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Power Profiles of Commercial Multifocal Soft Contact Lenses

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ABSTRACT

Purpose. To evaluate the optical power profiles of commercially available soft multifocal contact lenses and compare their optical designs.

Methods. The power profiles of 38 types of multifocal contact lenses—three lenses each—were measured in powers +6D, +3D, +1D, −1D, −3D, and −6D using NIMO TR1504 (Lambda-X, Belgium). All lenses were measured in phosphate buffered saline across 8 mm optic zone diameter. Refractive index of each lens material was measured using CLR 12-70 (Index Instruments, UK), which was used for converting measured power in the medium to in-air radial power profiles.

Results. Three basic types of power profiles were identified: center-near, center-distance, and concentric-zone ring-type designs. For most of the lens types, the relative plus with respect to prescription power was lower than the corresponding spectacle add. For some lens types, the measured power profiles were shifted by up to 1D across the power range relative to their labeled power. Most of the lenses were designed with noticeable amounts of spherical aberration. The sign and magnitude of spherical aberration can either be power dependent or consistent across the power range.

Conclusions. Power profiles can vary widely between the different lens types; however, certain similarities were also observed between some of the center-near designs. For the more recently released lens types, there seems to be a trend emerging to reduce the relative plus with respect to prescription power, include negative spherical aberration, and keep the power profiles consistent across the power range.

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Key Words: power profiles, contact lenses, multifocal, presbyopia, spherical aberration

Concomitant with the aging of the world population,[1] the average age of a contact lens wearer is increasing, contributing to a growing presbyopic contact lens market.[2] To capture the presbyopic contact lens market has been a quest of all major manufacturers for many years, to date with only limited success.[2–4] Although some of the reasons are generally age-related discomfort and handling issues,[5] dissatisfaction with the performance of multifocal soft lenses due to unwarranted visual compromise does not make it an attractive option for the potential presbyopic lens wearer. Advances in lens materials to provide better comfort and the widespread introduction of daily disposable lenses have helped to make soft contact lenses a more attractive alternative to reading glasses.[3] Manufacturers have also tried a wide variety of optical designs to optimize the visual performance over the full near-to-distance range under low and high illumination conditions.[6,7] Most of the current multifocal contact lenses are simultaneous-image type in which multiple powers correcting various distances are imposed over the pupil simultaneously. The most common designs comprise center-near, center-distance, and concentric-zone ring designs, spanning aspheric and stepped profiles. Each design has advantages and disadvantages in providing optimal vision for the majority of wearers with a range of different inherent ocular aberrations,[8–11] pupil sizes,[12] lens centration,[13,14] needs, and expectations.

Recent advances in ophthalmic instrumentation have enabled reliable measurements of optical power profiles of contact lenses,[9,15] which assist in manufacturing consistency and providing objective information about the optical design of the lens. Power profiles give insights into the distribution and magnitude of relative plus with respect to the prescription power in

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multifocal contact lenses. Such profiles can be used to discriminate lens designs and to correlate design features with visual performance. Wave-front sensing instruments used to objectively measure the optical properties of soft contact lenses utilize Moiré deflectometry, Hartmann-Shack, or Schlieren methods.

Based on the Hartmann-Shack principle, the SHSOphthalmic (Optocraft GmbH, Erlangen, Germany) instrument calculates power maps and optical profiles by passing a collimated light beam through the test lenses. The Hartmann-Shack sensor divides this beam into multiple beams of light using a lenslet array. The lateral position of each focal point is captured with a charge-coupled devices sensor, from which the wave-front distortions are determined and converted into power profiles. This instrument has previously been used to investigate the optical zone power profiles of commercial soft single vision contact lenses and multifocal contact lenses. Interestingly, negative spherical aberration was predominant in almost all of all lenses measured.[15]

The Phase Focus Lens Profiler (Phase Focus Ltd., Sheffield, UK) uses ptychographic imaging in which the diffraction patterns from neighboring points on the lens are used to reconstruct the thickness profile. Power profiles are then computed from the obtained thickness differentials. One other study provided power profiles of some multifocal contact lenses using this instrument.[9] The authors mathematically described the power profiles and interpreted how the optical designs relate to visual performance on the four simultaneous multifocal contact lenses—however basing their investigation only on plano powered lenses.

The NIMO TR1504 (Lambda-X, Nivelles, Belgium) instrument is based on the "Phase-Shifting Schlieren" technique, measuring light beam deviations with the help of Schlieren filters to calculate the power characteristics of optical lenses.[16] Soft contact lenses are measured in saline and effective power is converted to back vertex power in air using thin or thick lens equations. The reliability of measuring power profiles of soft contact lenses has been established previously.[17] The power profiles of single vision and multifocal simultaneous contact lenses have been evaluated previously using this instrument.[18–20] However, these studies only investigated −3.00D distance power lenses. They concluded that the pupil diameter plays a crucial factor in the refractive power provided by the aspheric designs.

Although the power profiles of multifocal contact lenses have been previously reported using different instruments, the majority of those studies were limited to only a few lens types and/or powers. The purpose of this current study was to comprehensively evaluate the optical power profiles of all the most commonly prescribed multifocal contact lenses across a wide range of prescription powers, which would also facilitate assessment of the effect of spherical aberration as a function of power.

METHODS

Contact Lenses

Thirty-eight types of commercially available multifocal soft lenses from four leading contact lens manufacturers were tested across six refractive powers −6.00D, −3.00D, −1.00D, +1.00D, +3.00D, and +6.00D (see Table 1) with a few exceptions. Highest plus power available in Biotrue ONEday for Presbyopia was +3.00D power. In the case of FOCUS DAILIES Progressives and Clariti 1 day lenses, highest plus power was +5.00D.

Instruments

CLR 12-70

The refractive indices of the contact lenses were measured using the CLR 12-70 (Index Instruments Ltd., Cambridge, UK) for each type. This digital refractometer measures refractive index by back reflection at 546 nm and as stated and verified by Index Instruments, it provides accuracy and reproducibility of refractive indices ±0.001 and refractive indices ±0.0003, respectively, for soft contact lenses. The "single scan" mode was used to read the refractive index value after it stabilized for each lens.

NIMO TR1504

The NIMO TR1504 (Lambda-X, Belgium) is a high-resolution power mapping instrument based on the phase-shifting Schlieren technique to measure the wave-front distortions of a collimated, green (546 nm) light beam passing through the lens. A high-resolution charge-coupled devices camera captures the Schlieren fringes generated by the laterally movable Schlieren filter. The effective optical power is measured in saline and converted to back vertex power using corresponding refractive indices of the materials measured using the CLR 12-70 digital refractometer. The accuracy and reproducibility of the instrument, as stated by Lambda-X, is better than 0.05D for sphere power of rotationally symmetric soft contact lenses. From the measured power maps, the NIMO TR1504 software in the "Multifocal" mode generates averaged radial power profiles across the selected 8 mm optic zone diameter, which can be exported in text format. The in-built ring analysis power calculation provided with the NIMO TR1504 measurement software (v2.8) was not used. The lenses were centered manually by aligning within the diameter circle on the alignment camera image. To enhance the resolution of sharp transitions within the power profiles, the filter settings in the option files, "MF Map Transition Distance" and "MF Map Filter Kernel Size," were changed from their default values of 20 and 20, to 5 and 10, respectively. All exported power profiles measured from NIMO TR1504 were normalized to 0.01 mm half chord intervals, by sequential interpolation using third-order polynomial curves fitted through four adjacent profile points, implemented in custom-written software, and imported into Excel (Microsoft, USA) for plotting.

Contact Lens Optical Quality Analyzer (CLOQA)

The CLOQA is a custom-built optical instrument (Brien Holden Vision Institute) based on the Foucault knife-edge test that allows the rapid visual assessment of the optical design and quality of a contact lens. Detailed description of the instrument can be found elsewhere.[21] This instrument was used in this study to screen for any obvious optical defects.

TABLE 1.

List of commercially available soft multifocal contact lenses used in this study

Brand	Labelled Addition*	Manufacturer	Material/RI	BC	Dia (mm)	Water Content	Modality	Lens Design
ACUVUE OASYS for PRESBYOPIA	Lo (+1.25) Mid (+1.75) Hi (+2.50)	Vistakon, Johnson & Johnson, USA	(Silicone Hydrogel) senofilcon A/1.42	8.4	14.3	38%	Bi-Weekly	Center-distance concentric aspheric zones
1-DAY ACUVUE MOIST MF	Lo (+1.25) Mid (+1.75) Hi (+2.50)		(Hydrogel) etafilcon A/1.40	8.4	14.3	58%	Daily Wear	Center-near aspheric
AIR OPTIX AQUA MF	Lo (+1.00) Mid (+2.00) Hi (+2.50)	ALCON, USA	(Silicone Hydrogel) lotrafilcon B/1.42	8.6	14.2	33%	Daily Wear	Center-near Bi-aspheric
FOCUS DAILIES Progressives	—		(Hydrogel) nelfilcon A/1.38	8.6	13.8	69%	Daily Wear	Center-near Bi-aspheric
DAILIES AquaComfort Plus MF	Lo (+1.25) Mid (+2.00) Hi (+2.50)		(Hydrogel) nelfilcon A/1.38	8.7	14.0	69%	Daily Wear	Center-near aspheric
Biofinity MF (Near & Distance)	+1.00 +1.50 +2.00 +2.50	Cooper Vision, USA	(Silicone Hydrogel) comfilcon A/1.40	8.6	14.0	48%	Monthly Wear	Balanced progressive technology
Proclear MF (Near & Distance)	+1.00 +1.50 +2.00 +2.50		(Hydrogel) omafilcon B/1.39	8.7	14.4	62%	Monthly Wear	Balanced progressive technology
Proclear 1 day MF	—		(Hydrogel) omafilcon A/1.387	8.7	14.2	62%	Daily Wear	Center-near aspheric
Clariti 1 day MF	Lo Hi		(Silicone Hydrogel) somofilcon A/1.4003	8.6	14.1	56%	Daily Wear	Daily Wear
PureVision2 for Presbyopia	Lo (+1.00) Hi (+2.50)	Bausch & Lomb, USA	(Silicone Hydrogel) balafilcon A/1.426	8.6	14.0	36%	Daily Wear	Center-near aspheric (3-zone progressive
SofLens MF	Lo Hi		Polymacon/1.43	8.5	14.5	38%	Bi-Weekly	Center-near aspheric
Biotrue ONEday for Presbyopia	Lo Hi		(Hydrogel) nesofilcon A/1.374	8.6	14.2	78%	Daily Wear	Center-near aspheric (3-zone progressive)

*Labelled maximum add power taken from manufacturer packaging.
Lo = Low and Hi = High.

Measurements

All lenses were removed from blister packs and soaked in standard phosphate buffered saline (PBS)[22] with a refractive index of 1.334 for at least 24 hours before measuring. This was to provide for comparable measurement conditions, which also closely mimic the ocular environment in terms of pH and osmolarity as recommended in ISO 18369-3.[22] Power profiles and CLOQA measurements were performed using a cuvette filled with standard PBS at room temperature of 20 °C (±5 °C). Single refractive index measurements were performed on three lenses from each lens material (n = 11 material types × 3 lenses) also at room temperature of 20 °C (±5 °C). Using the measured refractive index, single power profile measurements were performed on three lenses from each lens type (n = 38 lens types × 3 lenses × 6 powers). Visual assessment was performed on one lens from each lens type (n = 38 lens types × 1 lens × 6 powers).

RESULTS

Refractive Indices

The measured refractive indices (RIs) of each lens material are shown in Table 2 with the corresponding nominal refractive index claimed by the manufacturers. The differences between the measured and the nominal varied up to 0.014. The 95% LoA was from −0.017 to 0.012. The standard deviation between the three lenses of each material types are very small and within the ISO tolerance.[23]

TABLE 2.

The RI measured for each material compared to its nominal refractive index. The values are averaged and shown with the standard deviation between the three lenses per material

Material	Nominal RI	Average measured RI
senofilcon A	1.42	1.4090 ± 0.0018
etafilcon A	1.40	1.4085 ± 0.0017
lotrafilcon B	1.42	1.4181 ± 0.0015
nelfilcon A	1.38	1.3833 ± 0.0013
comfilcon A	1.40	1.4058 ± 0.0005
omafilcon B	1.39	1.3987 ± 0.0003
omafilcon A	1.387	1.3952 ± 0.0013
somofilcon A	1.4003	1.4016 ± 0.0015
balafilcon A	1.426	1.4164 ± 0.0001
polymacon	1.43	1.4439 ± 0.0003
nesofilcon A	1.374	1.3735 ± 0.0006

CLOQA Images

Selected CLOQA images are shown in Fig. 1 where the design features and/or detection of possible defects are easily observed. The distinct lens design of ACUVUE OASYS for PRESBYOPIA with alternating distance and near zones can be easily observed in the CLOQA image (see Fig. 1A). Similarly, for the Clariti 1 day and PureVision2 for Presbyopia Hi addition lenses, the gradation stepped power change can be observed (see Fig. 1B and C, respectively). Examples of optical and/or surface defects are shown in Fig. 1D to F.

Power Profiles

The measured power profiles using NIMO TR1504 were analyzed and graphed as absolute and relative refractive powers. The power profiles for each lens designs are plotted using the average values of the three lenses measured. The standard deviations between the three lenses were lower than 0.5D except for the central 0.5 mm half chord. Only the −3.00D lens powers are plotted to observe the shape of each lens designs. The measurements for central 0.5 mm are unreliable[17] and hence were ignored and not used in the evaluations.

Absolute Refractive Power Profiles

Only the −3.00D lens powers are plotted to demonstrate the differences and similarities between the different lens types. The Proclear multifocal and Biofinity multifocal lenses are based on the same optical design, and this can be observed in the profile shapes in Fig. 2 (except for Biofinity center-distance + 1.00D addition power lens, where there is no distinct add power). Both Proclear and Biofinity multifocal lenses are available in four addition powers. For the center-distance designs, the change from distance to near zone power occurs from 1.6 to 2.1 mm semi-diameter. For the center-near design, the transition from near to distance zone power occurs from 1.2 to 2.0 mm semi-diameter.

The ACUVUE OASYS for PRESBYOPIA lenses have a distinct profile pattern with alternating distance and near zones. The width of these zones varies with wider zone widths for the higher addition powers (see Fig. 3). The amplitude of the refractive zones also varies; greater amplitude for higher addition powers. The 1-DAY ACUVUE MOIST lenses, on the other hand, have a gradual change in power between near and distance zones. There is no distinct relative plus power to the distance prescription in the Lo addition lens. Similarly, AIR OPTIX AQUA and DAILIES

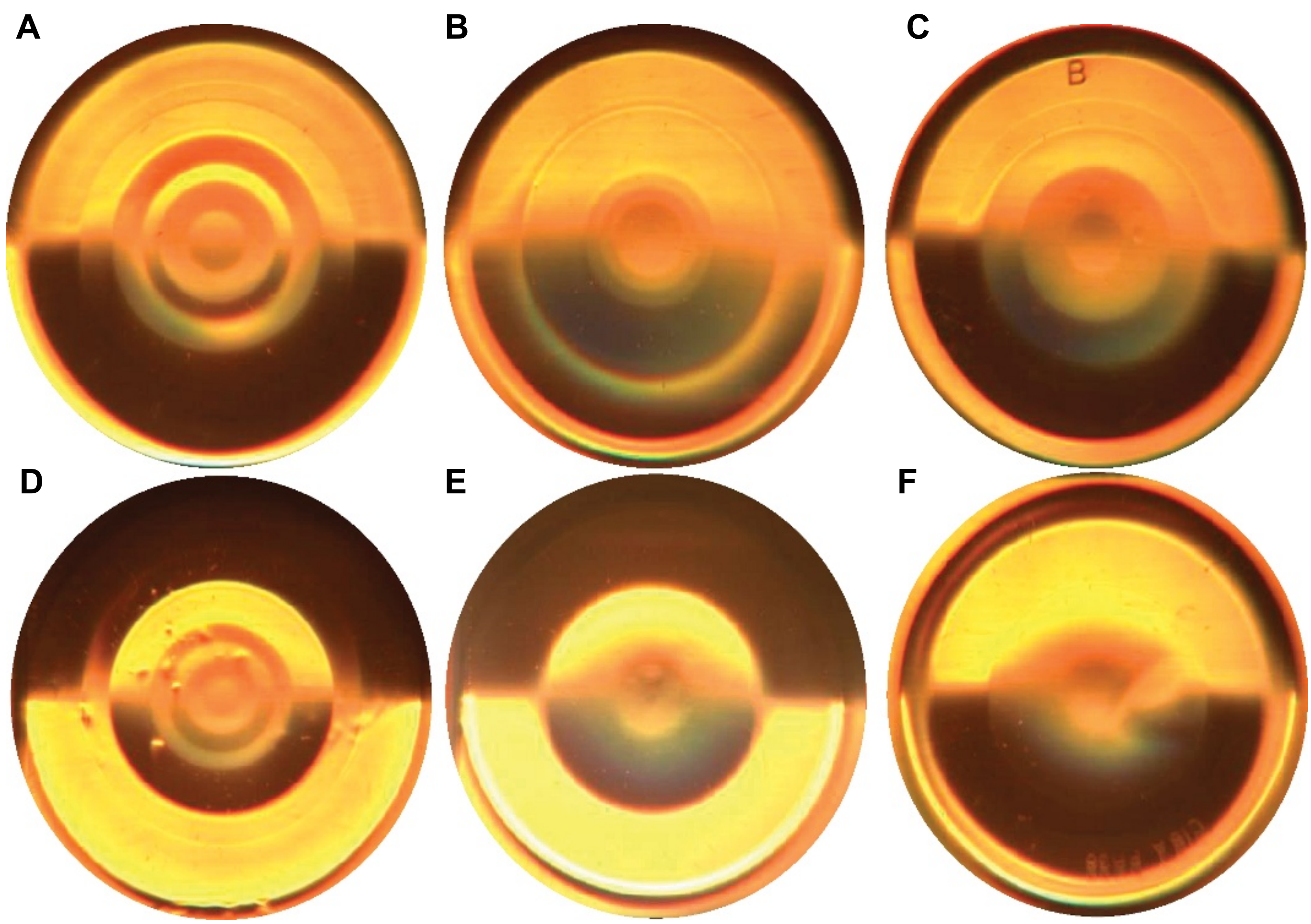

FIGURE 1.

CLOQA image of ACUVUE OASYS for PRESBYOPIA Hi Add Power −1.00D (A), Clariti 1 day Hi Add Power −3.00D lens (B), PureVision2 for Presbyopia Hi Add Power +1.00D lens (C), ACUVUE OASYS for PRESBYOPIA Mid Add Power −6.00D lens (D), Proclear multifocal center-near 1.00 Add Power −6.00D lens (E), AIR OPTIX AQUA High Add Power +1.00D lens (F).

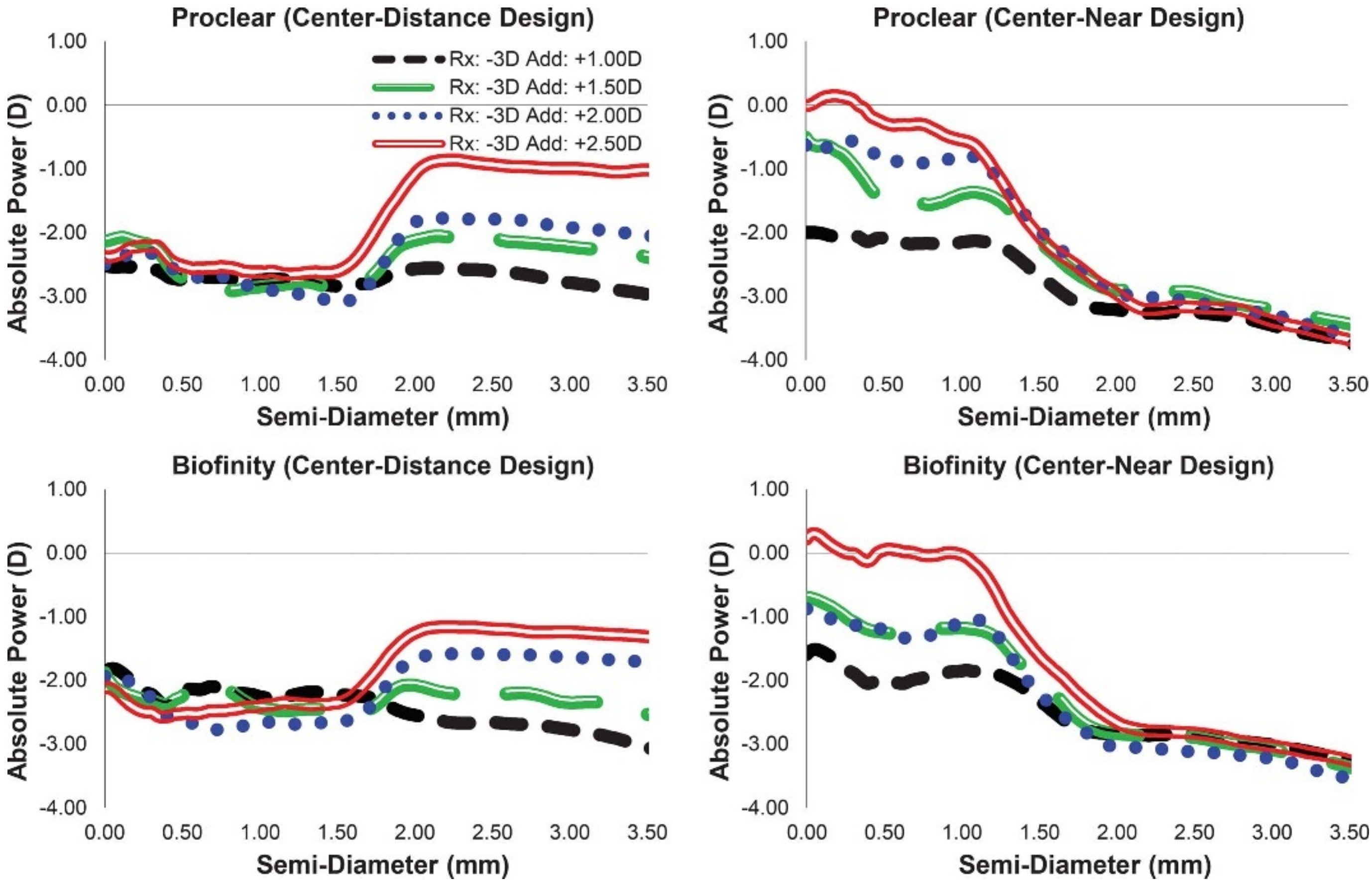

FIGURE 2.

Absolute refractive power profiles of Proclear and Biofinity multifocal contact lenses—in four different addition powers. The measurements for central 0.5 mm are unreliable and hence were ignored in all graphs.

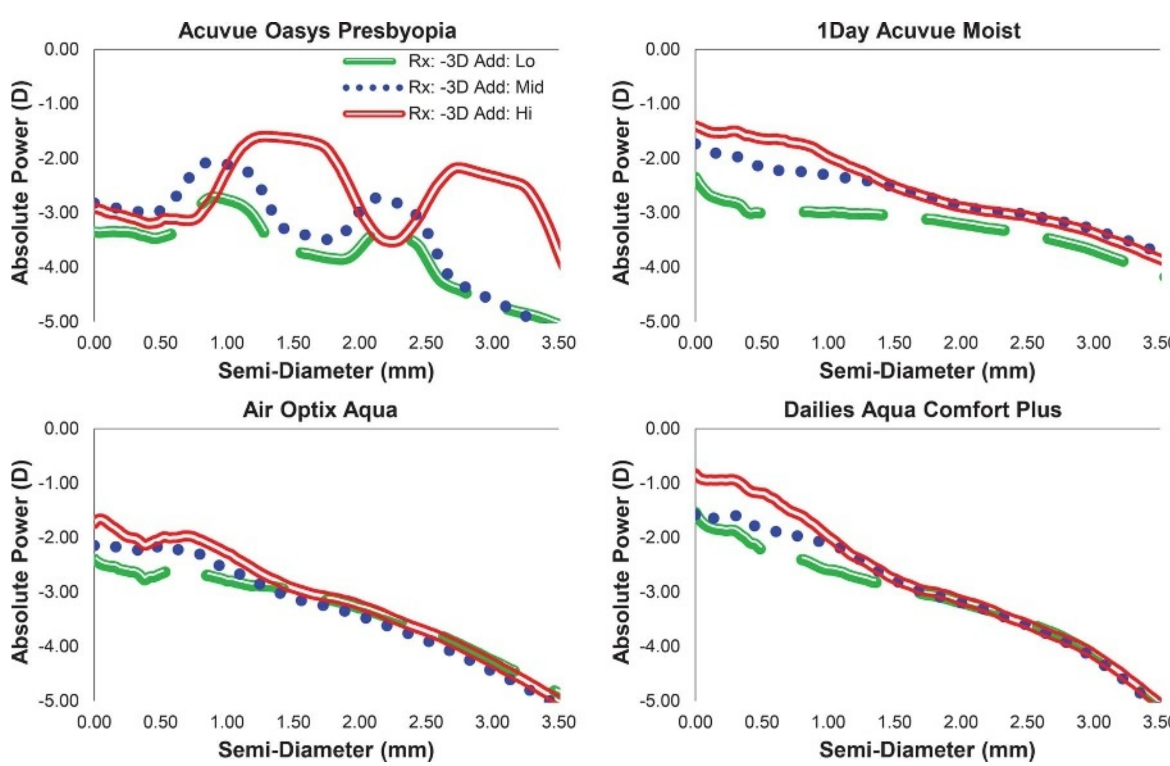

FIGURE 3.

Absolute refractive power profiles of ACUVUE OASYS for PRESBYOPIA, 1-DAY ACUVUE MOIST, AIR OPTIX AQUA, and DAILIES Aqua Comfort Plus and multifocal contact lenses—in three different addition powers.

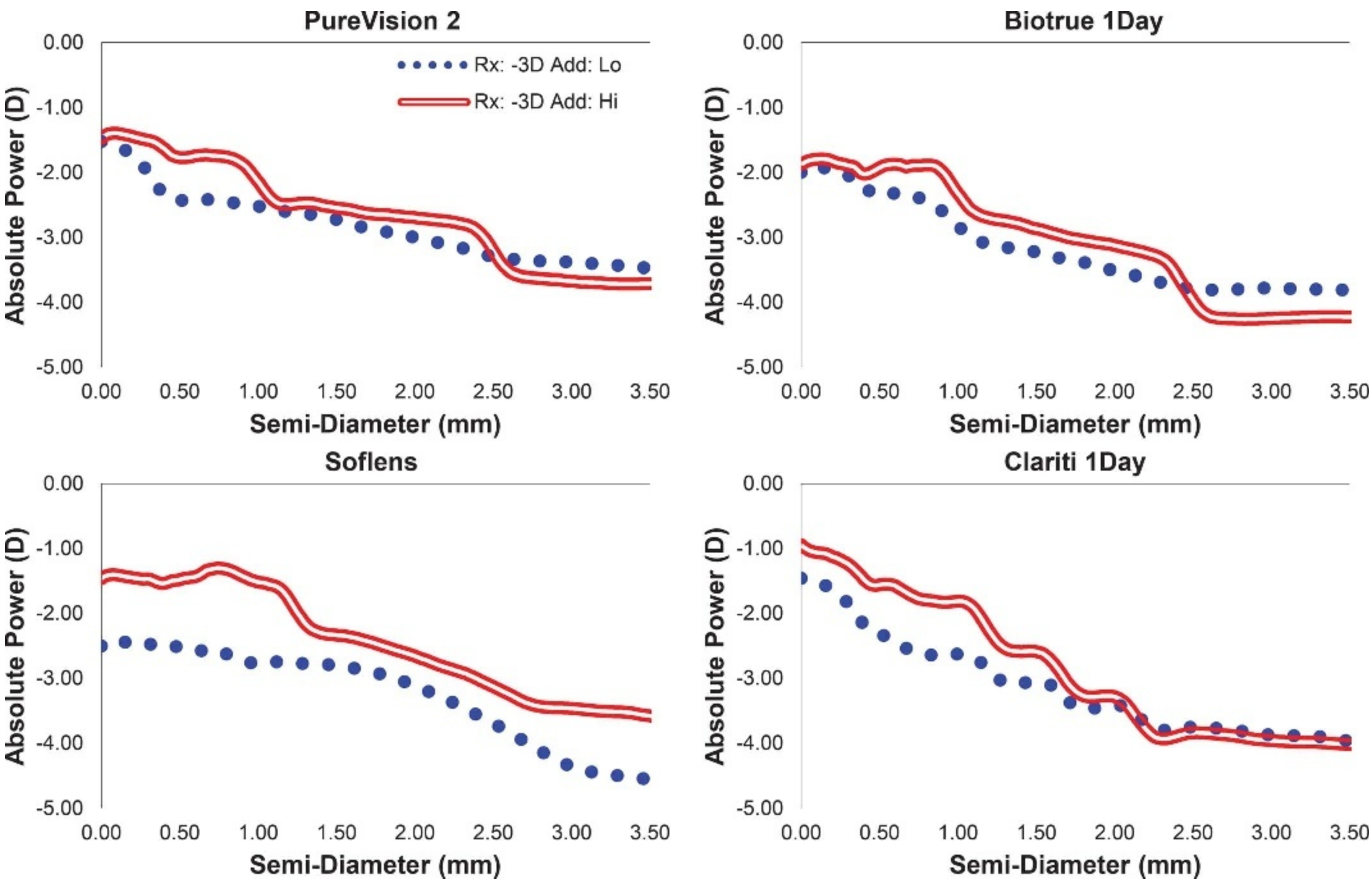

FIGURE 4.
Absolute refractive power profiles of PureVision2 for Presbyopia, SofLens, Biotrue ONEday for Presbyopia, and Clariti 1 day multifocal contact lenses—in two different addition powers.

AquaComfort Plus have a gradual change in power between near and distance zones with similar amounts of central relative plus powers and negative spherical aberration in the periphery.

PureVision2 for Presbyopia and Biotrue ONEday for Presbyopia lenses are based on a "3-Zone Progressive" design with a center-near zone, middle intermediate zone, and the outer distance zone (see Fig. 4). The Lo addition power lens shows a more gradual change between the three zones. The Hi addition power lens shows distinct stepped changes between the three zones with a central zone of increased power. Both the Hi add lenses have relative plus power of around 2.00 D, but with the intermediate zone being closer to the labeled distance power, the effective add may translate to be about +1.00 to +1.50D.

SofLens lens has a gradual power increase from the periphery to the center with the high addition lens having a noticeably increased power step in the central zone. Both PureVision2 for Presbyopia and SofLens show wide intermediate zones at 1.0 to 2.5 mm half chord and 1.4 to 2.8 mm half chord, respectively. Clariti 1 day lens has gradation zones—stepped powers in the intermediate zone starting at 1.2 to 2.4 mm half chord for both Lo and Hi addition power lenses.

The FOCUS DAILIES Progressives are available in one addition power with a large central add amplitude but less than 2 mm in diameter (see Fig. 5). There is a distinct abrupt transition between the center and the periphery zones. The Proclear 1 day lens has a smooth power profile. The nominal distance power was observed at 0.9 and 1.2 mm semi-diameter for FOCUS DAILIES Progressives and Proclear 1 day lenses, respectively.

Relative Refractive Power Profiles

The relative refractive power profiles were calculated by subtracting the label powers from their measured profiles for all the lens designs. DAILIES AquaComfort Plus and AIR OPTIX AQUA multifocal lenses showed the most negative spherical aberration in both Lo and Hi addition lenses compared to the other multifocal lenses measured in this study (see Fig. 6).

All measured lens types showed some degree of negative spherical aberration across the optic zones. They can be categorized into two distinct groups—uniform and non-uniform negative spherical aberration across the optic zones as a function of power which was subjectively categorized from the general shape of the power profile.

Uniform Spherical Aberration as a Function of Labeled Power

The lens types with uniform negative spherical aberration across the six refractive powers are shown in Fig. 7. The closeness

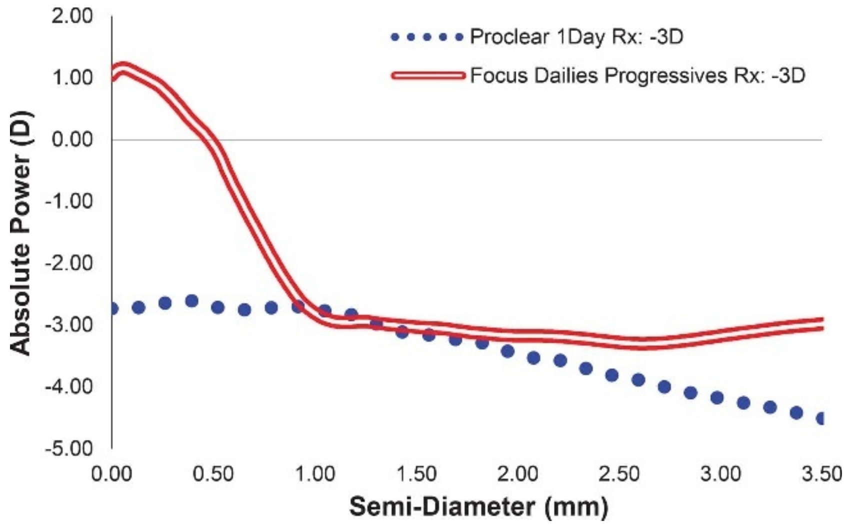

FIGURE 5.
Absolute refractive power profiles of FOCUS DAILIES Progressives and Proclear 1 day multifocal contact lenses—in single progressive addition power.

of the measured power profiles to its labeled power can be also observed for each of the measured powers for each design. In terms of absolute power targeting, the ACUVUE OASYS for PRESBYOPIA and Biotrue ONEday for Presbyopia lenses showed increasing under labeling for the higher minus powers.

Non-uniform Spherical Aberration as a Function of Labeled Power

The lens types with non-uniform negative spherical aberration across the six refractive powers are shown in Figs. 8 and 9. The high plus powers showed most positive spherical aberrations whereas the most minus powers showed most negative

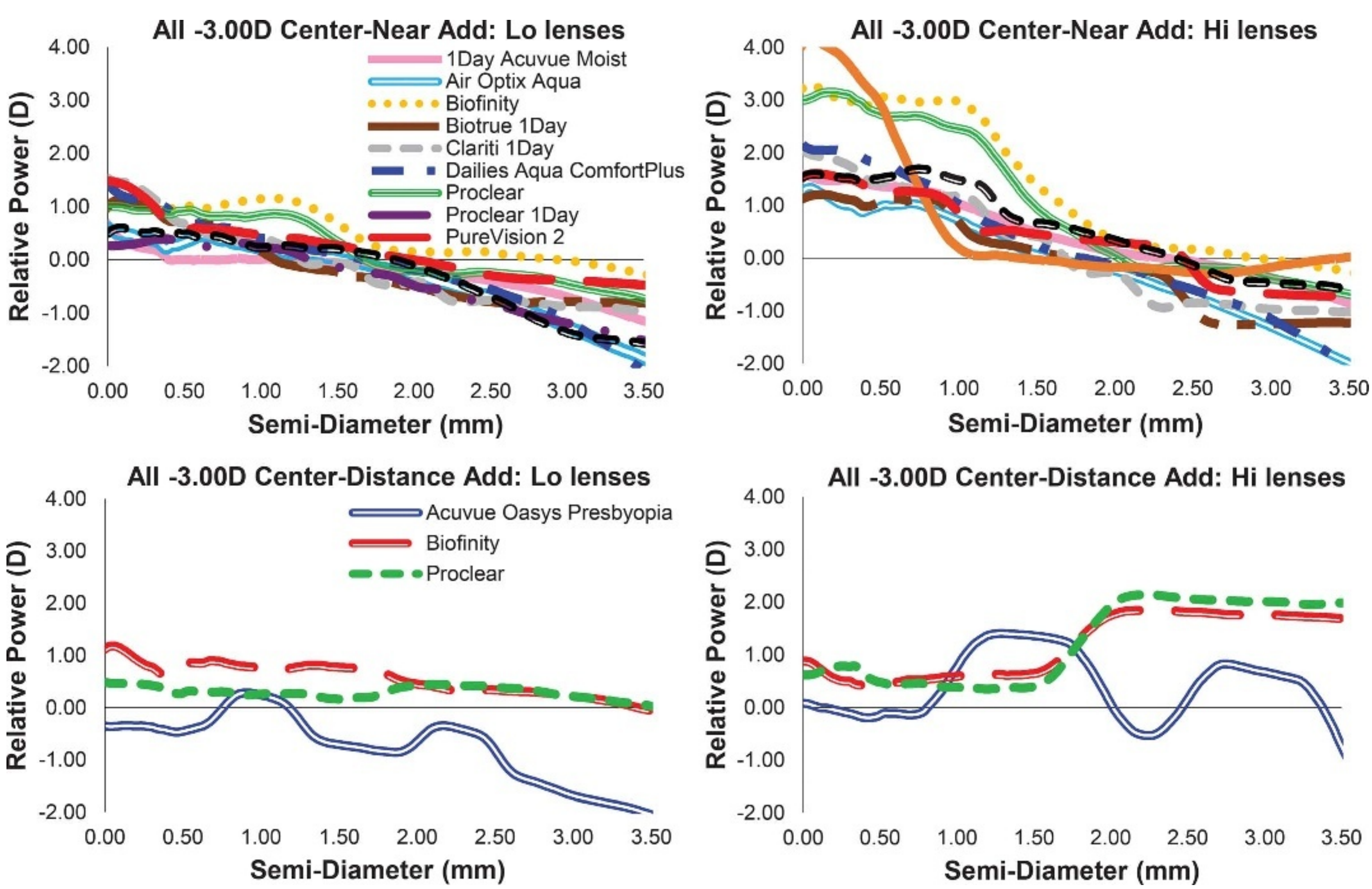

FIGURE 6.
Relative refractive power profiles of all −3.00D multifocal lenses.

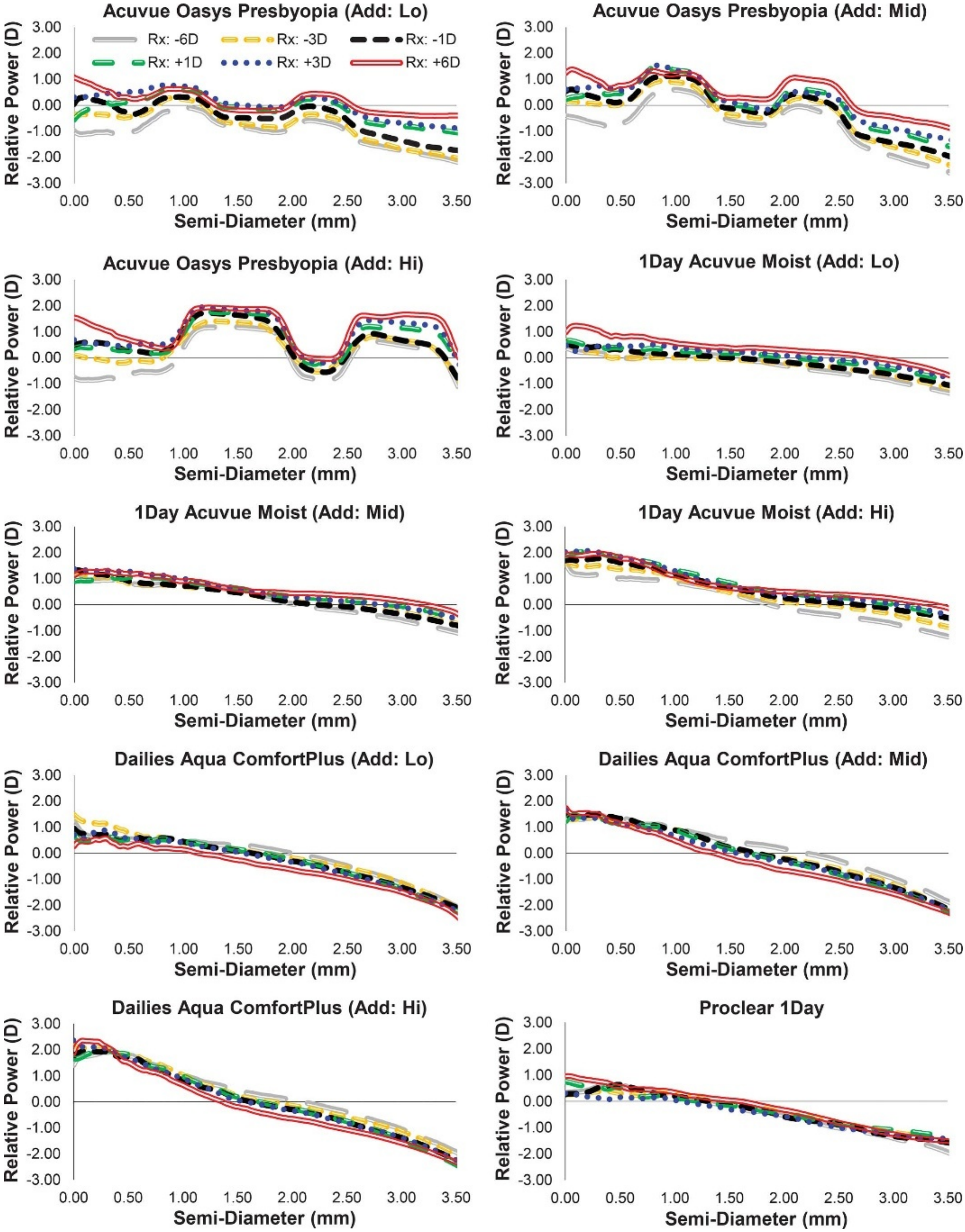

FIGURE 7.
Multifocal contact lenses where spherical aberration is uniform as a function of power.

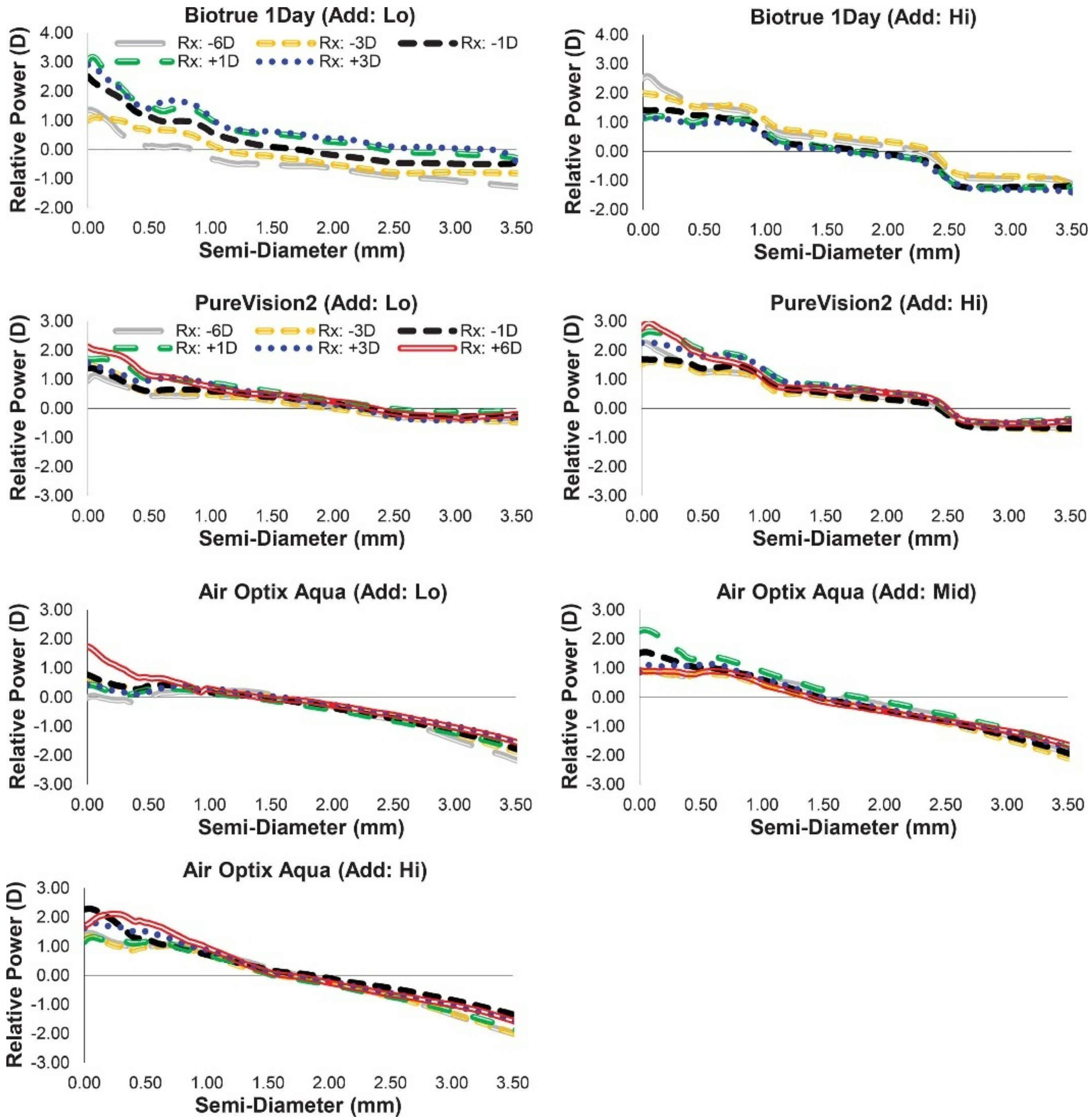

FIGURE 7 (***cont.***)
Multifocal contact lenses where spherical aberration is uniform as a function of power.

spherical aberrations. This is generally noticeable only in the peripheral optic zone beyond around 4 mm diameter. Power offset variations across the power range of more than 1.00D relative to labeled power were observed for some lens of the types.

DISCUSSION

In this study, the power profiles of the most commonly prescribed multifocal soft contact lenses across a wide range of refraction powers were analyzed using the NIMO TR1504. The NIMO TR1504 instrument has previously been reported to measure reliable power data for single vision[20,24] and multifocal[25] soft contact lenses, except for the central 0.5 mm semi-diameter. This measurement uncertainty is a common deficiency with most wave-front sensing instruments and is due to the geometrical function which produces a very large error in optical power for only minor errors in the measured angle of the refracted light close to the optical center.[9] The design features of each lens, including the center, were visualized using the CLOQA image, which indicates that there is very little power variation within the very center of any of the lenses.

The NIMO TR1504 software applies a smoothing algorithm to the raw measured data, which can distort the power profiles of lenses with rapid power changes along the optic zone diameter. To minimize this distortion, the filter settings in the data processing options were reduced from the default settings. Profile smoothing also occurs by the fact that points along the power profile are an average of all data points of the entire optic zone power map with equal distance to the presumed center of the lens. Even small decentrations can smooth out sharp transition and make the power profiles appear smoother than what they are.[17] Due care was taken to minimize this effect, while executing manual centration routines.

For each material, RIs were measured using the CLR 12-70 refractometer as the nominal RIs reported by manufacturers are in two decimal places only and lack the accuracy for measuring optical powers with the lenses immersed in saline. When applying the measured wet lens power to power in air, an error of 0.015 in the refractive index can lead to an error of more than 1.00D.[26]

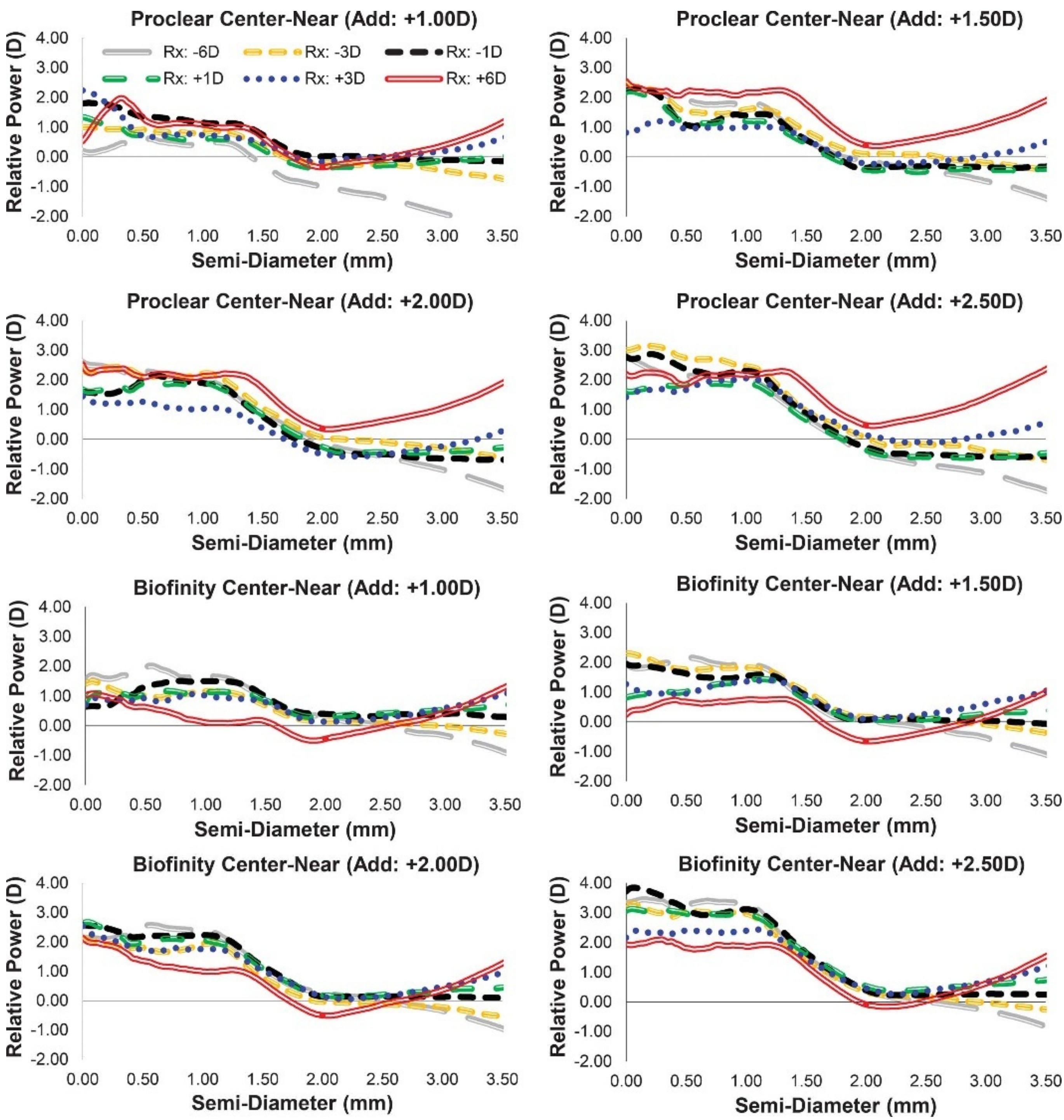

FIGURE 8.
Multifocal contact lenses where spherical aberration is not uniform as a function of power; center-near designs.

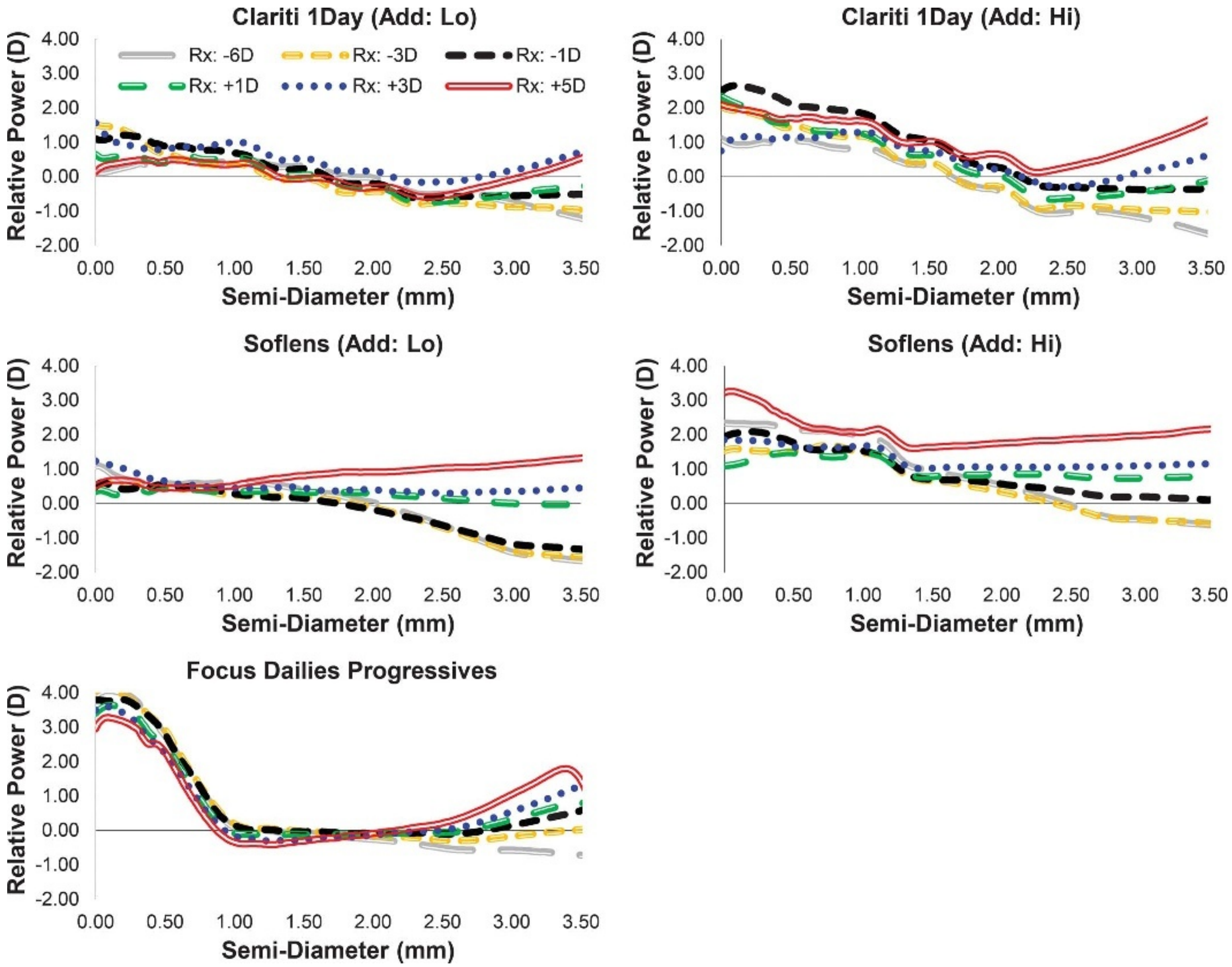

FIGURE 8 (*cont.*)

Multifocal contact lenses where spherical aberration is not uniform as a function of power; center-near designs.

Nichols et al.[27] previously investigated the reliability of the CLR 12-70 refractometer. They found excellent reliability within and between operators. They also concluded the validity between the measured against the nominal reported by the manufacturers was not statistically different from zero. In the current study, the difference between measured and nominal refractive index varied up to 0.014. This difference may in part be due to the wavelength of 546 nm used in the CLR12-70 instrument. Most manufacturers specify the refractive index of their materials at wavelength 589 nm. However, because the NIMO TR1504 instrument uses the 546 nm wavelength to measure the power, this corresponding refractive index should be used for the power conversion.

The manufacturing consistency was generally good for most lenses. This was observed by the minimal standard deviations between the three lenses measured of the same lens type and power. Through the CLOQA images, optical and/or surface defects were observed for some of the lenses measured in the current study. These defects may alter the measured power profiles and hence lenses with obvious optical defects were not included in the analysis.

Based on the power profiles, multifocal contact lenses can be grouped into three distinct categories: the most common center-near, the center-distance, and the concentric-zone ring designs. These lens types behave differently on eye in their response to changes in pupil size, which is chiefly controlled by ambient light levels. As light levels increase, the smaller pupil diameter will reduce the areas within a lens diameter that predominantly provide distance power for the center-near lens types. It can therefore be assumed that the near performance increases at the cost of reduced distance vision. The opposite effect can be expected for the center-distance lenses, where the near vision should improve for the larger pupil sizes at the cost of distance vision. However, the currently available center-distance lenses, Proclear multifocal and Biofinity multifocal, are recommended to be fitted with a corresponding center-near lens in the contralateral eye. This effectively becomes a form of modified monovision whereby one eye is providing better distance and the other eye better near vision depending on the illumination. The ACUVUE OASYS for PRESBYOPIA lens is the only one with the concentric ring patterns. This design aims to achieve pupil independent performance by alternatively including distance and near power zones with increasing pupil diameter.[9]

With presbyopia being a progressive condition in which the eye gradually loses its ability to focus up close, contact lens

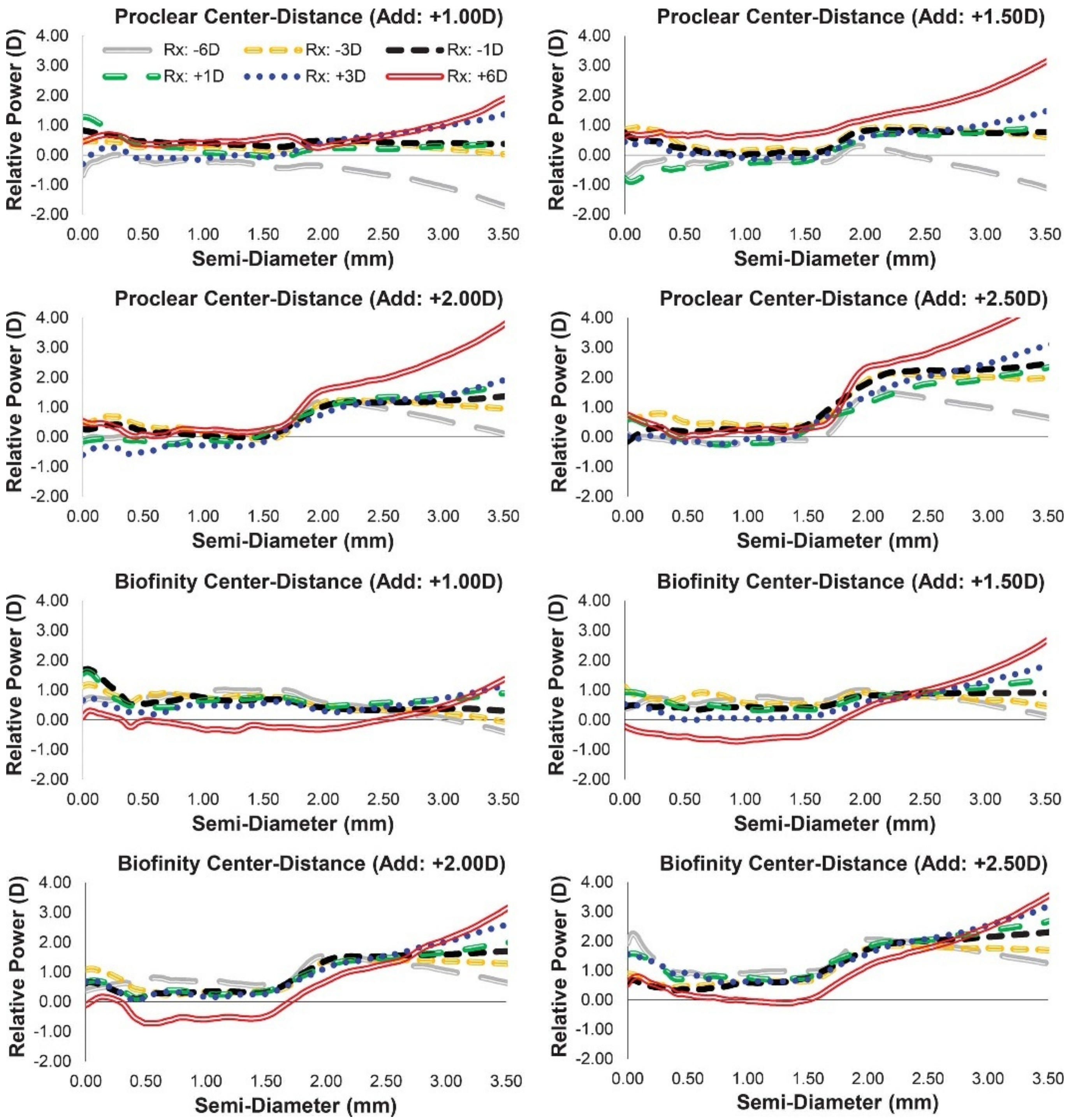

FIGURE 9.

Multifocal contact lenses where spherical aberration is not uniform as a function of power; center-distance designs.

manufacturers try to capture the full age range of presbyopes by offering a range of add powers. For any of the lens types, it is generally the case that the visual compromises increase with the add power.[8,11,13,14] For early presbyopes with considerable amount of residual accommodation, a lens with low add power will be sufficient to provide good reading performance without sacrificing distance and intermediate vision. With the exception of FOCUS DAILIES Progressives and Proclear 1 day multifocal, all other simultaneous multifocal lenses come in either 2, 3, or 4 add powers.

When the first bi- and multifocal soft contact lenses appeared on the market, the lenses were labeled with their distance and add power. In recent years, most of the newly released lenses only use descriptors like low, medium, and high add power and make reference to the equivalent spectacle add power in the fitting guide. Comparing the measured add amplitude to the corresponding recommended spectacle add power, it seems that for most lenses, the former is substantially lower than would be required to provide the full reading add. For example, add power amplitude obtained from Fig. 2 shows that for the four nominal add powers of 2.50D, 2.00D, 1.50D, and 1.00D of the center-distance Biofinity and Proclear multifocal lenses, the measured add amplitude between 1.6 and 2.1 mm semi-diameter is only 1.07D, 1.01D, 0.36D, and 0.35D, and 1.55D, 1.27D, 0.77D, and 0.26D, respectively. Similarly, the center-near types of these lenses have an add amplitude of 2.13D, 1.83D, 1.54D, and 0.97D, and 2.00D, 1.90D, 1.47D, and 1.04D, respectively, for the Biofinity and Proclear multifocal lenses, measured between 1.2 and 2.0 mm semi-diameter. This further supports the trend in marketing that primarily targets the emerging presbyopes and to provide them with good distance vision.

Although it is difficult to extract the effective distance power from the measured profiles, the relative power plots for the ACUVUE OASYS for PRESBYOPIA and the Biotrue ONEday for Presbyopia lenses show an increasing shift towards more positive powers of up to 1.00D across the power range from −6.00D to +6.00D. Without careful over-refraction by eye care practitioners, these lenses may not be prescribed properly. Some of these apparent differences between the measured and labeled power could possibly be due to the different solutions, measurement techniques, and methods used by the respective manufacturers to assign label powers. Unfortunately, ISO 18369-3[22] does not provide clear guidelines on how multifocal soft contact lenses are to be measured and labeled. In this study, our aim was to provide practitioners with information that closely relates to on-eye conditions, which is most accurately achieved using phosphate buffered saline as the standard measurement medium.

With respect to profile consistency across the power range, all the lenses showed some degree of spherical aberration across the optic zones with two apparent patterns. Although the DAILIES AquaComfort Plus, AIR OPTIX AQUA, PureVision2 for Presbyopia, Biotrue ONEday for Presbyopia, Proclear 1 day, and both of the ACUVUE lenses maintain almost identical profile across all their plus and minus lenses, all of the Proclear and Biofinity and the SofLens, Clariti 1 day, and FOCUS DAILIES Progressives multifocal lenses have variable amounts of spherical aberrations depending on their distance power. Generally, these lenses have increased negative spherical aberration for the higher minus powers and an increase in positive spherical aberration for the plus powers. These aberration patterns may be a remnant of the times when only spherical curvatures were used to generate contact lens surface, or they may be a deliberate manipulation to enhance visual performance for myopes and hyperopes, which on average have different inherent spherical aberrations.[8,11,12]

The benefits of abrupt, smooth, or stair-cased transition between the power zones of a bi- or multifocal contact lens has been an ongoing investigation for more than a decade with no leading design emerging. This is reflected in the different approaches manufacturers have considered when designing the optics of the transition zones. By the nature of their design, the ACUVUE OASYS for PRESBYOPIA ring design has large abrupt steps with sharp transition zones, which could be responsible for the often reported significant levels of ghosting associated with these lenses.[28] The two steps in the power profiles of the PureVision2 for Presbyopia and Biotrue ONEday for Presbyopia lenses form three distinct power rings, effectively creating a trifocal lens design. The plateaus between the stair-cased reduction of power in the Clariti 1 day lenses are probably too narrow to provide any functional focusing. It seems more likely that these steps were added to reduce the rapid change in power across the optic diameter, which may precipitate to ghosting symptoms, although the actual clinical performance of this particular design feature still remains to be independently validated. The opposite approach can be observed in power profiles like the 1-DAY ACUVUE MOIST or the DAILIES AquaComfort Plus lenses. Even the high add power profiles of these lenses show hardly any distinct transition point between the near and distance powers within the optical zone.

In terms of generational changes, manufacturers seem to have reduced the effective add power of their more recently released multifocal lenses. For example, the relative plus power for the −3.00D PureVision Hi add multifocal lens measured approximately 2.50D (unpublished data, previously measured with the same instrument and methods), which reduced to 2.00D for the PureVision2 lens. The same trend was also seen with the ACUVUE lenses where the relative plus for the −3.00D ACUVUE Bifocal Hi add multifocal lens measured 3.00D (unpublished data, previously measured with the same instrument and methods), which dropped to 1.70D for the ACUVUE OASYS for PRESBYOPIA and further dropped to 1.35D for the 1-DAY ACUVUE MOIST multifocal.

Power profiles can vary widely between the different lens types; however, certain similarities were also observed between some of the center-near designs. For the more recently released lens types, there seems to be a trend emerging to reduce the add amplitude, include negative spherical aberration, to keep the power profiles consistent across the power range, and to offer lenses in at least three add powers and a daily disposable wearing mode.

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REFERENCES

1. Holden BA, Fricke TR, Ho SM, et al. Global vision impairment due to uncorrected presbyopia. Arch Ophthalmol 2008;126:1731–9.
2. Morgan PB, Efron N, Helland M, et al. Demographics of international contact lens prescribing. Cont Lens Anterior Eye 2010; 33:27–9.
3. Efron N, Morgan PB, Woods CA; International Contact Lens Prescribing Survey Consortium. An international survey of daily disposable contact lens prescribing. Clin Exp Optom 2013;96:58–64.
4. Efron N, Nichols JJ, Woods CA, et al. Trends in US Contact Lens Prescribing 2002 to 2014. Optom Vis Sci 2015;92:758–67.
5. Akerman DH. 40 is the New 20/20—presbyopia equals opportunity. Contact Lens Spectrum 2010;25:3. Available at: http://www.clspectrum.com/articleviewer.aspx?articleID=103978. Accessed: July 15, 2016.

6. Vasudevan B, Flores M, Gaib S. Objective and subjective visual performance of multifocal contact lenses: pilot study. Cont Lens Anterior Eye 2014;37:168–74.
7. Llorente-Guillemot A, Garcia-Lazaro S, Ferrer-Blasco T, et al. Visual performance with simultaneous vision multifocal contact lenses. Clin Exp Optom 2012;95:54–9.
8. Bakaraju RC, Ehrmann K, Ho A, et al. Inherent ocular spherical aberration and multifocal contact lens optical performance. Optom Vis Sci 2010;87:1009–22.
9. Plainis S, Atchison DA, Charman WN. Power profiles of multifocal contact lenses and their interpretation. Optom Vis Sci 2013;90:1066–77.
10. Plakitsi A, Neil Charman W. On the reliability of focimeter measurements of simultaneous-vision varifocal contact lenses. J Brit Contact Lens Assoc 1992;15:115–24.
11. Plakitsi A, Charman WN. Comparison of the depths of focus with the naked eye and with three types of presbyopic contact lens correction. J Brit Contact Lens Assoc 1995;18:119–25.
12. Plainis S, Ntzilepis G, Atchison DA, et al. Through-focus performance with multifocal contact lenses: effect of binocularity, pupil diameter and inherent ocular aberrations. Ophthalmic Physiol Opt 2013;33:42–50.
13. Bakaraju RC, Ehrmann K, Falk D, et al. Optical performance of multifocal soft contact lenses via a single-pass method. Optom Vis Sci 2012;89:1107–18.
14. Charman WN, Saunders B. Theoretical and practical factors influencing the optical performance of contact lenses for the presbyope. J Brit Contact Lens Assoc 1990;13:67–75.
15. Wagner S, Conrad F, Bakaraju RC, et al. Power profiles of single vision and multifocal soft contact lenses. Cont Lens Anterior Eye 2015;38:2–14.
16. Joannes L, Dubois F, Legros JC. Phase-shifting schlieren: high-resolution quantitative schlieren that uses the phase-shifting technique principle. Appl Opt 2003;42:5046–53.
17. Kim E, Bakaraju RC, Ehrmann K. Reliability of power profiles measured on NIMO TR1504 (Lambda-X) and effects of lens decentration for single vision, bifocal and multifocal contact lenses. J Optom 2016;9:126–36.
18. Madrid-Costa D, Ruiz-Alcocer J, Garcia-Lazaro S, et al. Optical power distribution of refractive and aspheric multifocal contact lenses: effect of pupil size. Cont Lens Anterior Eye 2015;38:317–21.
19. Montes-Mico R, Madrid-Costa D, Dominguez-Vicent A, et al. In vitro power profiles of multifocal simultaneous vision contact lenses. Cont Lens Anterior Eye 2014;37:162–7.
20. Belda-Salmeron L, Madrid-Costa D, Ferrer-Blasco T, et al. In vitro power profiles of daily disposable contact lenses. Cont Lens Anterior Eye 2013;36:247–52.
21. Ho A, Ehrmann K. Knife-edge system for evaluating contact lenses. In: BiOS 2000: The International Symposium on Biomedical Optics. International Society for Optics and Photonics. Bellevue, WA: SPIE 2000:102–7.
22. International Organisation for Standardization (ISO). Ophthalmic Optics—Contact Lenses—Part 3: Measurement Methods: ISO 18369-3:2006. Geneva, Switzerland: ISO; 2006.
23. International Organisation for Standardization (ISO). Ophthalmic Optics—Contact Lenses—Part 4: Physiochemical Properties of Contact Lens Materials: ISO 18369-4:2006. Geneva, Switzerland: ISO; 2006.
24. Joannes L, Hough T, Hutsebaut X, et al. The reproducibility of a new power mapping instrument based on the phase shifting schlieren method for the measurement of spherical and toric contact lenses. Cont Lens Anterior Eye 2010;33:3–8.
25. Domínguez-Vicent A, Marín-Franch I, Esteve-Taboada JJ, et al. Repeatability of in vitro power profile measurements for multifocal contact lenses. Cont Lens Anterior Eye 2015;38:168–72.
26. Campbell CE. Converting wet cell measured soft lens power to vertex power in air. Int Contact Lens Clin 1984;11(3):168–71.
27. Nichols JJ, Berntsen DA. The assessment of automated measures of hydrogel contact lens refractive index. Ophthalmic and Physiol Opt 2003;23:517–25.
28. Sha J, Bakaraju R, Tilia D, et al. Short-term visual performance of soft multifocal contact lenses for presbyopia. Arq Bras Oftalmol 2016;79(2):73–7.

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