci 1993;70:1044-8.
16. Moezzi AM, Fonn D, Simpson TL, Sorbara L. Contact lens-induced corneal swelling and surface changes measured with the Orbscan II corneal topographer. Optom Vis Sci 2004;81:189-93.
17. Applegate RA, Wolf M. Disability glare increased by hydrogel lens wear. Am J Optom Physiol Opt 1987;64:309-12.
18. Applegate RA, Jones DH. Disability glare and hydrogel lens wear–revisited. Optom Vis Sci 1989;66:756-9.
19. Elliott DB, Mitchell S, Whitaker D. Factors affecting light scatter in contact lens wearers. Optom Vis Sci 1991;68:629-33.
20. Lohmann CP, Fitzke F, O'Brart D, Muir MK, Timberlake G, Marshall J. Corneal light scattering and visual performance in myopic individuals with spectacles, contact lenses, or excimer laser photorefractive keratectomy. Am J Ophthalmol 1993;115:444-53.
21. Nio YK, Jansonius NM, Wijdh RH, Beekhuis WH, Worst JG, Norrby S, Kooijman AC. Effect of methods of myopia correction on visual acuity, contrast sensitivity, and depth of focus. J Cataract Refract Surg 2003;29:2082-95.

22. Elliott DB, Bullimore MA. Assessing the reliability, discriminative ability, and validity of disability glare tests. Invest Ophthalmol Vis Sci 1993;34:108-19.
23. Franssen L, Coppens JE, van den Berg TJ. Compensation comparison method for assessment of retinal straylight. Invest Ophthalmol Vis Sci 2006;47:768-76.
24. Cervino A, Gonzalez-Meijome JM, Linhares JM, Hosking SL, Montes-Mico R. Effect of sport-tinted contact lenses for contrast enhancement on retinal straylight measurements. Ophthalmic Physiol Opt 2008;28:151-6.
25. Van der Meulen IJ, Engelbrecht LA, van Vliet JM, Lapid-Gortzak R, Nieuwendaal CP, Mourits MP, Schlingemann RO, van den Berg TJ. Straylight measurements in contact lens wear. Cornea 2010;29:516-22.
26. Fortuin MF, Schilperoort J, Evans BJ, Edgar DF, van den Berg TJ, Kiers H. Randomised controlled trial of the effects of two rigid gas permeable (RGP) contact lens materials and two surface cleaners on straylight values. Ophthalmic Physiol Opt 2009;29:497-508.
27. Rajagopalan AS, Bennett ES, Lakshminarayanan V. Visual performance of subjects wearing presbyopic contact lenses. Optom Vis Sci 2006;83:611-5.
28. Chu BS, Wood JM, Collins MJ. Effect of presbyopic vision corrections on perceptions of driving difficulty. Eye Contact Lens 2009;35:133-43.
29. Plainis S, Atchison DA, Charman WN. Power profiles of multifocal contact lenses and their interpretation. Optom Vis Sci 2013;90:1066-77.
30. Coppens JE, Franssen L, Van Rijn L, van den Berg TJ. Reliability of the compensation comparison stray-light measurement method. J Biomed Opt 2006;11:034027–9.
31. Cervino A, Montes-Mico R, Hosking SL. Performance of the compensation comparison method for retinal straylight measurement: effect of patient's age on repeatability. Br J Ophthalmol 2008;92:788-91.
32. Guber I, Bachmann LM, Guber J, Bochmann F, Lange AP, Thiel MA. Reproducibility of straylight measurement by C-Quant for assessment of retinal straylight using the compensation comparison method. Graefes Arch Clin Exp Ophthalmol 2011;249:1367-71.
33. De Wit GC, Coppens JE. Stray light of spectacle lenses compared with stray light in the eye. Optom Vis Sci 2003;80:395-400.
34. Montenegro GA, Michael R, van den Berg TJ. Variation of straylight between contra lateral eyes - results from 1017 healthy subjects. Acta Ophthalmol 2012;90:e332-3.
35. Franssen L, Tabernero J, Coppens JE, van den Berg TJ. Pupil size and retinal straylight in the normal eye. Invest Ophthalmol Vis Sci 2007;48:2375-82.
36. Dominguez-Vicent A, Marin-Franch I, Esteve-Taboada JJ, Madrid-Costa D, Montes-Mico R. Repeatability of in vitro power profile measurements for multifocal contact lenses. Cont Lens Anterior Eye 2015;38:168-72.
37. Wagner S, Conrad F, Bakaraju RC, Fedtke C, Ehrmann K, Holden BA. Power profiles of single vision and multifocal soft contact lenses. Cont Lens Anterior Eye 2015;38:2-14.
38. Giraldez MJ, Resua CG, Lira M, Oliveira MECR, Magarinos B, Toranzo AE, Yebra-Pimentel E. Contact lens hydrophobicity and roughness effects on bacterial adhesion. Optom Vis Sci 2010;87:E426-E31.
39. Lira M, Santos L, Azeredo J, Yebra-Pimentel E, Oliveira M. Comparative study of silicone-hydrogel contact lenses surfaces before and after wear using atomic force microscopy. J Biomed Mater Res B Appl Biomater 2008;85:361-7.
40. Montenegro GA, Marvan P, Dexl A, Pico A, Canut MI, Grabner G, Barraquer RI, Michael R. Posterior capsule opacification assessment and factors that influence visual quality after posterior capsulotomy. Am J Ophthalmol 2010;150:248-53.