Published in final edited form as:

Optom Vis Sci. 2009 February ; 86(2): 115–122. doi:10.1097/OPX.0b013e318194e951.

Higher-Order Aberrations when wearing Sphere and Toric Soft Contact Lenses

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Abstract

Purpose—To determine the on-eye effect of spherical and toric contact lens design on higher-order aberrations (HOA).

Methods—Thirty eyes (15 subjects) entered a masked, randomized, cross-over study. Each eye was fitted with the spherical and toric lens of the following brands in random order: Acuvue Advance, Biomedics 55, Frequency 55, and SofLens 66. HOAs were measured using the Zywave II Aberrometer over a 6-mm aperture up to fifth order. A linear model accounting for the fixed effect of lens type and random effects of subject and eye was created. Paired t-tests were completed between lens brands within the spherical and toric lenses and between the spherical and toric lens within each brand. Best-corrected visual acuity (VA) was measured and compared.

Results—No clinically meaningful differences in total HOAs were found between brands or between the spherical and toric lens within a brand. Positive spherical aberration (SA) was reduced by all spherical and toric lenses compared to wearing no lens by 0.07 to 0.23 μm ($p < 0.0001$). Frequency toric induced the greatest change in SA. The thin-zone design lens (Acuvue Advance for Astigmatism) had a statistically different amount of vertical coma ($-0.04 \mu\text{m}$) than the three prism-balast toric lenses (0.11 to 0.23 μm ; $p < 0.0001$). SofLens toric had the greatest amount of vertical coma, but better VA than Acuvue Advance for Astigmatism and Frequency toric. With the exception of Acuvue Advance for Astigmatism, toric lenses had greater absolute magnitude of vertical coma than their sphere counterparts (all $p < 0.002$). No other significant HOA differences were observed.

Conclusions—Toric contact lenses with prism-ballast designs demonstrated more vertical coma, but better VA. Positive SA was reduced by spherical and toric contact lenses. The visual quality effect of lens design and material on induced HOAs warrants further investigation.

Keywords

toric contact lens; higher-order aberrations; spherical contact lens; astigmatism; contact lens design

When toric contact lenses were first introduced in the 1970s, they experienced issues involving variable lens quality and stability;¹⁻³ however, improved lens designs and the availability of disposable toric contact lenses have resulted in improved health benefits and visual acuity.⁴ Based on 2006 United States contact lens fitting data, there is only a 10% difference in the proportion of soft toric contact lens fits compared to soft spherical contact lens fits.⁵ Quantifying the on-eye aberrations induced by various contact lens designs is important because of the effect that higher-order aberrations may have on visual acuity and visual quality.

Several studies have been published reporting on the aberrations induced, and the visual acuity obtained, with various contact lens designs. Rigid contact lenses have been shown to provide better aberration profiles on average than soft contact lens designs;⁶⁻⁸ however, significant individual variations between subjects have been noted in these studies. In some cases, rigid contact lenses did not provide a subject with the best aberration profile.⁸

Soft spherical contact lens optics have also been investigated. One study reported that optical quality with soft contact lenses is similar to that with spectacles.⁷ Others have reported that soft contact lenses increase higher-order aberrations when compared to not wearing a contact lens.^{8, 9} A more recent study examined three different soft spherical contact lens designs and reported that higher-order aberration differences were found between lenses with different materials and manufacturing processes; however, the study was not able to determine with certainty whether the lens design, manufacturing process, or lens material caused the higher-order aberration differences.¹⁰ In addition, the lenses used in the study are not regularly fitted in the United States.

Soft aspheric contact lenses have been suggested as an alternative to a toric lens for low astigmatic patients. The level of spherical aberration of a soft contact lens on the eye has been reported to have the same optical effect as when the contact lens is off the eye,¹¹ suggesting it may be possible to correct ocular spherical aberration with soft contact lenses. However, clinical studies have reported that non-toric aspheric soft contact lenses did not improve visual acuity significantly when compared to spherical lenses on low astigmats.^{12, 13} One reason why these non-toric lenses do not improve visual acuity is that aspheric soft contact lenses do not correct astigmatism. Additionally, decentration of spherical aberration correction has been shown to induce coma-like aberrations.^{12, 14} Another possible explanation is that some lenses that are designed to be aspheric may not yield the intended asphericity once the lens was placed on the eye.

To our knowledge, no studies have examined higher-order aberration differences between the toric and spherical soft contact lens brands most frequently fitted in the United States. We are also not aware of published studies investigating higher-order aberration differences between the spherical and toric lens design of the same lens brand manufactured in the same material. By measuring both the spherical and toric lens design of each brand on the eye, we are able to measure the on-eye, within-brand difference in higher-order aberrations that occur due to the lens design. Because the spherical and toric lens of each brand is made of the same material, we are able to differentiate between aberration differences due the material versus the lens design.

This study examined both best-corrected visual acuity and on-eye higher-order aberration differences between lens designs. Others have used similar methods to examine on-eye contact lens aberrations.^{11, 12} Although this study does not provide information about the aberration differences of each lens in air, the on-eye aberrations are vital to understanding visual performance when a lens is worn by a patient. The visual acuity results have already been published and showed visual acuity differences between toric soft contact lens brands.¹⁵ Unlike rotationally symmetric spherical contact lenses, toric contact lenses must incorporate a stabilization method into the lens design to properly orient the astigmatic correction on the eye. Design differences (e.g., diameter, curve junctions, stabilization method) and material differences may lead to significant differences in the on-eye aberration profile of the contact lens.

The purpose of this paper is to report the effect of spherical and toric soft contact lens design on higher-order aberrations *in vivo*. When planning the study, we hypothesized that lens design differences would result in on-eye, higher-order aberration differences between spherical and

toric soft contact lenses, and that contact lens design differences would result in higher-order aberration differences between lens brands.

METHODS

Design

Thirty eyes of 15 subjects with low to moderate astigmatism were enrolled in a masked, randomized, cross-over study. Subjects were recruited using posters and e-mail announcements at The Ohio State University. The study protocol was approved by the Western Institutional Review Board and followed the tenets of the Declaration of Helsinki. Patients were provided an informed consent document and were required to review and sign this form before beginning any testing.

To be eligible for the study, subjects had to have no prior history of refractive surgery, no contraindications for contact lens wear, be at least 18 years of age, have between -0.50 DS and -6.00 DS of spherical correction in the corneal plane, and have between -0.75 DC and -2.00 DC of astigmatism in the corneal plane, and have a best spectacle-corrected Snellen visual acuity of at least 20/25 in each eye. The study exclusion criteria were as follows: anterior segment pathology, including cataracts; residual, recurrent, or active ocular disease or corneal abnormality; previous intraocular or corneal surgery of any kind; and, gas permeable or hard contact lens wear within the last 6 months.

Visit 1

Both eyes of each subject were fitted with both the spherical and toric lens design of each of the following contact lens brands: Acuvue Advance (Vistakon), Biomedics 55 (CooperVision, previously Ocular Sciences), Frequency 55 (CooperVision), and SofLens 66 (Bausch & Lomb). The lens brands were fitted by an unmasked examiner in random order according to a randomization chart and the spherical lens of each brand was always fitted before the toric lens of the same brand. The parameters of the lenses used are listed in Table 1. An over-refraction was performed to determine the best-correcting spherical and toric lens power in each brand to order for the next visit. Spherical over-refractions were performed with spherical contact lenses and spherocylindrical over-refractions were performed with toric contact lenses.

Visit 2

Higher-order aberrations were measured by a masked examiner using the Zywave II aberrometer (Bausch & Lomb; Rochester, NY) over a 6-mm aperture up to the fifth order. The Zywave aberrometer has been previously shown to be repeatable and equivalent to other aberrometers.¹⁶⁻¹⁸ The subjects' pupils were dilated for all measurements using 1% tropicamide and 2.5% phenylephrine. Zernike coefficients were converted to comply with ANSI Z80.28 standards.¹⁹ Nine wavefront measurements were captured and averaged without a lens and while wearing each lens.

As described in detail elsewhere,¹⁵ photopic and mesopic high- and low-contrast logMAR visual acuity (BCVA) was measured through a fixed 6-mm aperture by a masked examiner. The 6-mm aperture was placed in a trial frame, and every effort was made by the masked examiner to center the aperture along the subject's line of sight. While wearing each contact lens as ordered based on Visit 1, a new over-refraction was performed at Visit 2. As at Visit 1, spherical over-refractions were performed with spherical contact lenses to ensure the optimal spherical equivalent was used for visual acuity testing, and spherocylindrical over-refractions were performed with toric contact lenses to correct any residual lower-order aberrations that remained, leaving only higher-order aberrations from the combination of the eye and the toric contact lens.

Visual acuity measurements were performed both with and without the new over-refraction in place. The purpose of measuring visual acuity with the new over-refraction that was performed at Visit 2 was to correct any residual lower-order aberrations (i.e., refractive error) that were correctable by the specific lens type (sphere or toric). The 6-mm aperture ensured that all visual acuity measurements were made under the same viewing conditions for each subject and that the pupil size matched the aberration analysis diameter. As reported elsewhere,¹⁵ spherical over-refractions were performed with spherical lenses because another purpose of this study was to measure the improvement in visual acuity when astigmatic eyes are fitted with toric contact lenses instead of spherical lenses with the best spherical-equivalent.

Decentration of each lens was also measured. After each lens was placed on the eye and allowed to settle a minimum of 5 minutes, lens overlap was measured nasally, temporally, and inferiorly with the subject looking in primary gaze. Lens overlap is defined as the distance between the most nasal, temporal, and inferior edge of the limbus and the edge of the contact lens as measured using a millimeter scale in one of the slit-lamp oculars. The diameter of the cornea was also measured. Using the published diameter of each contact lens, lens decentration was calculated using trigonometry.

Data Analysis

The mean difference in Zywave higher-order aberrations between lens brands within each of the spherical lenses and the toric lenses was determined using a linear model. The model included the fixed effect of lens brand and the random effects of subject and eye in order to account for the correlation obtained by having each eye wear each of the lenses. Pair wise t-tests were completed between the lens brands using this model. Comparisons between spherical and toric lenses within a lens brand were completed using a paired t-test. Statistical significance was set a priori at an alpha level of less than 0.01. Based on a previous study,²⁰ a clinically meaningful change in root mean square (RMS) wavefront error was defined a priori as a change greater than 0.10 μm . The visual acuity data were analyzed as previously described in the literature.¹⁵

Based on the aberration results, relevant analyses of the contact lens decentration data were performed. The vertical lens decentration data were analyzed using a repeated-measures ANOVA. The factors included in the ANOVA included lens brand, lens type (sphere or toric), and eye (right or left). Appropriate post-hoc t-test comparisons were performed using the method described by Tukey and the appropriate mean square error from the analysis of variance.

RESULTS

Of the 15 subjects enrolled, nine (60%) were male. All subjects were over 18 years of age and were habitual soft contact lens wearers. The average spherical refractive error vertexed to the corneal plane was (mean $\pm$ SD) -2.83 ± 1.70 DS (range: -0.50 D to -6.00 DS) and the average cylindrical refractive error was -1.34 ± 0.44 DC (range: -0.75 to -2.00 DC). The baseline higher-order aberrations measured without contact lenses are shown in Table 2 for reference. No differences between right and left eyes were found. All results presented in the figures report the combined higher-order aberrations for the eye and contact lens being measured. All clinically meaningful differences reported also met our a priori alpha level for statistical significance.

When examining differences in total higher-order aberrations (Figure 1) and third-order, fourth-order, and fifth-order aberrations (Figures 2a through 2c, respectively), no clinically meaningful differences were found between lens brands (i.e. Acuvue, Biomedics, Frequency, or SofLens) for the spherical or toric lenses, and no clinically meaningful differences were

found when comparing the spherical and toric lens design within each lens brand ($p > 0.01$ in all cases).

Positive spherical aberration was reduced by all spherical and toric lenses compared to wearing no lens by between $0.07\ \mu\text{m}$ to $0.23\ \mu\text{m}$ ($p < 0.0001$; Figure 3). The Frequency toric induced the greatest total change in spherical aberration ($0.23\ \mu\text{m}$), creating an average change from $0.13\ \mu\text{m}$ (positive spherical aberration) without a contact lens to $-0.11\ \mu\text{m}$ (negative spherical aberration) with the lens. Among the toric lenses tested, the resultant absolute magnitude of spherical aberration was significantly greater in the Frequency toric than in the Acuvue Advance toric and the SofLens toric ($p < 0.0001$). Although no difference in visual acuity was found between the Frequency toric and the Acuvue Advance for Astigmatism, visual acuity with the SofLens toric was 2.5 letters better than with the Frequency toric.

Acuvue Advance for Astigmatism was the only toric lens in this study that uses a dual thin-zone stabilization design, compared to the prism-ballast design used by the other three toric lenses studied. Visual acuity with the Acuvue Advance for Astigmatism was 2.5 and 3 letters worse than with the Biomedics toric and SofLens 66 toric, respectively; however, it showed a significantly lower amount of on-eye vertical coma ($-0.04\ \mu\text{m}$; $p < 0.0001$) compared to the three prism-ballast design toric lenses, which ranged from $0.11\ \mu\text{m}$ to $0.23\ \mu\text{m}$ (Figure 4). The SofLens toric had the greatest magnitude of vertical coma ($0.23\ \mu\text{m}$). With the exception of Acuvue Advance for Astigmatism, all toric lenses had a clinically greater absolute magnitude of vertical coma than their sphere counterparts (all $p < 0.002$). Although the Acuvue Advance for Astigmatism induced a statistically significant increase in the amount of vertical coma when compared to its sphere counterpart (toric = $-0.04\ \mu\text{m}$; sphere = $0.002\ \mu\text{m}$; $p = 0.01$), the change in vertical coma did not meet our a priori criterion for a clinically meaningful change of $0.10\ \mu\text{m}$. No other statistically significant and clinically meaningful differences in individual higher-order aberrations were measured.

Because statistically significant and clinically meaningful differences in vertical coma were found between toric lens brands, the amount of vertical lens decentration was analyzed (Figure 5). Differences in vertical lens decentration between brands depended on whether spherical or toric lenses were examined ($p = 0.005$). Differences in vertical lens decentration between brands did not depend on whether the lens was worn on the right eye or the left eye ($p = 0.38$). Post-hoc testing showed that among spherical lenses, the amount of vertical decentration of the Acuvue Advance was significantly different than the other three lens brands ($p < 0.05$; Tukey's HSD). Among the toric lenses, there was not a significant difference in the amount of vertical lens decentration between brands ($p > 0.05$; Tukey's HSD).

DISCUSSION

With the increase in the number of soft toric contact lenses available, and the continued increase in their use by eye care professionals, it is important to understand the influence that contact lens design and material have on aberrations and visual acuity. This study took an initial look at differences in higher-order aberrations between contact lens brands that are commonly fitted in the United States. Because aberrations may affect quality of vision, we will briefly summarize relevant findings from the visual acuity arm of this study.

In a previous publication,¹⁵ we reported that visual acuity with spherical lenses on low- to moderate-astigmatic eyes was not significantly different between lens brands and that visual acuity with toric lenses was better than with spherical lenses, which was not surprising. However, we did find that the visual acuity improvement gained by being fitted in a toric lens depended on the contact lens brand. Overall, regardless of over-refraction, visual acuity was better with Biomedics toric and SofLens toric than with Acuvue Advance for Astigmatism by

0.05 logMAR (2.5 letters) and 0.06 logMAR (3 letters), respectively. We also found that visual acuity with SofLens toric was better than Frequency toric by 0.05 logMAR (2.5 letters). Our analysis showed that there was no difference in visual acuity regardless of whether it was measured through the best-fitted contact lens alone or the best-fitted contact lens and the final over-refraction ($p = 0.50$). Although unlikely, it is possible that a fractional refractive error of less than 0.25 D that a subject could not distinguish during an over-refraction could have had an impact on the final toric lens visual acuity obtained by the subject.

When examining the higher-order aberration results, there were no clinically meaningful differences between total higher-order, third-order, fourth-order, or fifth-order aberrations between brands for spherical or toric soft contact lenses on eye. There were also no clinically meaningful on-eye differences between the sphere and toric lens of each brand. All of the minus powered contact lenses fitted in this study significantly reduced the inherent positive spherical aberration of the eye, though the amount of change in spherical aberration was brand dependent. The reduction in positive spherical aberration was expected because negative powered contact lenses inherently induce negative spherical aberration that is related to the amount of minus power in the lens.¹¹ One possible reason why visual acuity with the Frequency toric was worse than with the SofLens toric could be that the resultant negative spherical aberration ($-0.11 \mu\text{m}$) with the Frequency toric was significantly greater than the spherical aberration with the SofLens toric ($0.02 \mu\text{m}$). Possible reasons why the spherical aberration changes measured were different between brands could include that the manufacturers made no attempt to control spherical aberration, that manufacturers attempted to alter spherical aberration with aspheric contact lens surfaces, that unintended changes in the spherical aberration of the lens occurred during the manufacturing process, and that there were differences in how the contact lens flexed when placed on the eye. Further work is necessary to determine the cause of the on-eye spherical aberration differences.

Perhaps the most interesting finding relates to the greater absolute amount of vertical coma found in the prism-ballasted toric lenses compared to the dual thin-zone design toric lens. The Biomedics, Frequency, and SofLens toric lenses all use a prism-ballast stabilization design while the Acuvue Advance toric uses a dual thin-zone design for stabilization. Our decentration results show that there was not a significant difference in the amount of on-eye vertical lens decentration between the four toric lens brands; therefore, the reason that the Acuvue Advance for Astigmatism (thin-zone design) induced less vertical coma than the three prism-ballasted toric lenses is not because it decentered less than the other lenses. We should note that while the method used to measure lens centration did not show the lens decentration relative to the line of sight, it provided decentration of each contact lens on the cornea relative to the other lenses placed on the same eye.

It is likely that the prism-ballast design is associated with the increased on-eye vertical coma measured in the Biomedics, Frequency, and SofLens toric lenses. However, while one might expect the lenses with greater amounts of vertical coma to have worse visual acuity, the opposite was true.¹⁵ Although the Acuvue Advance for Astigmatism had the lowest absolute magnitude of vertical coma, the best-corrected visual acuity with this lens was worse on average than with the prism-ballasted Biomedics and SofLens toric lenses.

Although SofLens toric had the highest absolute magnitude of vertical coma of all toric lenses, better visual acuity was achieved with SofLens toric than with Acuvue Advance for Astigmatism and Frequency toric. Applegate et al. have reported that equal amounts of RMS wavefront error do not result in equal losses in visual acuity.²¹ They also reported that interactions between Zernike modes can result in improved visual acuity. Therefore, one possible explanation is that other aberrations combined with the vertical coma induced by the SofLens toric in a synergistic manner and resulted in better image quality. Alternatively, coma

has been reported to result in an increased depth of focus,²² which could have potentially aided visual acuity in our study; however, in the same report,²² the coma actually resulted in reduced visual acuity.

The amount of on-eye spherical aberration associated with each lens could also play a role in differences observed in vertical coma. Decentration of spherical aberration has been reported to induce coma.¹⁴ To our knowledge, none of the contact lenses in this study have a specifically designed amount of spherical aberration that is corrected for across all lens powers. If one contact lens brand were to have more on-eye spherical aberration when perfectly centered than another brand, the same amount of decentration of the lens with more spherical aberration would result in more induced coma than decentration of a lens with less spherical aberration. The amount of on-eye spherical aberration that is present before the lens decenters would need to be known to investigate whether differences in spherical aberration contributed to the differences found in vertical coma after the lens decentered. However, although differences in vertical coma were found in this study between toric lens brands which did not decenter differently, there was not a significant difference in vertical coma between spherical lens brands, which did decenter differently. Because the sphere and toric lenses of each brand resulted in similar amounts of on-eye spherical aberration, we feel that this provides support for prism-ballast lens designs, once manufactured, potentially contributing to the vertical coma measured. Further studies are necessary to determine the main cause of the on-eye vertical coma measured with the prism-ballast lenses.

At the time that this study was conducted, Acuvue Advance was the only contact lens brand that had both a spherical and toric silicone-hydrogel contact lens available in the United States. This has since changed with the launch of new toric silicone-hydrogel contact lenses in the US by Bausch & Lomb, CIBA Vision, and Vistakon. This study did not test the anterior aspheric optics design in the Bausch & Lomb PureVision sphere and toric lenses and also did not test the bi-aspheric lens design in the CIBA Vision O₂ Optix sphere and Air Optix for Astigmatism lenses. The Acuvue Oasys for Astigmatism lens, which shares the design of the Acuvue Advance for Astigmatism, was also not available at the time this study was conducted. Acuvue Advance for Astigmatism is also the only toric lens in this study that does not use a prism-ballast stabilization design. A limitation of this study is that we were only able to include one lens brand that is manufactured in a silicone-hydrogel material. Because the Acuvue Advance for Astigmatism was the only lens stabilized using a thin-zone design, it is not possible to determine conclusively whether visual acuity differences in this lens are due to the silicone-hydrogel material, or the thin-zone lens design. Additional studies are necessary to further explore this area.

It should be noted that this study did not directly measure the effect of different lens manufacturing processes on higher-order aberrations. However, because the manufacturing process directly influences the final design characteristics of the contact lens, it is an inseparable part of any commercially available contact lens. In this paper, we did not attempt to separate the influence of the manufacturing process from the overall lens design. It is unlikely that the prism-ballast lenses in this study were designed to have coma in the optic zone; however, factors involved in the manufacturing process, such as how the polymer cures in the contact lens mold, may contribute to the final aberration fingerprint of the lens. These factors may result in different on-eye aberration profiles. This is a possible explanation for why the three prism-ballast lenses evaluated in this study yielded an on-eye aberration profile that included vertical coma.

Although this study did not measure how on-eye lens flexure changes the aberrations of the contact lens when compared to the lens when off of the eye, every eye in this study was fitted

and measured with every lens design that was evaluated. Therefore, this study examined each lens in a manner consistent with the way that they are fitted and prescribed in clinical practice.

The purpose of this study was to evaluate the contact lenses as they are used clinically; therefore, the combined aberrations of the eye and the lens were reported in this manuscript. When reported this way, the aberrations reflect what was clinically present when the subjects in this study wore each lens and when their visual acuity was measured. We should note that other approaches do exist if the purpose of the study is to determine the specific aberrations of the contact lens itself when on the eye. In this case, it would be appropriate to report the aberrations of the lens after subtracting the subject's baseline aberrations. However, because we were interested in the clinical performance of patients while wearing these lenses, the resulting aberrations of the eye and contact lens together were reported.

Because the purpose of this study was to examine *in vivo* differences in higher-order aberrations between lens designs, it was necessary to dilate our subjects and use a standard analysis diameter in order to make higher-order aberration comparisons. Because subjects have variable pupil sizes when in different lighting conditions, the aberration data presented here may not reflect the actual aberrations that a subject might experience if wearing the contact lenses in their habitual environment. Single-valued metrics that quantify visual quality have been reported that correlate with high-contrast visual acuity performance.²³ The metrics of retinal image quality have been shown to correlate best with low-contrast, mesopic visual acuity.^{24, 25} In future studies, these metrics could be used to examine visual quality differences while using each subject's habitual pupil size.

In summary, no differences in total higher-order aberrations were found between lens brands or between spherical and toric lenses of the same brand when measured *in vivo*. All lenses reduced positive spherical aberration, although one brand induced a significant amount of negative spherical aberration. The toric contact lenses that used a prism-ballast stabilization design induced more vertical coma, but generally demonstrated better visual acuity, than the toric contact lens with a thin-zone design. Further investigation of aberration and visual acuity differences caused by lens design differences (prism-ballast versus thin-zone) and material differences (hydrogel versus silicone-hydrogel) is necessary.

ACKNOWLEDGMENTS

Funding for this study was provided by Bausch & Lomb, Inc. Supported by NIH/NEI grants T32-EY015447 (DAB & KR) and K12-EY013359 (DAB) and by AOF Ezell Fellowships sponsored by the AAO Section on Cornea and Contact Lenses (DAB), AOF Presidents Circle (DAB), and Bausch & Lomb (KR). Presented, in part, at the 2007 Association for Research in Vision and Ophthalmology (ARVO) annual meeting in Ft. Lauderdale, Florida.

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Figure 1.

Total higher-order aberration findings for spherical and toric soft contact lenses tested. No clinically meaningful differences were found. (Error bars represent 95% Confidence Interval)

Figure 2.

Third-order (a), fourth-order (b), and fifth-order (c) aberration findings for spherical and toric soft contact lenses tested. No clinically meaningful differences were found. (Error bars represent 95% Confidence Interval)

Figure 3. Spherical Aberration (Z^4_0) for spherical contact lenses, toric contact lenses, and no lens. Positive spherical aberration was reduced by all spherical and toric lenses compared to wearing no lens. (Error bars represent 95% Confidence Interval)

Figure 4.

Vertical coma (Z^3_{-1}) for spherical and toric soft contact lenses tested. Acuvue Advance for Astigmatism (a thin-zone toric lens) had significantly less vertical coma than the other three prism-ballast toric lenses). (Error bars represent 95% Confidence Interval)

Figure 5.

Vertical contact lens decentration for spherical and toric contact lenses tested. Among the spherical lenses, the vertical decentration of the Acuvue Advance sphere was significantly different than the other spherical lens brands. No significant differences in vertical decentration were present among the toric lens brands. (Error bars represent 95% Confidence Interval)

Parameters of the contact lenses used in this study as listed in Tyler's Quarterly. (H₂O = percent water content; BC = base curve used; Diam = overall lens diameter; CT = lens center thickness; Dk = oxygen permeability)

Lens	Material	H ₂ O	Design	FDA Class	BC	Diam	CT	Dk
Acuvue Advance Acuvue Advance for Astigmatism	Silicone Hydrogel Galyfilcon A	47%	Stabilized, soft molding Thin zones	1	8.7	14.0	.07	60
					8.6	14.5	N/A	
Biomedics 55 Biomedics Toric	Hydrogel Ocufilcon D	55%	Cast molded Prism Ballast	4	8.6	14.2	.07	19.7
					8.7	14.5	.11	
Frequency 55 Frequency 55 Toric	Hydrogel Methafilcon A	55%	Ultra-sync cast molded Prism Ballast	4	8.7	14.2	.07	18.8
					8.7	14.4	.12	
Softlens 66 Softlens 66 Toric	Hydrogel Alphafilcon A	66%	Cast molded Prism Ballast	2	F/M	14.2	.1	32
					8.5	14.5	.195	

Table 2

Baseline (mean $\pm$ SD) aberrations for a 6-mm pupil of the eyes tested. (Habitual aberrations without a contact lens on the eye.)

Baseline Aberrations (No contact lens)	Mean $\pm$ SD (microns)
Higher-order RMS	0.37 $\pm$ 0.15
Third-order RMS	0.29 $\pm$ 0.12
Fourth-order RMS	0.22 $\pm$ 0.11
Fifth-order RMS	0.06 $\pm$ 0.03
Spherical Aberration	0.13 $\pm$ 0.14
Vertical Coma	0.01 $\pm$ 0.19