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Ocular aberrations and visual function with multifocal versus single vision soft contact lenses

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ABSTRACT

Purpose: To investigate differences in ocular aberrations induced by centre-near multifocal soft contact lenses (SCL) relative to single vision SCLs and their effect on contrast sensitivity function (CSF).
Methods: Ocular aberrometry was measured in 18 cyclopleged subjects (19–24 years) while wearing Ciba Air Optix low (AOlow) and high (AOhigh) add, Bausch & Lomb PureVision low (PVlow) and high (PVhigh) add multifocals, and a Bausch & Lomb PureVision single vision (PVsv) control with the same −3.00 D distance back vertex power. Zernike polynomials were scaled to 4, 5 and 6 mm pupils. CSF was measured at equivalent distances of 6 m, 1 m and 40 cm while fully corrected with spherical trial lenses at 6 m.
Results: AOlow, AOhigh and PVhigh induced a negative shift in primary spherical aberration (Z12) from PVsv and all multifocal SCLs induced a positive shift in secondary spherical aberration (Z24) (all $p < 0.01$), without significantly increasing coma. Area under the CSF (AUCSF) reduced at 40 cm for all multifocals relative to PVsv ($p < 0.05$), but was not significantly different at 6 m or 1 m. A moderate correlation ($r = -0.80$, $p < 0.005$) was found between changes in Z12 and AUCSF at 40 cm for AOhigh, with an increase in negative Z12 reducing multifocal-induced loss of CSF.
Conclusions: Centre-near multifocal SCLs induced a negative shift in Z12 and a positive shift in Z24. Although CSF was unaffected at 6 m and 1 m it was reduced at 40 cm, possibly because changes in Z12 and Z24 were not great enough to induce a significant shift in centre of focus and increase in depth of field.

1. Introduction

An ageing global population is resulting in an increased prevalence of presbyopia, and with new presbyopes being described as more active than their predecessors, contact lenses (CLs) provide an ideal vision correction modality. By virtue of their fixed focus design, CLs are unable to replace the near focussing mechanism that presbyopia diminishes. Monovision was an early solution, where single vision CLs are used to correct one eye for distance and the fellow eye for near. Multifocal CLs, which are designed to provide simultaneous binocular focus at distance and near, offer an alternative approach for correction of presbyopia. However, despite the advantage of preserved binocularity and stereoacuity offered by multifocal CLs [1], it is only in recent years that they have started to reveal preferable subjective rating over monovision [2] and dominate in actual fitting volume over monovision, as shown in presbyopic CL fitting surveys [3,4]. Furthermore, international prescribing trends for 2005–2009 indicate that combined fits of multifocal and monovision only account for 37% of all presbyopic CL fits, meaning that the majority of presbyopic CL wearers are being fitted with single vision distance correction and supplementary spectacles for near tasks [3]. This does not appear to be due to practitioner reluctance to fit multifocal CLs, with a recent annual survey of USA practitioners revealing 67% preference towards fitting multifocal CLs to their presbyopic CL patients [5], but more a reflection that the multifocal CLs themselves are not providing appropriate visual benefits [6,7].

The majority of current soft multifocal CL options are of a centre-near design, where the centre of the lens provides near correction blending towards distance correction in the periphery. The underlying principle is that under normal viewing conditions the pupil will be large enough to simultaneously encompass the near and peripheral distance focussing areas of the lens [8,9]. However, the consequence is that at any time there may be a number of objects at different distances simultaneously focussed in the retinal plane, leading to image rivalry and consequent degradation in image quality [10]. Contrast sensitivity function (CSF) offers a way to measure the effect of multifocal CL designs on visual function, and has been shown to reduce with bifocal soft CLs relative to progressive spectacles and bifocal rigid CLs for distance vision [11]. Centre-near multifocal CL designs have been shown to reduce CSF

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at distance and near relative to spectacle correction [12], but exhibited no difference when compared to soft CL monovision correction [1].

Aspheric centre-near multifocal CLs also induce changes in spherical aberration (SA) [13]. This gives an advantage of increased range of focus due to longitudinal spread of the image in the retinal plane, but at the cost of aberration-induced loss of image clarity [7,14–20]. In addition it has been shown that when a CL is designed to alter SA, as is the case for a centre-near design multifocal, lens decentration will cause changes in coma [21] which, if sufficiently increased, could further degrade image quality [22]. Little has been published on the associations between multifocal CL-induced aberrations and measured visual function. However, Martin and Roorda [25] have shown that visual quality with bifocal soft CLs can be predicted based on CL-induced ocular aberrations.

The purpose of this study was to investigate the influence of centre-near multifocal CLs on visual function measured as CSF at distances of 6 m, 1 m and 40 cm using two commercially available multifocal CL designs (Bausch & Lomb PureVision and Ciba Air Optix) relative to an aspheric soft single vision CL control (Bausch & Lomb PureVision). In addition whole eye ocular aberrations were measured to test for associations with changes in CSF. A single vision CL rather than uncorrected control was chosen to specifically investigate how centre-near multifocal soft CLs differ from a single vision soft CL design. All lenses had −3.00 DS back vertex power so that any difference in CSF and ocular aberrations between the multifocal CL designs and the single vision CL could be attributed to differences in lens design. The primary interest was how centre-near multifocal CL designs affect visual function relative to aspheric single vision CLs rather than attempting to draw direct comparisons between designs from different manufacturers.

2. Methods

2.1. Subjects

Twenty subjects were enrolled from the University of New South Wales student community. Sample size was determined using data from Lindskoog Pettersson et al. [23] and Soni et al. [24]. Calculations using G*Power (version 3.1.2, Dusseldorf, Germany) revealed that 16 subjects were required for an 80% power to detect a 0.035 μm difference in Z12 and 0.38 difference in contrast sensitivity between the lens types being investigated at the 0.05 level. Twenty subjects were enrolled to protect against a possible subject dropout rate of 20%.

Data from two subjects were excluded at the data analysis stage because of unacceptably poor Hartmann–Shack image capture at one or more measurement intervals. Eighteen subjects completed the study (mean age 22.2 ± 1.1 years, range 19.4–24.1 years; 2M, 16F). All subjects had best corrected visual acuity of at least 6/9 (20/30), subjective refraction ≤±6.00 D with ≤−0.75 D ocular or corneal astigmatism in both eyes, and no evidence of ocular disease or previous ocular surgery. Participants were excluded if they were soft extended or rigid CL wearers. Daytime soft CL wearers were enrolled as long as they had not been wearing CLs for at least 3 days prior to participating in the study. Approval from the institutional human research ethics committee was obtained before the study began. All subjects gave informed written consent, and were screened before enrolment to ensure that they met study eligibility criteria. All subjects were treated in accordance with the tenets of the Declaration of Helsinki.

2.2. Contact lenses

The single vision lenses used in this study were Bausch & Lomb PureVision (balafilcon A, water content 36%, Dk/t 101, base curve 8.6, diameter 14 mm). PureVision single vision (PVsv) CLs are described by the manufacturer as having an aspheric anterior surface designed to reduce SA, although published outcomes vary with Lindskoog Pettersson et al. [26] reporting 0.19 μm change in SA with PureVision CLs, whereas McAlinden et al. [27] more recently reported no significant change in SA. The multifocal CLs were Bausch & Lomb PureVision (PV) multifocal (balafilcon A, water content 36%, Dk/t 101, base curve 8.6, diameter 14 mm) and Ciba Air Optix (AO) multifocal (lotrafilcon B, water content 33%, Dk/t 138, base curve 8.6, diameter 14.2 mm). Both multifocal lens designs have aspheric front and back surfaces and were tested in low add (targeted to correct up to +1.50 add) and high add (PV targeted to correct +1.75 to +2.50 D add; AO targeted to correct +2.25 to +2.50 D add) iterations. To provide consistent comparisons between lens additions and across subjects, the same distance BVP of −3.00 D was used throughout for all lenses.

2.3. Study protocol

Subjects attended a preliminary examination to check eligibility for enrolment, to confirm sufficient iris chamber angle and anterior chamber depth to allow safe cycloplegia, and to measure baseline aberrometry, corneal topography, objective and subjective refraction. Subjects were then scheduled to return for the main study session where one drop each of 0.5% proxymetacaine hydrochloride (Alcaine) and 1% cyclopentolate hydrochloride were instilled in both eyes. After waiting 30 min, the effect of the cycloplegia was checked by measuring accommodative amplitude, and if necessary an extra drop of 1% cyclopentolate was instilled followed by a further waiting period of 30 min. PVsv were then inserted in both eyes and allowed to settle for 8 min before lens ocular aberrometry and contrast sensitivity measurements were taken. Lenses were then removed and either PV or AO multifocal lenses were randomly assigned and inserted with the low add iteration in one eye and the high add iteration in the fellow eye. These lenses were allowed to settle for 8 min and ocular aberrometry repeated followed by measurement of monocular near visual acuity and monocular range of clear near vision. These lenses were then removed and the remaining multifocal lenses were inserted followed by the same measurements after a further 8 min settling period. In this manner each subject wore PVsv in both eyes, and a PV multifocal and AO multifocal in each eye in either low or high add iteration, while the fellow eye wore the alternate add power for each design. In all cases both the investigator and subject were masked as to which multifocal CL type had been inserted.

Due to the large number of CS grating presentations required to generate each CSF, subjects were randomly allocated into two equal groups to have CSF measured either while wearing PVlow and PVhigh or AOlow and AOhigh. Consequently nine subjects had CSF measured while wearing the AO multifocal lenses and nine while wearing the PV multifocal lenses. CSF in both eyes was measured monocularly for all subjects at distance while wearing the PVsv control, and at distance, intermediate and near while wearing the multifocal CLs.

2.4. Measurements

The Discovery (software version 1.44.0.0, Innovative Visual Systems, Elmhurst, IL, USA) was used to capture whole eye aberrometry. The instrument uses a Hartmann–Shack screen with apertures of 0.125 mm at 0.25 mm spacing to provide 800 samples over an 8 mm pupil. Three ocular wavefront images were captured at each measurement session.