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ORIGINAL ARTICLE

Reliability of power profiles measured on NIMO TR1504 (Lambda-X) and effects of lens decentration for single vision, bifocal and multifocal contact lenses

Eon Kim[a,*], **Ravi C. Bakaraju**[a], **Klaus Ehrmann**[a,b,c]

[a] *Brien Holden Vision Institute, Sydney, Australia*
[b] *Vision CRC, Sydney, Australia*
[c] *School of Optometry and Vision Science, University of New South Wales, Sydney, Australia*

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Abstract
Purpose: To evaluate the repeatability of power profiles measured on NIMO TR1504 (Lambda-X, Belgium) and investigate the effects of lens decentration on the power profiles for single vision (SV), bifocal (BF) and multifocal (MF) contact lenses.
Methods: Accuracy of the sphere power was evaluated using single vision BK-7 calibration glass lenses of six minus and six plus powers. Three SV and four BF/MF contact lenses – three lenses each, were measured five times to calculate the coefficients of repeatability (COR) of the instrument. The COR was computed for each chord position, lens design, prescription power and operator. One lens from each type was measured with a deliberate decentration up to ±0.5 mm in 0.1 mm steps.
Results: For all lenses, the COR varied across different regions of the half-chord position. In general, SV lenses showed lower COR compared to the BF/MF group lenses. There were no noticeable trends of COR between prescription powers for SV and BF/MF lenses. The shape of the power profiles was not affected when lenses were deliberately decentered for all SV and PureVision MF lenses. However, for Acuvue BF lenses, the peak to trough amplitude of the power profiles flattened up to 1.00 D.
Conclusion: The COR across the half-chord of the optic zone diameter was mostly within clinical relevance except for the central 0.5 mm half-chord position. COR were dependent on the lens type, whereby BF/MF group produced higher COR than SV lenses. The effects of deliberate decentration on the shape of power profiles were pronounced for lenses where the profiles had sharp transitions of power.

* Corresponding author at: Level 5, North Wing, Rupert Myers Building, Gate 14, Barker Street, University of New South Wales, Sydney, NSW 2052, Australia.
E-mail address: e.kim@brienholdenvision.org (E. Kim) .

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PALABRAS CLAVE
NIMO;
Perfil de potencia;
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Lentes de contacto;
Multifocales;
Monofocales

Fiabilidad de los perfiles de potencia medidos con NIMO TR1504 (Lambda-X), y efectos del descentramiento de las lentes monofocales, bifocales y multifocales

Resumen
Objetivo: Evaluar la repetibilidad de los perfiles de potencia medidos con NIMO TR1504 (Lambda-X, Bélgica) e investigar los efectos del descentramiento de las lentes sobre los perfiles de potencia de las lentes de contacto monofocales (SV) bifocales (BF) y multifocales (MF).
Métodos: Se evaluó la exactitud de la medida de la potencia esférica utilizando lentes de vidrio monofocales de calibración BK-7, con lentes de seis potencias positivas y seis potencias negativas. Se realizaron cinco mediciones en tres muestras de cada una de las tres lentes monofocales y cuatro lentes bifocales/multifocales diferentes, para calcular los coeficientes de repetibilidad (COR) del instrumento. Se calculó el COR para cada posición de la cuerda, diseño de la lente, prescripción de potencia, y operador. Se midió una lente de cada tipo con un descentramiento deliberada de hasta ±0,5 mm, en intervalos de 0,1 mm.
Resultados: Para todas las lentes, el COR reflejó variaciones en las diferentes regiones de la posición de media cuerda. En general, las lentes monofocales reflejaron un COR menor en comparación a las lentes del grupo BF/MF. No se produjeron variaciones notorias del COR entre las prescripciones de potencia de las lentes monofocales y bifocales/multifocales. La forma de los perfiles de potencia no se vio afectada al descentrar deliberadamente todas las lentes monofocales y PureVision MF. Sin embargo, para lentes Acuvue BF, la amplitud entre el punto más alto y el más bajo de los perfiles de potencia reflejó un aplanamiento de hasta 1,00 D.
Conclusión: El COR a lo largo de la cuerda media del diámetro de la zona óptica se mostró dentro de la relevancia clínica, excepto en la posición central de la cuerda media de 0,5 mm. Los COR dependieron del tipo de lente, reflejando el grupo de lentes bifocales/multifocales un COR superior al de las lentes monofocales. Los efectos del descentramiento deliberado en la forma de los perfiles de potencia fueron significativos en aquellas lentes en las que dichos perfiles tenían unas transiciones de potencia más abruptas.

Introduction

It is of interest to researchers, clinicians and manufacturers to reliably measure the optical power and power profiles of soft contact lenses. Such evaluation can be used to assess manufacturing consistency and provides visual information about optical design such as the spherical or aspherical nature of the lens as well as correlating design features of the lens with visual performance. Power profiles can also give insights about the distribution and magnitude of add power in multifocal lenses.

Traditional methods of measuring the lens power as specified in ISO 18369-3[1] use the focimeter,[2] the Moiré deflectometer[3] and the Hartmann–Shack[4] method. While the focimeter measures lenses in air, the other two methods measure lenses in a cuvette to maintain their hydrated state. Since the publication of this standard, several methods and instruments have become available to measure the optical power and profiles of contact lenses. The SHSOphthalmic (Optocraft GmbH, Erlangen, Germany) instrument, based on the Hartmann–Shack principle, calculates the power maps and optical profiles by passing a collimated light beam through the test lens. 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 CCD sensor, from which the wave-front distortions are determined and converted into power profiles. Wagner et al.[5] investigated the repeatability of the power profiles for various commercial soft lenses using this instrument. They found the repeatability acceptable, but variation increased noticeably within the central 0.5 mm of the half chord. The Phase Focus Lens Profiler (Phase Focus Ltd., Sheffield, UK) uses ptychographic imaging technique in which the diffraction patterns from neighboring points on the lens are used to reconstruct the thickness profile, and power profiles are then computed from the obtained thickness differentials. Plainis et al.[6] published power profiles of multifocal contact lenses using this instrument and interpreted how the optical designs relate to visual performance. They also found the reproducibility in general is good ≤0.05 D, except close to the lens center.

The NIMO TR1504 (Lambda-X, Nivelles, Belgium) is a relatively new instrument 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.[7] 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 power profiles of daily disposable and multifocal simultaneous contact lenses have been evaluated previously using this instrument.[8,9] Belda-Salmeron et al.[8] have evaluated the power profiles of daily disposable and multifocal simultaneous contact lenses respectively using this instrument. They showed a gradual increase in the lens power from the center to the periphery of the optical zone and found that for larger pupil sizes, the effective on-eye power increased. They also found that induced lens decentration produced a shift in the power profiles toward the negative direction. Montes-Mico et al.[9] used the NIMO TR1504 instrument to investigate the power profiles of multifocal contact lenses. They addressed the relationship between the pupil diameter and the power profile of multifocal lenses and how this relationship crucially impacts the distance correction and the near add.

The reproducibility of NIMO TR1504 instrument has been reported by Joannes et al.[10] for the spherical and toric contact lenses. They have concluded that single measurements are sufficient to determine the sphere power to current ISO tolerance limits with 95% confidence with reproducibility standard deviations of 0.05 D. Domínguez-Vicent et al.[11] recently reported the repeatability of lower than 0.12 D for multifocal contact lenses using NIMO TR1504.

The purpose of the present study was to expand previously reported evaluations of the repeatability of the NIMO TR1504 instrument with respect to back vertex power and power profiles of various commercially available single vision (SV), bifocal (BF) and multifocal (MF) contact lenses. This included measuring different prescription powers and operators which were not previously reported. The accuracy of the sphere power measurements was also investigated using BK-7 calibration glass lenses. As the lateral alignment of the lens measured with the NIMO TR1504 affects the accuracy of the power profiles, the effect of lens decentration was also evaluated in this study by deliberately decentering the lens by defined amounts.

Materials and methods

Contact lenses

Seven types of commercially available soft contact lenses from various manufacturers were classified into three groups: SV, BF/MF Low (add power +1.50 D) and BF/MF High (add power +2.50 D). Prescription powers of high minus (−6.00 D) and low minus (−1.00 D or −0.75 D) were selected from all lens designs. Usage frequency of positive contact lens prescriptions is in general lower than the minus prescriptions. Hence, our interest was centered on the later. To serve the +1.00 prescription power, one lens type per group was randomly selected (see Table 1). PureVision MF is a center-near aspheric design, whereas Acuvue BF is a concentric bifocal design with five alternating distance and near ring zones, starting out with the center distance zone.

All lenses were removed from their blister packs and soaked in standard phosphate buffered solution (PBS)[1] with a refractive index of 1.334 for 24 h before measuring.

NIMO TR1504

The NIMO TR1504 (Lambda-X, Belgium) is a high resolution power mapping instrument to measure and calculate the power characteristics of contact lenses (see Fig. 1). It uses a combination of phase-shifting and Schlieren techniques to measure the wave-front distortions of a collimated, green (546 nm) light beam passing through the test lens, from which effective optical power and power maps can be extracted. A high resolution CCD camera captures the Schlieren fringes generated by the laterally movable Schlieren filter. The NIMO TR1504 uses customized software to fit Zernike polynomials (36 Zernike coefficients) to the wave-front and to determine higher and lower order aberrations. The accuracy and reproducibility of the instrument, as stated by Lambda-X, is better than 0.05 D for sphere power of rotationally symmetric soft contact lenses.[10]

All measurements were performed using the quartz cuvette provided by Lambda-X, which is claimed to be aberration free. The lenses were centered manually by aligning within the diameter circle on the alignment camera image. Two of 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, to enhance the ability to resolve sharp transitions within the power profiles. These filter settings are applied in the central part of the map, where interpolations are performed to smooth out the radial power.

Instrument accuracy

According to the ISO 5725-1[12] accuracy refers to the closeness of agreement between the measurement results and the true reference value. The accuracy of the instrument was tested using single vision BK-7 calibration glass lenses (Optocraft GmbH, Germany) of six minus (plano-concave) and six plus (plano-convex) powers. These lenses claim precision of within 0.002 D mean power and are certified for their back vertex power in accordance with ISO 18369-3.[1] As the NIMO TR1504 instrument measures effective focal power, the back vertex power (BVP) values were converted to effective focal power (EFP) for direct comparison by measuring the center thickness using Model ET-3 (Electronic Thickness Gauge, Rehder Development Co., IN, USA) of each of the BK-7 calibration glass lenses and applying the thick lens formula:

$$\mathrm{EFP} = \frac{1}{(1/\mathrm{BVP}) + (\mathrm{CT}/n_L)}$$

where EFP = effective focal power, BVP = back vertex power. CT = center thickness, n_L = refractive index of BK-7 calibration glass lens.

Center thickness was measured with an accuracy of ±2 μm. The refractive index of the BK-7 calibration glass lens is n_L = 1.5187. Five measurements were performed consecutively for each lens with removal of the lens between each repeat measurement. The '*Single Vision*' measurement setting was selected with the optical zone diameter set to 3 mm and lens total diameter to 12.5 mm. BK-7 calibration glass lenses were measured in air and the 'wet to dry' conversion option was unselected.

Instrument repeatability (COR)

According to the ISO 5725-1,[12] repeatability refers to the closeness of agreement between repeated test results of the

Table 1 List of commercially available soft contact lenses used in this study.

Group	Lens name	Power (D)	Manufacturer	Material/refractive index
SV	Acuvue Advance with HYDRACLEAR	−6.00 −0.75 +1.00	Johnson & Johnson (New Brunswick, NJ, USA)	Galyfilcon A/1.41
SV	Clariti 1 day	−6.00 −1.00	Sauflon (Twickenham, UK)	Somofilcon A/1.40
SV	Focus Night & Day	−6.00 −1.00	Ciba Vision (Duluth, GA, USA)	Lotrafilcon A/1.43
BF Low	Acuvue BF Low Add	−6.00 −1.00 +1.00	Johnson & Johnson (New Brunswick, NJ, USA)	Etafilcon A/1.40
BF High	Acuvue BF High Add	−6.00 −1.00	Johnson & Johnson (New Brunswick, NJ, USA)	Etafilcon A/1.40
BF Low	PureVision MF Low Add	−6.00 −1.00	Bausch & Lomb (Rochester, NY, USA)	Balafilcon A/1.43
BF High	PureVision MF High Add	−6.00 −1.00 +1.00	Bausch & Lomb (Rochester, NY, USA)	Balafilcon A/1.43

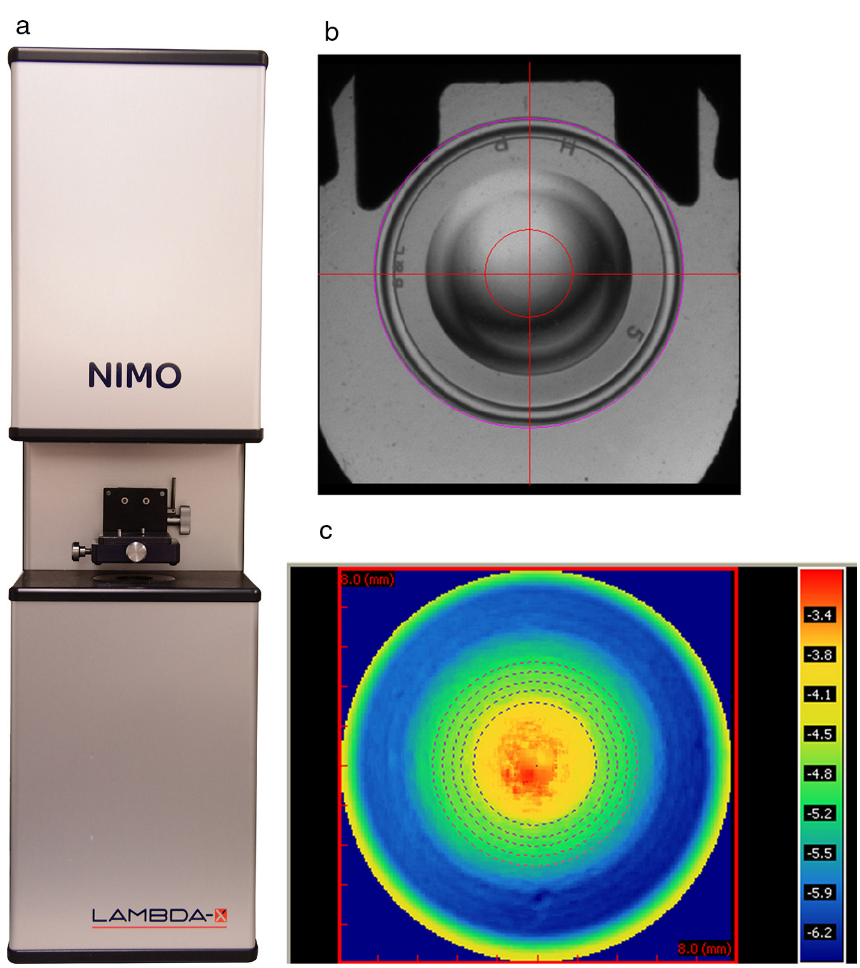

Figure 1 (a) The front view of the NIMO TR1504 instrument (top-left); (b) software captured high resolution image showing the Schlieren fringes and superimposed lens diameter to assist with lens centration (top-right); and (c) a sample output of the color-coded radial power map (bottom).

same sample. Repeatability of the instrument was assessed using different types of lenses including SV, BF and MF lenses. The averaged radial power profiles were measured across 8 mm optic zone diameter using the '*Multifocal*' measurement setting and corresponding refractive indices of the materials as supplied by the manufacturer. Three lenses from each lens design were measured five times to calculate the COR of the instrument. All profiles were plotted and normalized at 0.1 mm half chord intervals and COR at each position across the half chord was calculated.

All measurements were repeated by a second operator to determine if the results show operator dependency. The measurements were performed on different days using the same NIMO TR1504 instrument in a similar environment of room temperature 23 °C and humidity 65%. The same lenses were measured using the same cuvette and phosphate buffered solution (PBS).

Lens decentration

We aimed to investigate two different effects in the decentration aspect of the experiment, one is to see if there is a change in the actual shape of the power profiles with lens decentration and the other is to evaluate if there is a change in the resultant spherical power of the decentered lens (as a numerical result).

For the former, measurements performed in a '*Multifocal*' setting mode facilitated the averaged radial power profiles measured across 8 mm optic zone diameter. These data were used for comparison of the power profiles. The power profile from one lens of each design (PureVision MF High and Low Add, Acuvue Bifocal High and Low add, Clariti 1-Day SV, Acuvue Advance SV and Focus N&D SV) in −6.00 D power were measured once by one operator, while the lens was centered then deliberately decentered in 0.1 mm steps up to ±0.5 mm (see Fig. 2). Decentration was achieved using an option in the analysis software that allows the lateral shifting of the image by fixed amounts.

For the second objective, measurements were performed in '*Single Vision*' setting mode across 6.00 mm optic zone, where the average sphere powers displayed on the NIMO GUI were noted. The effect of lens decentration was quantified by the change in sphere power reading at each position. One lens each (−6.00 D) from all the SV-Acuvue Advance, Clariti 1-Day, Focus N&D; PureVision MF High Add and Low Add lenses were measured five times, by one operator.

Statistical analysis

The COR was computed according to the Bland and Altman[13] limits of agreement (LoA), as the within lens standard deviation (SD) due to repeat measurements multiplied by 1.96.

Within each operator, lens design, add power, prescription power and half chord position, the within lens SD was estimated using analysis of variance. The factors included in the general linear model were the lens number. The mean error sum of squares from this model was used to estimate the within lens SD and their COR at each half chord position, for a given operator, lens design, prescription power and add power. This was then plotted across the chord positions.

In order to obtain an overall COR, The half chord positions were divided into two segments based on the observed data: half chord position ≤0.5 mm and half chord position between 0.51 mm and 3.20 mm. Within these two half chord position groups, the within lens SD was estimated using analysis of variance for each lens design, add power and prescription power. The factors included in the general linear model were the interaction of lens number, half chord position and operator. The mean error sum of squares from this model was used to estimate the combined within lens SD for each lens design and their COR within each segment according to prescription power and add power.

Repeated measures one-way analysis of variance (ANOVA) using Dunnett's multiple comparison test was applied to determine if the changes in sphere power readings between centered and at decentered positions are statistically significant.

Results

Instrument accuracy

Measured center thickness values of the BK-7 calibration glass lenses are shown in Table 2 with the corresponding converted effective focal power (EFP) values. The mean of five repeated measurements of the EFP measured on NIMO was within ±0.05 D of the EFP nominal converted from BVP.

Instrument repeatability

The COR across the lens half chord for each lens design are plotted separately for the two operators (see Figs. 3 and 4). Generally, SV lenses showed lower COR across the half chord compared to the BF/MF lenses for all prescription powers. Higher CORs were calculated for the Acuvue BF lenses compared to other designs reaching up to 0.80 D within the center and 0.50 D across the rest of the half chord. For the −6.00 D lenses, the COR also reached over 0.80 D near the optic zone diameter at around 6.8 mm, however this region is of no significance and likely to be caused by the blending with the peripheral zone. There were no noticeable difference between the COR calculated for the two operators for all lens designs except for Acuvue BF High Add −6.00 D lens, PureVision High Add −1.00 D lens and Acuvue Advance −6.00 D lens.

The overall COR are plotted separately in Fig. 5 for each prescription power at two different half chord segments which factored the two operators into the calculation. The overall COR across the half chord position 0.51–3.20 mm segments were lowest for all lens designs and all prescription powers which fall within the clinical relevance, compared to COR across half chord position ≤0.50 mm. The Acuvue BF lenses had the highest COR of 0.27 D for High Add and 0.15 D for Low Add lenses. There was no noticeable difference between the prescription powers within each lens design across the half chord position 0.51–3.20 mm segments.

Lens decentration

The power profiles of the Acuvue BF lenses where affected most noticeably when lenses were measured in decentered positions. The amplitude of the power steps decreased and

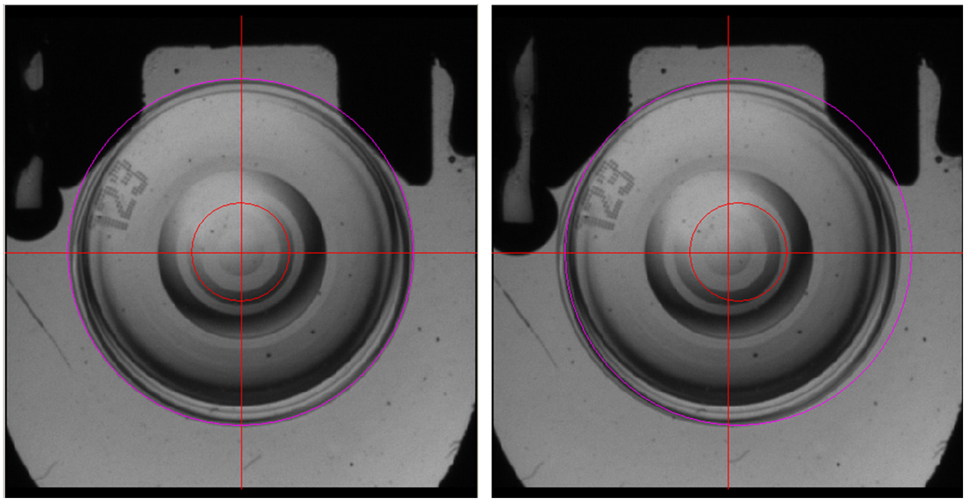

Figure 2 Example of Acuvue BF lens when well aligned (left) and the same lens when deliberately decentered by +0.5 mm (right).

Table 2 The nominal and the mean ± std dev of five repeated EFP measurements on NIMO of the BK-7 calibration glass lenses.

BK-7 calibration glass lens	Nominal BVP as certified (D)	CT (mm)	Converted nominal EFP (D)	Measured EFP on NIMO (D)	Difference (D) (measured − nominal)
Plus lenses	2.000	3.049	1.99	1.96 ± 0.00	−0.03
	4.038	3.069	4.01	3.99 ± 0.01	−0.01
	5.088	2.906	5.04	5.03 ± 0.01	−0.01
	10.306	2.996	10.10	10.10 ± 0.00	0.00
	14.268	2.386	13.96	13.94 ± 0.00	−0.02
	20.759	3.056	19.93	19.92 ± 0.00	−0.01
Minus lenses	−19.607	1.545	−20.01	−19.99 ± 0.00	0.02
	−15.706	2.069	−16.05	−16.01 ± 0.00	0.04
	−10.022	1.512	−10.12	−10.15 ± 0.00	−0.03
	−4.993	1.470	−5.02	−5.05 ± 0.00	−0.03
	−3.971	2.106	−3.99	−4.01 ± 0.00	−0.02
	−1.992	1.487	−2.00	−2.00 ± 0.00	0.00

the profiles flattened as the lenses were deliberately decentered (see Figs. 6 and 7). The power transition in the PureVision MF High Add lenses also flattened. No noticeable difference in the power profile shape for the SV and PureVision MF Low Add lenses was observed when they were deliberately decentered.

The changes in sphere power with decentration were quantified for all SV and PureVision MF (High Add and Low Add) lenses. Except for the SV-Focus N&D lenses, the sphere power reached statistical significance (p-value < 0.05) when the lenses were decentered by more than ±0.3 mm (see Fig. 8).

Discussion

In this study, we evaluated the reliability of NIMO TR1504 instrument to measure sphere power and power profiles. It was found to be accurate for measuring sphere power of single vision lenses. Accuracy of sphere power readings was tested using BK-7 calibration glass lenses. Although, these measurements produced results within ±0.05 D of the nominal BVP, these measurements were performed in air. By measuring lenses in air, the sensitivity of the power measurements is greatly improved, by up to five times depending on the lens material. It also removes the uncertainties associated with the use of inaccurate refractive indices of lens materials or saline solutions. For example, using the saline to air conversion factor $(N_{lens} - 1)/(N_{lens} - N_{saline})$ with $N_{lens} = 1.406$ and $N_{saline} = 1.334$, $(1.406 - 1)/(1.406 - 1.334) = 5.64$, an error of 0.02 D in power measured in saline would equate to error of 0.11 D in power measured in air.[14] It is therefore likely that the achievable accuracy for soft lenses measured in saline is worse than ±0.05 D.

The repeatability of the instrument was assessed first by calculating the COR separately for each lens design, prescription power and operator. The variability of the COR calculated across the half chord positions were different between the lens designs measured. The Acuvue BF High

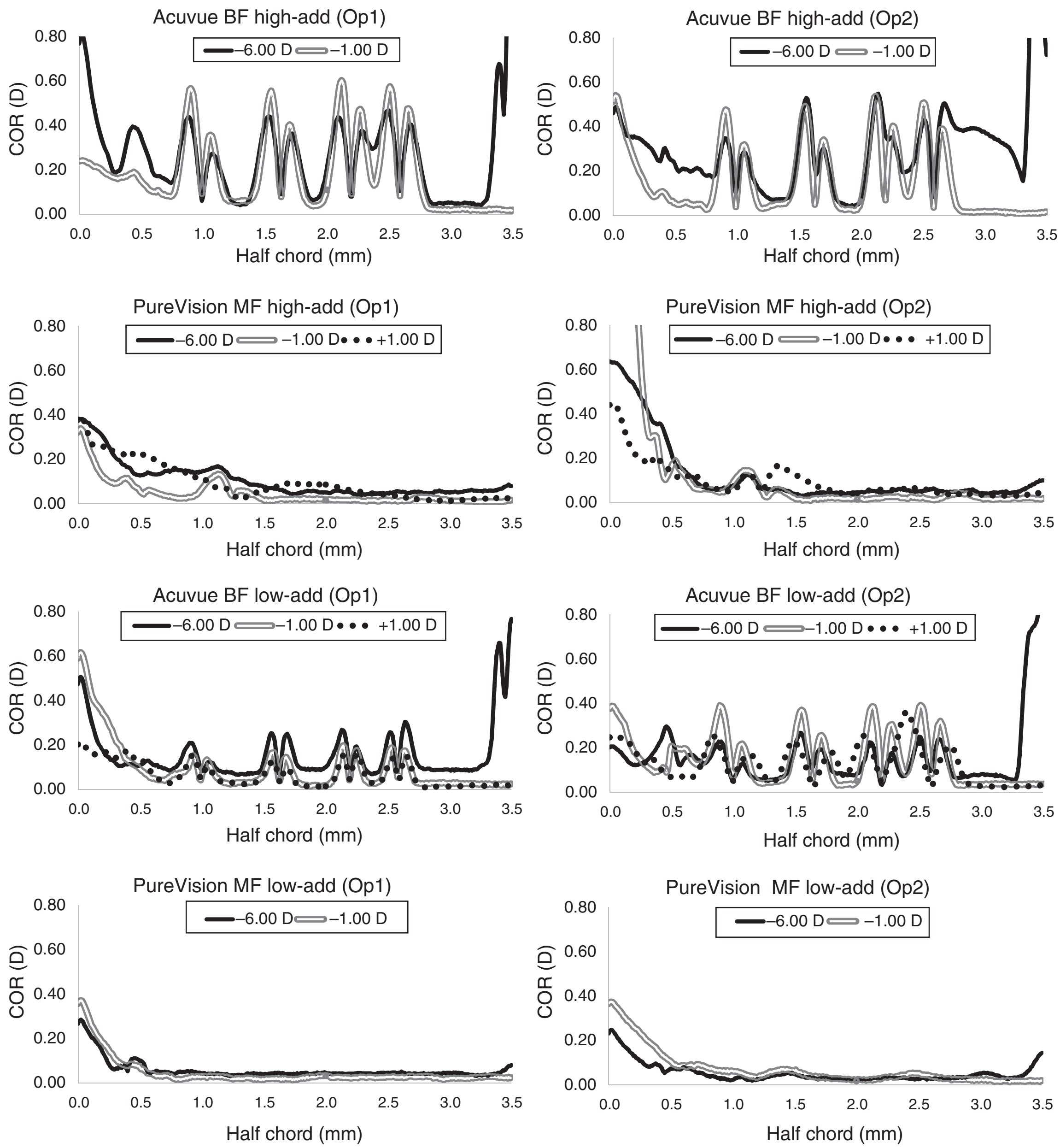

Figure 3 The COR for all the BF and MF designs (both operators) are presented here: Acuvue High Add BF (Operator 1: 1st row left; Operator 2: 1st row right), PureVision High Add MF (Operator 1: 2nd row left; Operator 2: 2nd row right), Acuvue Low Add BF (Operator 1: 3rd row left; Operator 2: 3rd row right) and PureVision Low Add MF (Operator 1: 4th row left; Operator 2: 4th row right).

Add lenses suffered the maximum variability of the COR calculated across the half chord, followed by the Acuvue BF Low Add lenses, observed for both operators. This can be explained by the more complex lens design showing distinct transitions of the power between the different regions of the optical zone. The location of the several peaks in the COR graphs coincide with the locations of the power steps in the Acuvue BF lenses as it also relates to the sensitivity of the measurement with lens centration. The COR of the SV lenses were lower than the COR of the BF/MF lenses for both operators. The COR results of the −6.00 D SV Acuvue Advance lens for operator 2 was unexpected and showed obvious difference compared to the operator 1. This error might have been due to an unclean cuvette or particles accumulating in the solution, altering the optical calculations. Other possible reasons are that the lens was measured too quickly before the lens is settled in the solution of the cuvette or the lens was not sitting properly before taking the measurement. The level of experience using NIMO TR1504 instrument between the two operators can be observed by the slight noticeable difference in the COR of the BF/MF lenses. It appears that a more experienced/careful operator can achieve more reliable results. For all lenses, the COR were mostly within 0.20 D across the half chord, except near the center and toward the edge of the optic zone, where COR values greater than

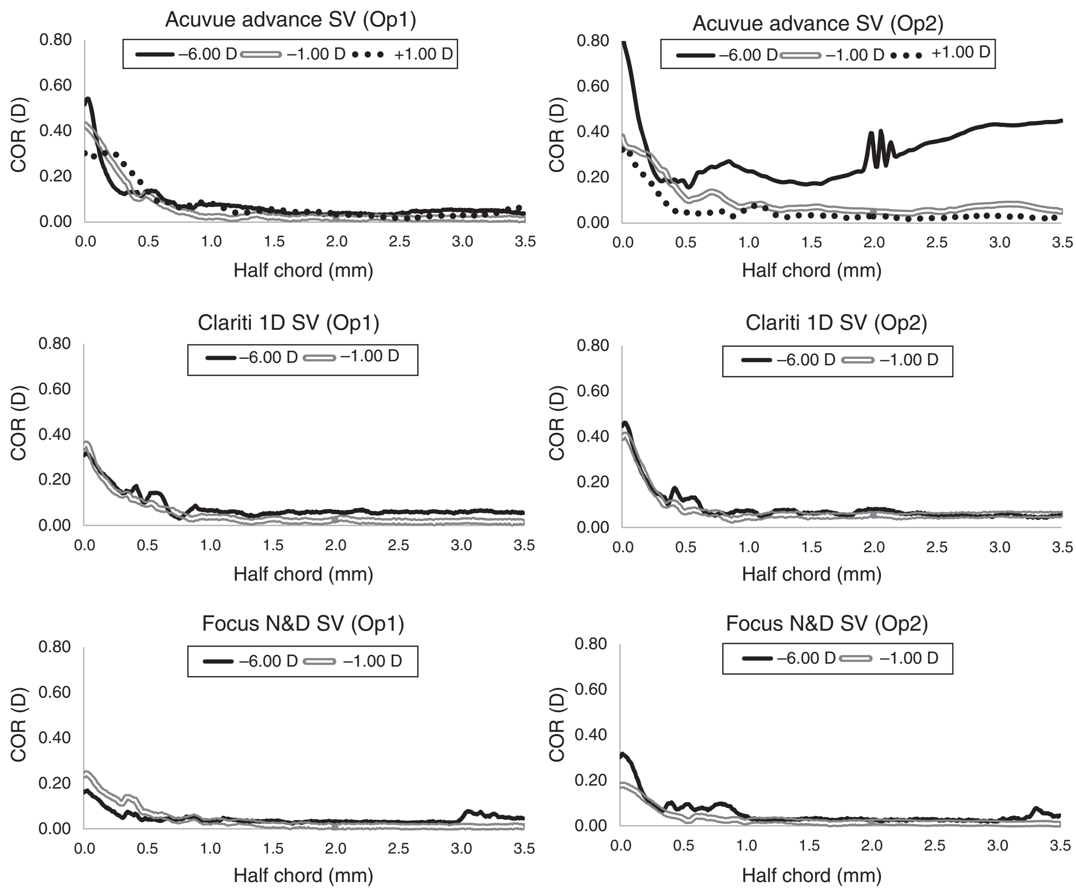

Figure 4 The COR for all the SV designs (both operators) are presented here: Acuvue Advance SV (Operator 1: 1st row left; Operator 2: 1st row right), Clariti 1-day SV (Operator 1: 2nd row left; Operator 2: 2nd row right) and Focus N&D SV (Operator 1: 3rd row left; Operator 2: 3rd row right).

1.00 D were observed. While the peripheral increase is likely to be caused by the blending between the optic and the peripheral zones and is of little clinical relevance, the relatively large variability within the central 1.00 mm diameter makes it difficult to accurately characterize BF/MF contact lens profiles, which often rely on carefully chosen power profiles in this region for optimized performance. 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.[15] Wagner et al. investigated the measurement repeatability of power profiles using the SHSOphthalmic instrument.[5] They selected two types of contact lenses (lotrafilcon A and somofilcon A High Add) and measured both independently ten times. Repeatability was generally good but also decreased toward the optical center. The calculated confidence interval increased to 0.20 D for the 0.5–1.0 mm half chord and to 0.39 D for the central 1 mm diameter. Plainis et al.[6] investigated MF contact lenses using the Phase Focus Lens Profiler and showed repeatability to be better than 0.05 D over most of the measured optic zone. Only within the central 0.6 mm half chord were the power profiles not reliable, which is in agreement with the observations made in this study.

The optic zone was divided into two segments along the half chord and the overall COR was calculated for each lens design and prescription power. The factors included in the general linear model to calculate this COR were the variability within the three lenses, half chord position and operator. The reason to divide the optic zone into two segments is to calculate the exact COR where we understand is giving precise reading. In general, half chord position ≤0.5 mm produced higher CORs compared to half chord position 0.51–3.2 mm range which is of clinically relevance. The variability of COR in the half chord position ≤0.5 mm segments were similar between different lens type. The COR for Acuvue BF High Add in −6.00 D and −1.00 D powers and Acuvue Advance in −6.00 D power lenses produced the highest COR within the half chord position 0.51–3.2 mm of 0.27 D, 0.25 D and 0.22 D respectively. The COR for the PureVision High and Low Add lenses were similar to those of the SV lenses, which were all within 0.10 D. This can be explained by the lens designs, whereby the transition of the power between the different regions of the optical zone of the PureVision lens is not as distinct as with the Acuvue BF lenses. There were no noticeable trends of the COR between the different prescription powers within each lens designs.

Domínguez-Vicent et al.[11] recently published similar work to this study in reporting the repeatability of power profiles for multifocal contact lenses using the NIMO TR1504

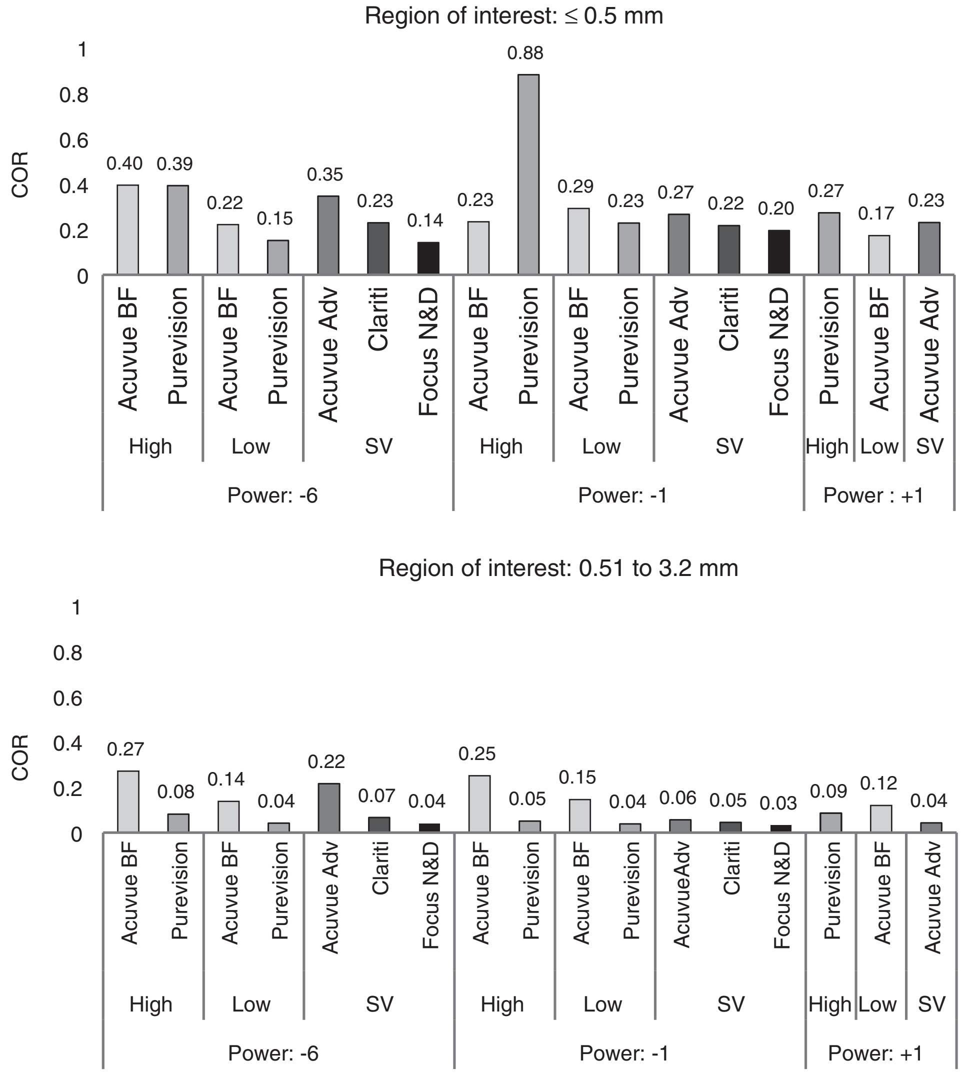

Figure 5 The overall COR of lens designs calculated for each prescription power in two regions of interest on the half chord of the optic zone: (i) central segment ≤ 0.5 mm and (ii) the half chord between 0.51 and 3.2 mm.

instrument. They have measured power profiles of 10 different contact lenses 30 times to evaluate the repeatability. Repeatability of lower than 0.12 D for all the measured multifocal contact lenses was reported in their study. The COR of most of the lenses measured in the current study were within 0.15 D except for Acuvue BF High Add lenses. The possible differences may be due to the option file settings of the NIMO instrument and also the number of repeats measured for each lens to calculate the COR. Both of these can contribute to smoothing out the power profiles hence smaller variability between repeats and hence better COR. It is somewhat surprising that they did not report an increase in variability toward the center of the power profiles. Possibly, they utilized the newly introduced auto-centration function within the NIMO TR1504 software, which may provide a more repeatable lens centration than manual lens centering.

Changes in shape of the power profiles were observed when decentering the lenses. The change was most pronounced for BF/MF type lenses where the lens design included a sharp transition of power across the half chord such as the Acuvue BF lenses. The peak to trough amplitude in the power profiles flattened up to 1.00 D when the lens was decentered by 0.50 mm for the Acuvue BF High Add lenses. The effect of decentration was quantified by comparing the sphere power readings for all the SV and PureVision MF contact lenses (High and Low Add). These results showed statistical significance in the sphere power when the lens was decentered more than 0.2–0.3 mm for measurements across a 6 mm optic zone for all lenses except Focus N&D SV contact lenses. Although the results were statistically significant, the difference in sphere power is small, reaching a maximum of 0.07 D at 0.5 mm decentration and is of no clinical significance. The PureVision MF Low Add lens which had the most negative spherical aberration showed the greatest effect when decentering the lens. The Focus N&D SV contact lenses had no statistical effect when the lens was decentered of up to 0.5 mm due to the lens having minimal spherical aberration. Belda-Salmeron et al.[8] also measured the effect of decentration with NIMO TR1504 by inducing a decentration of up to 1 mm in 0.2 mm steps. They found the

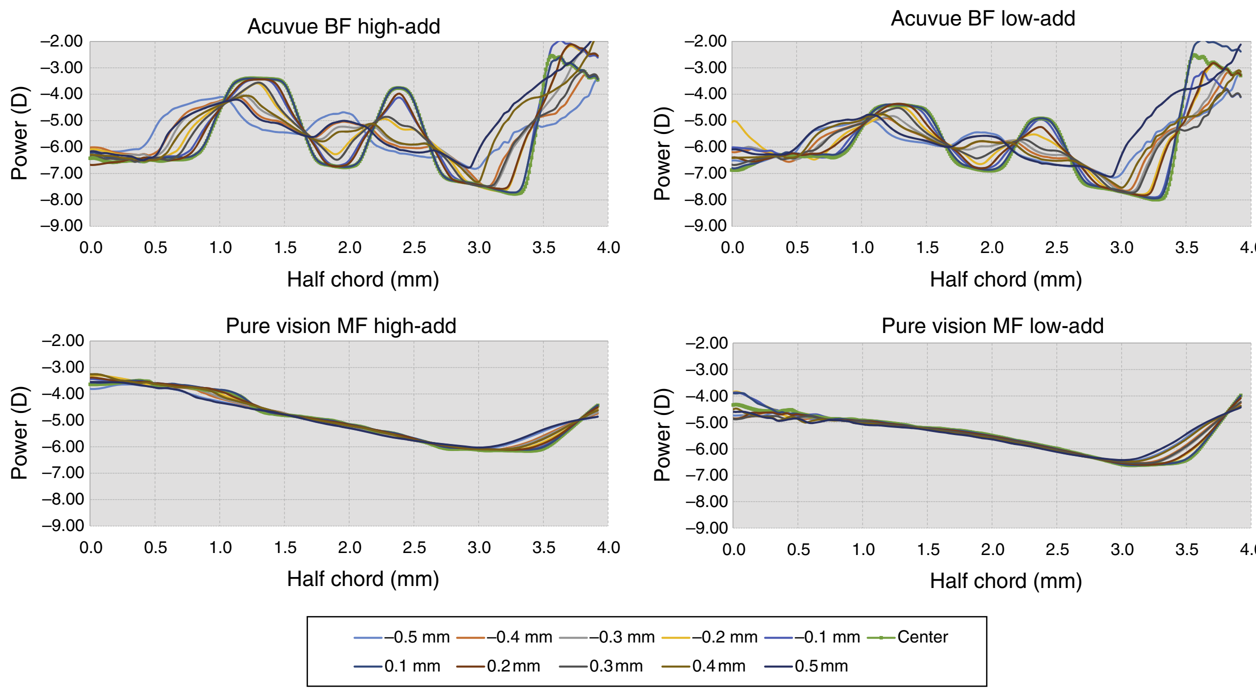

Figure 6 Power profiles of deliberately decentered BF and MF lenses: (a) Acuvue BF High-Add (top-left); (b) Acuvue BF Low-Add (top-right); (c) PureVision MF High-Add (bottom-left) and (d) PureVision MF Low-add (bottom-right).

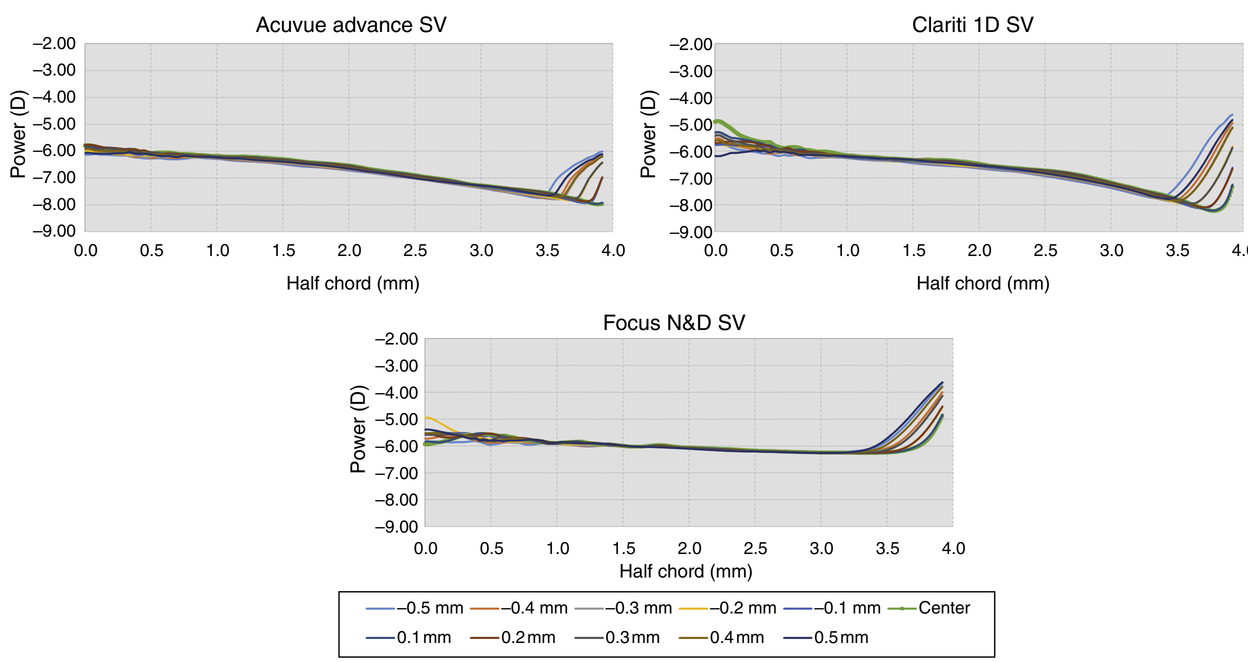

Figure 7 Power profiles of deliberately decentered SV lenses: (i) Acuvue Advance SV (top-left); (ii) Clariti 1-Day SV (top-right) and (iii) Focus N&D SV (bottom).

power curves were shifted in the negative direction with the increase of decentration. However, the changes were always lower than 0.25 D and they concluded that this effect is negligible for the daily disposable lenses measured within their study.

The results from the COR analysis and decentration experiment in this study confirm that centration of the lens is the dominant factor affecting the reliability of power measurements. It is also the only one that requires operator contribution to the otherwise fully automated measurement procedure. The small, but consistent difference between the two operators indicates that meticulous centration can produce more repeatable results. Lambda-X has recently released a new software version that includes an option for

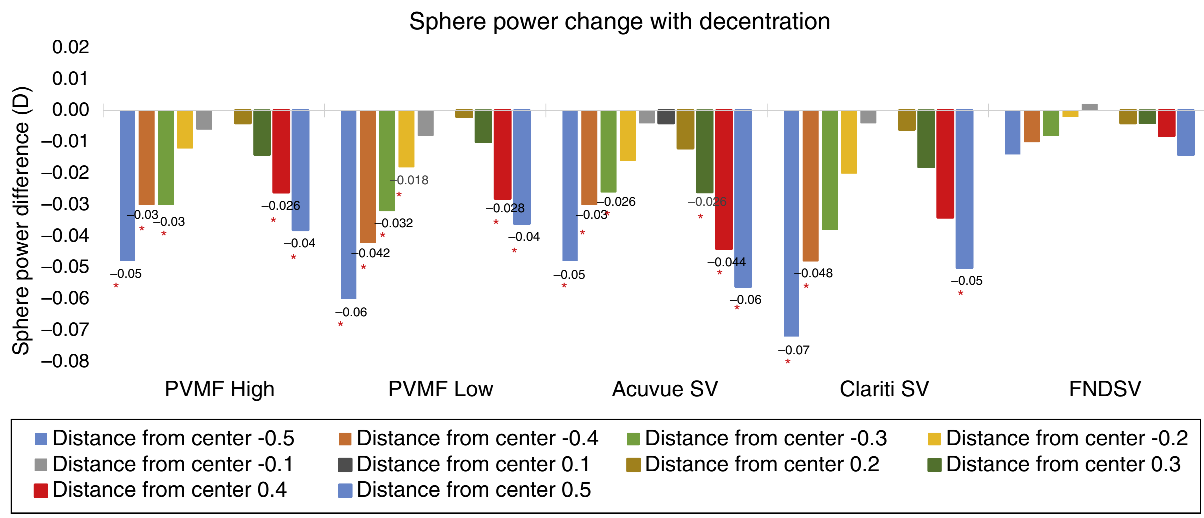

Figure 8 The average difference in sphere power reading from NIMO measured at center and across ±0.5 mm decentration. *Statistically significant changes.

automated edge detection that is then used to center the lens without any user input. It remains to be verified how reliable this feature is and if it can reduce the COR.

In summary, the power measurements using the NIMO TR1504 instrument produced reliable results for SV, BF and MF soft contact lenses across the half chord segments between 0.51 and 3.2 mm. For SV group lenses, the overall COR were within 0.10 D, for more complex geometries as with BF/MF High Add and Low Add lenses, the overall COR generally worsens to within 0.25 and 0.15 D respectively. Measurement variability of up to 0.88 D can be expected for power profiles within the central 1.0 mm diameter, which is similar to other wave-front sensing instruments. For lenses with stepped power profiles, decentration needs to be less than 0.1 mm to avoid profile smoothing. Knowing about the limitations of the equipment used to verify manufacturing accuracy may help to produce more consistent lens quality and thereby benefit practitioners and patients.

Conflicts of interest

The authors have no conflicts of interest to declare.

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