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Abstract

Purpose: The aim of this cross-over study was to investigate the changes in corneal thickness, anterior and posterior corneal topography, corneal refractive power and ocular wavefront aberrations, following the short term use of rigid contact lenses.

Method: Fourteen participants wore 4 different types of contact lenses (RGP lenses of 9.5 mm and 10.5 mm diameter, and for comparison a PMMA lens of 9.5 mm diameter and a soft silicone hydrogel lens) on 4 different days for a period of 8 hours on each day. Measures were collected before and after contact lens wear and additionally on a baseline day.

Results: Anterior corneal curvature generally showed a flattening with both of the RGP lenses and a steepening with the PMMA lens. A significant negative correlation was found between the change in corneal swelling and central and peripheral posterior corneal curvature (all $p \leq 0.001$). RGP contact lenses caused a significant decrease in corneal refractive power (hyperopic shift) of approximately 0.5 D. The PMMA contact lenses caused the greatest corneal swelling in both the central (27.92 ± 15.49 µm, $p<0.001$) and peripheral (17.78 ± 12.11 µm, $p = 0.001$) corneal regions, a significant flattening of the posterior cornea and an increase in ocular aberrations (all $p \leq 0.05$).

Conclusion: The corneal swelling associated with RGP lenses was relatively minor, but there was slight central corneal flattening and a clinically significant hyperopic change in corneal refractive power after the first day of lens wear. The PMMA contact lenses resulted in significant corneal swelling and reduced optical performance of the cornea.

Keywords: Rigid contact lens, corneal thickness, corneal topography, Pentacam, wavefront error, corneal refractive power

1. Introduction

Rigid gas permeable (RGP) contact lenses are used to correct common refractive errors, along with specialist applications such as orthokeratology [1], keratoconus [2, 3], post refractive surgery [4], post keratoplasty [5] and post trauma [6]. As well as correcting the spherical component of refractive errors, the tear lens behind the rigid lens serves to largely correct corneal astigmatism and other higher order aberrations that arise from any corneal surface irregularity [3].

Studies of changes in corneal thickness due to short-term RGP contact lens wear have shown differing outcomes, due to factors such as the contact lens material (Dk), lens diameter, lens fitting and period of lens wear used. Fonn et al. [7] reported an increase in corneal thickness of 1.2 to 4.4% after 6 hours wear of RGP contact lenses with varying centre thickness and fitting characteristics. Sarver et al. [8] did not find any significant changes in mean central corneal thickness with RGP lenses after 8 hours of use. Yeniad et al. [9] reported an increase in central corneal thickness in the first month of RGP lens wear, but thinning after 6 months of lens use on a daily wear basis. Corneal thickness described in these studies was usually based on a single point in the central or peripheral cornea, but little is known about the topographical changes in corneal thickness.

Reports of longer term (1 month to a few years) corneal topographic changes induced by daily wear of RGP contact lenses are also inconsistent, with some studies reporting corneal steepening [10, 11], some reporting flattening under a decentred lens [12, 13], and others reporting no significant changes [14, 15]. Yeniad et al. [9] noted corneal flattening in the first month of wear, with steepening at 6 months, in a group of subjects using RGP contact lenses on a daily wear basis. Although it is well known that specially designed rigid contact lenses (such as those used in orthokeratology [16, 17]) can cause substantial changes in corneal topography in the short term, there are few controlled studies in the literature reporting the effect of conventional rigid contact lenses on anterior corneal curvature after short-term use and none investigating the effect of rigid lenses on posterior corneal curvature.

Contact lens induced corneal topography changes can result in changes in refraction (sphere, cylinder and higher order components) and consequent reductions in retinal image quality after lens removal, since during lens wear the post-lens tear layer would neutralize most of the corneal surface changes. Therefore, the aim of this cross-over study was to investigate the changes in corneal thickness, anterior and posterior corneal topography, corneal refractive power and ocular wavefront aberrations, following the short term (8 hrs) wear of different types of rigid contact lenses. We examined the relative influence of two different RGP contact lenses (9.5 and 10.5 mm diameter) in Boston XO material on these corneal and ocular measurements. For comparison, a rigid lens in polymethyl methacrylate

material [18] of identical design (in 9.5 mm diameter), and a commercially available silicone hydrogel lens were also included.

2. Methods

This study was approved by the QUT university human research ethics committee and followed the tenets of the declaration of Helsinki. All subjects gave written informed consent to participate. The study participants included 14 young, healthy adult subjects aged between 20 to 33 years (mean ± SD age 27.8 ± 4.0 years) with visual acuity of 6/6 or better and corneal astigmatism of ≤ 1.5 D, as determined by the Medmont E300 videokeratoscope. The mean corneal astigmatism was 0.76 ± 0.33 D. Five of the subjects were females. The mean spherical equivalent refractive error was –0.6 ± 1.3 D. Prior to commencement of the study, all subjects were screened to exclude those with any significant tear film or anterior segment abnormalities. Two of the subjects were habitual soft contact lens wearers but they discontinued lens wear one month prior to commencing the study, to allow any effects of soft lens wear to largely resolve. None of the subjects were previous rigid contact lens wearers.

For each subject we investigated the influence of 8 hours of wear of four different contact lenses upon measures of corneal topography, corneal thickness and ocular aberrations. The study was conducted over a period of 5 days (one baseline and 4 lens wearing days). On each day, measurements were taken in the morning and then again in the afternoon 8 hours later. On day one, baseline measurements were taken without any contact lens in the eye, in the morning (0 hours) and repeated in the afternoon after 8 hours. On days 2, 3, 4 and 5 of the study, the subjects wore different types of contact lenses in their left eye only, with measurements collected in the morning before the lens was inserted and again immediately after lens removal following 8 hours of wear. A 2-3 day recovery period was observed after each lens wear day before commencing wear of another lens to ensure that there were no significant carry-over effects from the prior lens wearing day. All ocular measurements on all days were collected on the left eye only. Since for most subjects the right eye is the dominant eye [19], it was decided that the contact lens should cause less visual disturbance for the majority of subjects if used in the left eye. Lens wear typically commenced between 8 and 11 am and at least 2 hours after waking, to limit the potential influence of the corneal changes that are typically evident immediately after sleep [20]. The lenses were removed in the afternoon between 4 and 7 pm, after 8 hours of lens wear, with ocular measurements collected immediately after lens removal.

Three different types of custom-made rigid contact lenses and one soft contact lens were ordered for the left eye of each subject. The rigid lenses were 9.5 and 10.5 mm in diameter with a spherical back optic zone radius (BOZR) and an aspheric periphery, and manufactured from either PMMA or Boston XO material (i.e. identical designs in both PMMA

and Boston XO for the 9.5 mm diameter). The lens design was chosen as it is a commonly prescribed in Australia and it allowed an 'alignment' fit to be achieved for our population of subjects with normal corneal curvature and low levels of corneal astigmatism. A contact lens trial fitting was performed for each subject with the rigid lenses before ordering, to determine the optimum back optic zone radius (BOZR) for each lens diameter (9.5 and 10.5 mm). Within the limitations of the lens design, an optimum "alignment" fitting was achieved for each subject for both diameters, (that is, the lenses were fit "in alignment" with the flatter k). For the smaller diameter lens (9.5 mm) the optimum "alignment" fit required a group mean BOZR of 7.77 ± 0.32 mm, while for the larger diameter lens (10.5 mm) this "alignment" fitting required a slightly flatter BOZR (7.85 ± 0.30 mm), (that is, approximately 0.1 mm flatter than the flat k) (Table 1). The mean flat K for the subject group was 7.77 ± 0.31 mm. All lens fitting fluorescein patterns were assessed by the same experienced examiner (GT), at both the trial lens fitting and on the day of lens wear and were documented with digital slit lamp images. The fluorescein patterns for all subjects typically showed central alignment, slight mid-peripheral bearing and moderate edge lift. The lenses supplied by the manufacturer were checked for back vertex power, lens diameter, BOZR, edge and surface quality before use in the study. The soft contact lens that was used was a Bausch & Lomb PureVision (Balafilcon A) silicone hydrogel lens with 14.0 mm diameter and BOZR of 8.6 mm and this lens gave an acceptable fitting for all subjects (Table 1). The type of lens to be worn on each study day was randomised.

A range of ocular measurements were collected at each measurement session in order to quantify corneal shape and thickness, and ocular optics over the course of the study. Anterior and posterior corneal topography and regional corneal thickness were measured using the Pentacam HR system (Oculus, Wetzlar, Germany) which uses a rotating Scheimpflug camera (a digital camera with a slit illumination system) to evaluate the anterior segment of the eye. A total of 5 measurements were completed using the "25 picture 3D scan" mode, which gives 25 cross-sectional images of the anterior eye. Anterior corneal topography was also measured using the Medmont E300 videokeratoscope (Medmont Pty. Ltd., Victoria, Australia) which is based on the Placido disc principle. A total of 4 corneal topography measurements, with a quality score of 95 or greater were taken at each measurement session and saved for analysis. Ocular monochromatic aberrations were measured using the Complete Ophthalmic Analysis System (COAS, Wavefront Sciences Ltd, USA), a wavefront sensor based upon the Shack-Hartman principle. Measurements were performed without the use of any eye drops under natural pupil conditions and in dim room illumination. A total of 4 measurements were taken during each measurement session, with 20 frames per measurement.

Subjects were instructed to refrain from performing any significant reading work or any other activities involving substantial amounts of downward gaze [21], immediately before each measurement session. A questionnaire was also completed by each subject to monitor the visual tasks performed during the period of lens wear. Subjects were found to be engaged in similar tasks (e.g. computer work) during the study period each day. The morning and afternoon measurements on contact lens wearing days were conducted at around same time of day as on the baseline day (day 1) to allow comparison without confounding effects due to diurnal variations [20, 22, 23].

2.1. Data Analysis

Pentacam corneal thickness and axial (anterior and posterior) curvature data and Medmont corneal height data from each measurement session were exported from the two instruments. An average of the 5 maps from the Pentacam and 4 maps from the Medmont, taken for each subject during each measurement session, was calculated using custom-written software.

In order to compare the baseline maps to post-lens wear maps, thickness and curvature difference maps from Pentacam data were generated. ‘Thickness difference maps’ were generated by subtracting the ‘average baseline thickness’ map from the ‘average thickness map after 8 hours of lens wear’. Similarly, ‘curvature difference maps’ were generated by subtracting the ‘average baseline curvature map’ from the ‘average curvature map after 8 hours of lens wear’. Group average difference maps were also generated by averaging the data from all the subjects for each of the 4 lens types. It has previously been reported that small but significant diurnal variations in corneal thickness and curvature occur within the 8 hours duration of the study [24]. Thus all difference maps in this study were generated by subtracting the thickness map of the baseline day (afternoon) from the thickness map after lens wear (afternoon).

The Pentacam average maps from all the subjects were further analysed using custom-written software in order to study the regional changes in corneal thickness and curvature following lens wear. The average corneal thickness and curvature was calculated for each subject within both central (0 - 4 mm) and peripheral (4 - 8 mm) annular corneal regions.

Corneal anterior surface refractive power was estimated using custom written software, based upon each subject’s average corneal height maps from the Medmont videokeratoscope, assuming a corneal refractive index of 1.376 and least squares fitting of a sphero-cylindrical surface to the refractive power map [25]. The surface was referenced to the videokeratoscope axis. The refractive power data was described and analysed in terms

of power vectors [26] “M” (best fit sphere), “J0” (with/against-the-rule astigmatism) and “J45” (oblique astigmatism) for 4 and 6 mm corneal diameters.

Zernike coefficients up to the 8th radial order describing the ocular wavefront aberrations at each measurement session, were exported from the COAS aberrometer and then averaged for each subject using custom written software for 4 mm (photopic) and 5.5 mm (scotopic) pupil sizes. These coefficients were further analysed to calculate higher-order root mean square (HO RMS), 2nd, 3rd and 4th order RMS for the baseline and contact lens wearing days. The total HO RMS, 2nd, 3rd and 4th order RMS wavefront error were calculated for all 14 subjects for a 4 mm pupil and for 10 subjects for a 5.5 mm pupil (as the pupil size for 4 subjects was less than 5.5 mm).

To study the statistical significance of changes due to contact lens wear, a repeated measures analysis of variance (ANOVA) was used with lens type and corneal region as within-subject factors (for analysis of corneal thickness and curvature changes), lens type and corneal diameter (for analysis of corneal refractive power changes) and lens type and pupil diameter (for the analysis of wavefront error changes). Degrees of freedom were adjusted using Greenhouse-Geisser correction to prevent any type 1 errors, where violation of the sphericity assumption occurred. Bonferroni adjusted pair-wise comparisons were carried out for individual comparisons. Linear regression and Pearson’s correlation were used to study the association between the changes in corneal thickness and anterior and posterior curvature changes in the central and peripheral corneal regions. The correlation was calculated for the mean of the results from all four lenses. All statistical analysis was carried out using SPSS (version 17.0) statistical software.

3. Results

A range of significant changes in corneal thickness, curvature and optics were found after 8 hours of contact lens wear. The following results are grouped under corneal curvature, thickness and refractive power and ocular wavefront error changes.

3.1. Anterior corneal axial curvature

The type of lens had a significant effect on the changes in anterior axial corneal curvature ($p<0.001$, repeated measures ANOVA). Figure 1 shows the group mean change in anterior axial corneal curvature (relative to the baseline day) for the four types of lenses. While the changes in curvature were relatively small, the PMMA/9.5 lens caused mainly corneal steepening, whereas the RGP lenses (RGP/9.5, RGP/10.5) caused flattening in both the central and peripheral anterior corneal surface. The PMMA/9.5 lens caused an average central corneal steepening of –0.05 ± 0.05 mm ($p=0.03$), while the RGP/10.5 lens led to significant flattening in the central (0.05 ± 0.04 mm, $p=0.007$) and peripheral (0.03 ± 0.02

mm, p<0.001) corneal regions. Corneal flattening that was significant only in the peripheral corneal region was also observed following wear of the RGP/9.5 lens (0.03 ± 0.02, p<0.001). Only small magnitude changes in corneal curvature were observed with the SiHy/14.0 lens, and these changes did not reach statistical significance.

3.2. Posterior corneal axial curvature

The type of lens also had a significant effect on the changes in posterior corneal axial curvature (p < 0.001, repeated measures ANOVA). Figure 2 shows the group mean change in posterior corneal curvature (compared to the baseline day) for the four lenses. The PMMA/9.5 lens caused flattening in both the central (0.09 ± 0.05 mm, p<0.001) and peripheral (0.04 ± 0.03 mm, p=0.006) cornea, whereas the RGP/9.5, RGP/10.5 and SiHy/14.0 lenses caused no significant changes.

3.3. Corneal thickness

Corneal thickness was significantly affected by the type of lens and there were also differences as a function of corneal region (both p<0.001, repeated measures ANOVA).The group mean change in corneal thickness (relative to the baseline day) with the four lenses is shown in Figure 3. The PMMA/9.5 lens caused the greatest level of corneal swelling in both the central (27.92 ± 15.49 µm, p<0.001) and peripheral (17.78 ± 12.11 µm, p=0.001) corneal regions. The RGP lenses RGP/9.5 and RGP/10.5 led to lesser amounts of corneal swelling, while the SiHy/14.0 lens showed smaller changes again, none of which were statistically significant. The corneal swelling seen with PMMA/9.5 lens was significantly greater than the swelling seen with the RGP/9.5, RGP/10.5 and SiHy/14.0 lenses in the central region and significantly more than the SiHy/14.0 lens in the peripheral annular region. There were no significant differences in corneal swelling following wear of the RGP and SiHy lenses.

3.4. Correlation between corneal curvature and thickness

A linear regression was performed on the corresponding measures of change in corneal curvature and thickness following wear of the lenses. A significant negative correlation between the change in central corneal thickness (swelling) and central (R^2 = 0.63, p=0.001, F = 20.03, slope B = –2.183) and peripheral (R^2 = 0.57, p=0.002, F = 16.22, slope B = –1.386) posterior corneal curvature change was found. Similarly, there was a significant negative correlation between the change in peripheral corneal thickness and central (R^2 = 0.74, p<0.001, F = 34.54, slope B = –2.328) and peripheral (R^2 = 0.69, p<0.001, F = 26.78, slope B = –1.487) posterior corneal curvature change. The change in anterior corneal curvature did not show a significant correlation with the changes in corneal thickness.

3.5. Anterior corneal refractive power changes

The change in anterior corneal best fit sphere (M) was significantly affected by lens type and the size of corneal diameter analysed (both $p<0.001$, repeated measures ANOVA). The group mean changes in M relative to the baseline day for the four types of lenses, for 4 and 6 mm corneal diameter are shown in Table 2. The PMMA/9.5 lens (0.11 ± 0.07 D, $p=1.00$) led to a slight increase in corneal power after lens wear that was not statistically significant, whereas the RGP/9.5 (–0.34 ± 0.05 D, $p<0.001$), RGP/10.5 (–0.44 ± 0.07 D, $p<0.001$) and SiHy/14.0 (–0.11 ± 0.03 D, $p=0.01$) lenses all caused a significant decrease in refractive power for a 6 mm corneal diameter and showed a similar trend for the smaller 4 mm pupil. Neither J0 nor J45 showed a significant effect of lens type or corneal diameter.

3.6. Ocular wavefront error changes

The type of lens had a significant effect on the total HO RMS, 2nd, 3rd and 4th order RMS wavefront error for both 4 mm (all $p\leq0.002$) and 5.5 mm (all $p\leq0.02$) pupil diameters. This effect was mainly due to the PMMA/9.5 lens which caused a significant increase in total HO RMS (0.09 ± 0.07 µm, $p=0.005$), 2nd (0.22 ± 0.19 µm, $p=0.009$), 3rd (0.08 ± 0.07 µ, $p=0.007$) and 4th (0.03 ± 0.04 µm, $p=0.05$) order RMS, while the RGP/9.5 lens also caused a small but significant increase in the 4th (0.02 ± 0.02 µm, $p=0.01$) order RMS, for the 4 mm pupil diameter (Table 3).

There was also a significant increase in the total HO RMS (0.29 ± 0.10 µm, $p=0.001$), 3rd (0.09 ± 0.06 µm, $p=0.01$) and 4th (0.06 ± 0.05 µm, $p=0.05$) order RMS with the PMMA/9.5 lens for the 5.5 mm pupil diameter (Table 3). The soft contact lens and the larger RGP/10.5 lens caused no significant changes in any of the wavefront terms.

4. Discussion

We investigated the effect of short-term (8 hours) wear of different types of contact lenses (RGP, PMMA and SiHy) on corneal thickness and curvature. Substantial corneal swelling following the wear of PMMA contact lenses has been widely documented in the literature [7, 27-29], and our results are consistent with these findings. We found significantly more corneal swelling with the PMMA contact lens compared to the RGP lenses as reported earlier by Fonn et al. [7] and the distribution of this swelling showed a greater magnitude in the central compared to the peripheral corneal region. The corneal swelling with the RGP lenses did not reach statistical significance, however on average a greater magnitude of swelling was observed in peripheral corneal regions compared to central regions following wear of both of the RGP lenses. The different pattern of corneal swelling with the PMMA and RGP lenses appeared to be consistent with the changes that were observed in corneal curvature (Figure 4). Overall, the PMMA lenses caused central corneal thickening, anterior

corneal steepening and posterior corneal flattening (Figure 4 a), whereas RGP lenses resulted in peripheral corneal thickening, anterior corneal flattening and posterior steepening (Figure 4 b). Silicone hydrogel lens wear had little effect on corneal thickness or curvature. The corneal swelling due to the PMMA lenses was of much higher magnitude than that observed with the RGP lenses, and was confined largely to the central cornea resulting in significant anterior corneal steepening and posterior flattening. The difference in the effects of PMMA and RGP on corneal thickness was expected, due to the difference in Dk of the two lens materials. The fitting characteristics of the RGP/9.5 and PMMA/9.5 lens were identical for these subjects, so the corneal curvature changes due to mechanical forces should also have been similar. However it is difficult to exactly apportion causative mechanisms to the corneal curvature changes, since the surface curvature can be affected by corneal swelling and direct mechanical forces such as those occurring with orthokeratology [30].

We also examined the change in the best fit sphero-cylinder of the anterior corneal surface refractive power with short-term wear of the different types of contact lenses. The results were similar for both 4 mm and 6 mm corneal diameters. The PMMA lens showed a small (but statistically insignificant) increase (more plus) in best fit sphere (M) which can be attributed to significant central corneal swelling observed with this lens. However there was a clinically and statistically significant decrease (mean of approximately 0.50 D, more minus) in best fit sphere (M) following 8 hours wear of the RGP lenses. This significant refractive power change may be due to a combination of mechanical forces on the central anterior surface of the RGP lens (causing slight flattening) and peripheral corneal swelling (causing slight flattening). We could find no reports of this short term lens induced minus power shift in the clinical literature, which suggests that it may be a transient occurrence, resolving within a few days of adaptation to lens wear. Further research investigating corneal refractive power changes with longer periods of RGP lens wear are required to clarify the time course of these changes.

The changes in curvature and thickness following SiHy lens wear were very small and not statistically significant. Similarly, the soft SiHy contact lens resulted in a clinically insignificant change in corneal refractive power best fit sphere (M). While the SiHy and RGP lenses had similar Dk/t values, the minimal corneal curvature and refractive power changes noted with the SiHy lens most likely relate to the lens being thinner and having a substantially lower modulus of elasticity, which would be expected to result in reduced mechanical forces acting on the corneal surface during lens wear. These results support the view that modern SiHy contact lenses produce little refractive power changes due to lens pressure or corneal swelling, whereas rigid contact lenses can alter the shape of the cornea and can produce considerable short-term changes in corneal refractive power.

To our knowledge there are no experimental studies reporting upon the residual effects of contact lens wear on ocular aberrations measured after lens removal. We found little change in the ocular aberrations after the wearing of the SiHy or RGP lenses, however the PMMA lenses caused substantial increases in all aspects of the higher order aberrations of the eye. These changes are likely to result in significant reduction in retinal image quality after lens removal, however during PMMA lens wear the post-lens tear layer would neutralize most of the higher order aberrations and thereby “mask” the loss in image quality. We conjecture that these changes in higher order aberrations may be at least in part be responsible for reports of “spectacle blur” associated with PMMA lens wear [31, 32], where the patient reports blurred vision after PMMA lens wear (but not during wear).

This study involved only 8 hours of wear of each of the lens types and therefore represents a snap-shot of the effects on corneal thickness, shape and the eye’s optics of the first day of contact lens wear. The modern RGP and SiHy contact lenses typically caused small and mainly clinically insignificant changes in the cornea (thickness and curvature) and ocular aberrations. On the other hand, identical contact lenses manufactured with the older PMMA material, resulted in significant central corneal swelling and diminished optical performance of the cornea. These changes with PMMA lenses were expected and highlight the improved performance of modern contact lens materials. However, the RGP lenses, even with corneal alignment fitting, led to slight anterior corneal flattening and a clinically significant hyperopic change in corneal refraction after the first day of lens wear. Longer term studies can tell us how long these changes persist in the cornea.

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Conflict of Interest

There are no conflicts of interest for any of the authors.

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Table 1: Details of the four lenses used in the study

Lens	PMMA/9.5	RGP/9.5	RGP/10.5	SiHy/14.0
Design (BOZR)	Spherical	Spherical	Spherical	Spherical
Design (BPZ)	Aspheric	Aspheric	Aspheric	-
Material	PMMA	RGP (Boston XO)	RGP (Boston XO)	Silicone Hydrogel
Power (Dioptre)	–0.5	–0.5	–0.5	–0.5
Mean BOZR (mm)	7.77 ± 0.32	7.77 ± 0.32	7.85 ± 0.30	8.6
Total diameter (mm)	9.5	9.5	10.5	14.0
BOZD (mm)	8.1	8.1	8.8	8.9
Water content (%)	0	0	0	36
Dk	0.1	100	100	99
Modulus (MPa)	≈ 2000 *	1500 **	1500 **	1.1 *
Manufacturing method	Lathe	Lathe	Lathe	Cast moulding
Centre thickness (mm)	0.18 ± 0.02	0.19 ± 0.01	0.20 ± 0.01	NA
Central Dk/t	0.06	52.6	50	82.5

NA: Not applicable, PMMA: poly methyl methacrylate, RGP: rigid gas permeable, SiHy: silicone hydrogel, BOZ: back optic zone, BPZ: back peripheral zone, BOZR: back optic zone radius, BOZD: back optic zone diameter, Dk: oxygen permeability, MPa: megapascal, unit of modulus of elasticity, mm: millimetres. Unit of Dk/t = (cm/sec) (mLO_2/mL X mmHg),

*** [33]**

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Table 2: Mean change in best fit sphere (M) in Dioptres, relative to baseline day with the four contact lenses for the 4 and 6 mm corneal diameter.

Lens	Mean change in M ± SD (Dioptres)	p-value	Mean change in M ± SD (Dioptres)	p-value
	4 mm diameter		**6 mm diameter**	
PMMA/9.5	0.19 ± 0.32	0.47	0.11 ± 0.24	1.0
RGP/9.5	–0.31 ± 0.22	**0.002**	–0.34 ± 0.17	**<0.001**
RGP/10.5	–0.49 ± 0.32	**0.001**	–0.44 ± 0.26	**<0.001**
SiHy/14.0	–0.13 ± 0.15	0.09	–0.11 ± 0.10	**0.01**

Negative change in M represents decrease in corneal refractive power (hypermetropic shift). Positive change in M represents increase in corneal refractive power (myopic shift). p-values indicating a significant change from baseline (p<0.05) are highlighted in bold.

Table 3: Mean change in total HO RMS, 2nd, 3rd and 4th order RMS, relative to baseline day with the four contact lenses for 4 mm (n=14) and 5.5 mm (n=10) pupil diameter. 'n' is the number of subjects included in the analysis.

Lens	Mean HO RMS change ± SD (µm)	Mean 2nd order RMS change ± SD (µm)	Mean 3nd order RMS change ± SD (µm)	Mean 4nd order RMS change ± SD (µm)
4 mm pupil				
PMMA/9.5	0.09 ± 0.07 **(p=0.005)**	0.22 ± 0.19 **(p=0.009)**	0.08 ± 0.07 **(p=0.007)**	0.03 ± 0.04 **(p=0.05)**
RGP/9.5	0.13 ± 0.13 (p=0.38)	–0.02 ± 0.15 (p=1.00)	0.03 ± 0.08 (p=1.00)	0.02 ± 0.02 **(p=0.01)**
RGP/10.5	0.01 ± 0.02 (p=0.80)	–0.10 ± 0.15 (p=0.27)	0.01 ± 0.03 (p=1.00)	0.01 ± 0.02 (p=1.00)
SiHy/14.0	–0.001 ± 0.01 (p=1.00)	–0.03 ± 0.10 (p=1.00)	0.002 ± 0.01 (p=1.00)	–0.004 ± 0.01 (p=1.00)
5.5 mm pupil				
PMMA/9.5	0.29 ± 0.10 **(p=0.001)**	0.26 ± 0.39 (p=0.62)	0.09 ± 0.06 **(p=0.01)**	0.06 ± 0.05 **(p=0.05)**
RGP/9.5	0.21 ± 0.09 (p=1.00)	–0.01 ± 0.31 (p=1.00)	0.12 ± 0.09 (p = 1.00)	0.03 ± 0.04 (p=1.00)
RGP/10.5	0.17 ± 0.07 (p=1.00)	–0.10 ± 0.26 (p=1.00)	–0.02 ± 0.06 (p=1.00)	0.01 ± 0.05 (p=1.00)
SiHy/14.0	0.10 ± 0.08 (p=1.00)	–0.09 ± 0.24 (p=1.00)	–0.02 ± 0.05 (p=1.00)	–0.01 ± 0.03 (p=1.00)

Positive change represents increase and negative change represents decrease. p-values indicating a significant change from baseline (p<0.05) are highlighted in bold.

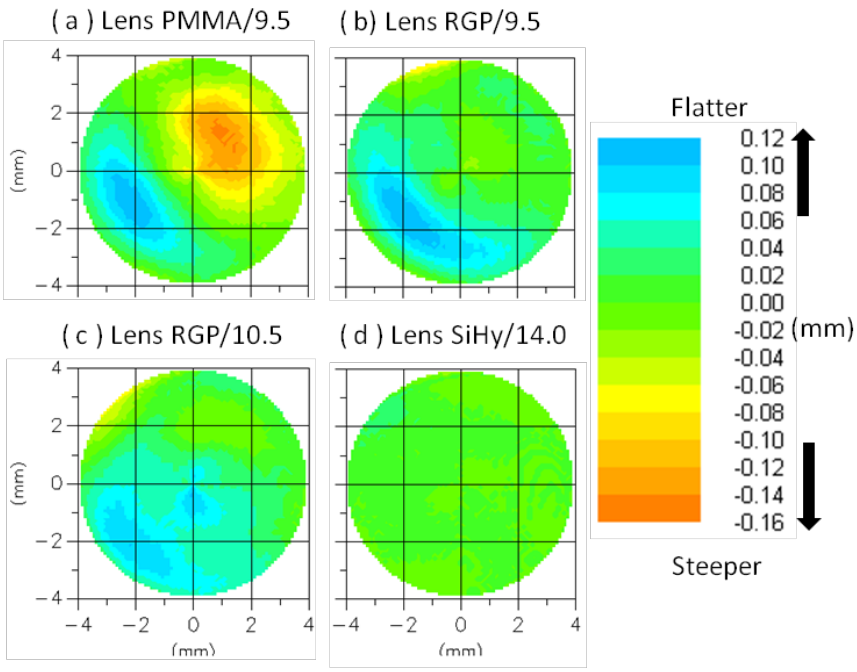

Figure 1: Group mean change in anterior axial corneal curvature (mm) relative to baseline day for the four different types of contact lenses. The lenses included different materials (PMMA, RGP and SiHy) and diameters (9.5, 10.5 and 14.0 mm). Details of the lenses are shown in Table 1. Positive change represents flattening and negative change represents steepening. Repeated measures ANOVA revealed the changes in the central region for the PMMA/9.5, the changes in the peripheral regions for the RGP/9.5 lens and both the central and peripheral regions for the RGP/10.5 were statistically significant. Changes with the SiHy lens were not significant.

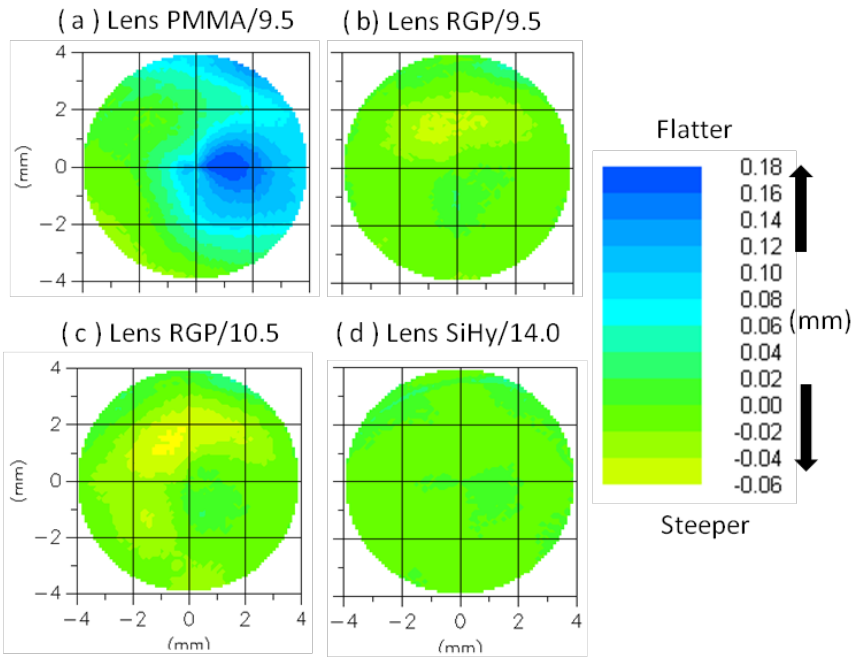

Figure 2: Group mean change in posterior axial corneal curvature (mm) relative to baseline day for the four different types of contact lenses. The lenses included different materials (PMMA, RGP and SiHy) and diameters (9.5, 10.5 and 14.0 mm). Details of the lenses are shown in Table 1. Positive change represents flattening and negative change represents steepening. Only the changes in posterior curvature in both the central and peripheral corneal regions with the PMMA/9.5 lens were statistically significant ($p<0.05$).

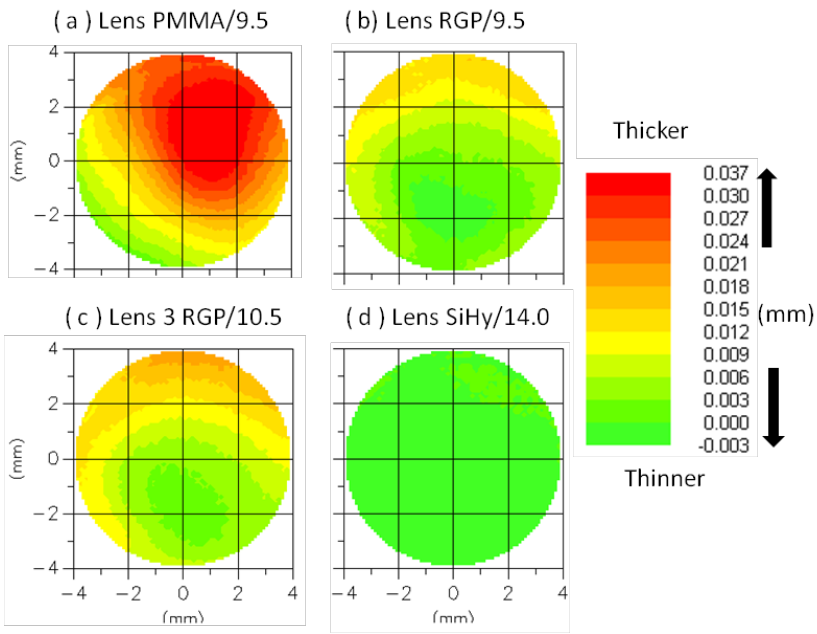

Figure 3: Group mean change in corneal thickness (mm) relative to baseline day for the four different types of contact lenses. The lenses included different materials (PMMA, RGP and SiHy) and diameters (9.5, 10.5 and 14.0 mm). Details of the lenses are shown in Table 1. Positive change represents swelling and negative change represents thinning. Only the changes in corneal thickness in both central and peripheral corneal regions with the PMMA/9.5 lens were statistically significant ($p<0.05$).

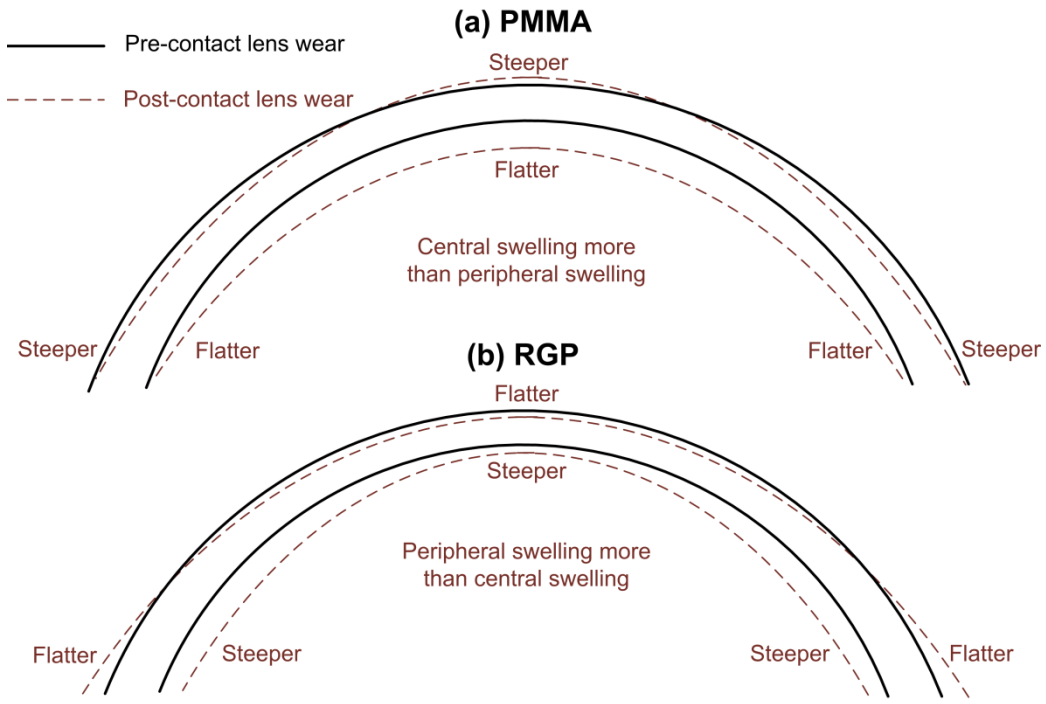

Figure 4: Schematic demonstration of anterior and posterior curvature and thickness of the cornea, before and after PMMA and RGP contact lens wear for 8 hours based on the experimental data. The solid lines represent the baseline anterior and posterior surfaces of cornea. The dotted line represents the anterior and posterior surfaces of the cornea after contact lens wear for 8 hours. (a) PMMA contact lens showed greater central corneal swelling compared to peripheral resulting in anterior corneal steepening and posterior corneal flattening. (b) RGP contact lens showed greater peripheral corneal swelling resulting in anterior corneal flattening and posterior corneal steepening. Note that the diagram is not to scale.