

Clark, C.A., P.S. Soni, and L.N. Thibos

Changes in Peripheral Refractive Error Due to Accommodation and Higher Order Aberrations

Invest. Ophthalmol. Vis. Sci., 2008. 49(5): p. 3326-.

Purpose Peripheral refractive error has been hypothesized to be a stimulus for myopia progression. In addition, myopia progression has been heavily associated with near work. To date, there is some question whether accommodation has an effect on peripheral refractive error as different studies have shown conflicting results. The purpose of this study is to examine the effects of accommodation on peripheral refractive error. **Methods** 20 subjects with refractive error in the range of +4.00 to -7.00 participated in this investigation. The Hartmann-Shack technique was used to measure the central and peripheral refractive error at $\pm 30^\circ$ in the nasal and temporal periphery along the horizontal meridian. A Badal optometer was installed to allow for targets at infinity and for a 3 diopter stimulus at near. Central and peripheral refractive error was measured with targets at distance and near. **Results** Peripheral refractive error was highly variable between subjects. Spherical aberration was correlated with accommodative changes in peripheral refractive error and explains much of the variance. This correlation was consistent with similar changes in peripheral refractive error and spherical aberration such as in orthokeratology. No other higher order aberrations were correlated with changes in peripheral refraction. **Conclusions** Changes in spherical aberration may have an association with changes in peripheral refractive error. If this is correct, it could explain some of the discrepancies between past studies. If peripheral refractive error is important for myopia progression, changes in spherical aberrations may be an important factor in determining progression.

Gifford, P., W. Au, B. Hon, *et al.*

Mechanism for Corneal Reshaping in Hyperopic Orthokeratology - Suction or Molding?

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Purpose To investigate the mechanism underlying hyperopic orthokeratology (OK) by comparing the short-term clinical effect of lenses before and after central lens fenestration. **Methods** Twelve subjects (age 21 to 24 years) were fitted with rigid hyperopic OK lenses (Capricornia Contact Lens Pty Ltd) in one eye only. The fellow eye acted as a non lens wearing control. Lens specifications were matched to provide the same post lens tear film profile in all subjects. Non-fenestrated lenses were worn in the open eye for 1 hour and in the closed eye for 4 nights. Subjective BVS refraction and corneal topography (Medmont E300) were measured at baseline, after 1hr lens wear, and within 1hr of waking on Days 1 and 4 of overnight lens wear. The lenses were then sent for three 0.75mm fenestrations within the central optic zone. The lens wearing and measurement procedures were then repeated. **Results** RE-ANOVA with post-hoc paired t-tests was employed to compare changes from baseline. BVS refraction changed after 1hr lens wear (0.46 ± 0.16 D), increasing to 0.81 ± 0.16 D by Day 4 with non-fenestrated lenses, and 0.38 ± 0.11 D increasing to 0.60 ± 0.10 D once fenestrations were applied ($p < 0.05$). Central corneal curvature steepened after 1hr (0.41 ± 0.18 D), increasing to 0.72 ± 0.17 D by Day 4 with non-fenestrated lenses, and 0.34 ± 0.12 D increasing to 0.78 ± 0.16 D once fenestrations were applied ($p < 0.05$). Average combined paracentral curvature flattened after 1hr (-0.33 ± 0.05 D), increasing to -0.62 ± 0.06 D by Day 4 with non-fenestrated lenses, and -0.37 ± 0.06 D increasing to -0.61 ± 0.06 D once fenestrations were applied ($p < 0.01$). There were no statistically significant differences between the lens types in either BVS refraction or corneal curvature changes. **Conclusions** A hyperopic OK effect was established in as little as 1 hour with increased effect with longer lens wearing time. Central fenestrations did not alter the clinical outcomes, indicating that lens compression in the paracentral region as opposed to central post lens tear film suction is the primary mechanism behind the hyperopic OK clinical effect. Further research is indicated to establish optimum lens curvature profiles within the compressive paracentral region to maximise the hyperopic OK treatment effect.

Hiraoka, T., C. Okamoto, Y. Ishii, *et al.*

Recovery of Corneal Irregular Astigmatism, Ocular Higher-Order Aberrations, and Contrast Sensitivity After Discontinuation of Overnight Orthokeratology

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Purpose Overnight orthokeratology has been reported to increase corneal irregular astigmatism and ocular higher-order aberrations, and reduce contrast sensitivity function. It remains unknown, however, whether these changes completely recover after discontinuation of orthokeratology. We conducted the current 13-month prospective study to address this question. **Methods** Thirty-four eyes of 17 subjects who underwent overnight orthokeratology for 12 months were included in the study. Their mean age was 23.9 ± 3.5 years (mean \pm standard deviation). Manifest refraction, corneal topography, wavefront aberrometry, high-contrast visual acuity test, and contrast sensitivity test were performed at baseline, 12-month after commencement of the procedure, and 1 week and 1 month after discontinuation of the treatment. Asymmetry and higher order irregularity components were calculated in the central 3-mm zone by using Fourier analysis of the corneal topography data. Ocular higher-order aberrations for a 4-mm pupil were measured, and the root-mean-square (RMS) of the third- and fourth-order aberrations was determined. Contrast sensitivity was assessed at four spatial frequencies, and the area under the log contrast sensitivity

function (AULCSF) was calculated. Results Overnight orthokeratology significantly reduced manifest spherical equivalent refraction ($P < 0.0001$, paired t-test), and significantly improved uncorrected visual acuity (UCVA) at 12 months after commencement of the procedure ($P < 0.0001$). Asymmetry and higher order irregularity components significantly increased ($P < 0.0001$, $P = 0.0045$, respectively), and third- and fourth-order RMS of wavefront aberration also significantly increased after the procedure ($P < 0.0001$). The treatment resulted in significant decreases in AULCSF ($P = 0.0033$). After discontinuing lens wear, asymmetry component, higher order irregularity component, third-order RMS, fourth-order RMS, and AULCSF fully returned to the baseline level within 1 week. Spherical equivalent and UCVA recovered to the pre-treatment level at 1 month after ceasing orthokeratology. Conclusions The current study confirmed that the effect of overnight orthokeratology is completely reversible in light of optical quality of the eye and quality of vision as well as refraction and visual acuity. The full recovery of corneal irregular astigmatism, ocular higher-order aberrations, and contrast sensitivity was faster than that of refraction and UCVA.

Liu, Y., J. Hsieh, and C.F. Wildsoet

A Study of the Repeatability of Peripheral Refraction Measurements and the Effects of Orthokeratology (OrthoK) Contact Lens Wear

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Purpose To examine the reliability of cycloplegic peripheral refraction measurements using Grand Seiko WR-5100K autorefractor and the effect of OrthoK lens wear on peripheral refractions. Speculation that peripheral refractive errors underlie myopia development and progression motivated this study. Methods Peripheral refractive errors were measured at 5-degree intervals out to 35 degrees eccentricity using Grand Seiko WR-5100K autorefractor with an add-on red LED fixation bar at 50cm. Both eyes of 27 young adult subjects (mean age: 24.3yr; mean RE: $-3.39A{\pm}1.08D$) were measured under very low room illumination, 20 minutes after instillation of a combination of 1% proparacaine, 2.5% phenylephrine, and 0.5% tropicamide. For each subject, baseline data were obtained within 1 week prior to the start of the OrthoK treatment, a 2nd set of data being collected approximately 1 month later, after vision had stabilized with overnight wear of OrthoK contact lenses. Refractions were converted to vector form; derived mean sphere (M), 90A{degrees} to 180A{degrees} astigmatism (J180), and 45A{degrees} to 135A{degrees} (J45) were then subject to multivariable regression ($y=ax^2+bx+c$; critical p-value of 0.05), paired t-test and descriptive analyses with OrthoK treatment as the major explanatory variable, adjusting for baseline central refraction, baseline corneal asphericity, within-subject correlation, and inter-ocular variability. Results Prior to OrthoK treatment, subjects showed either little change in mean sphere refraction with eccentricity or relative hyperopia compared to their central refraction. The OrthoK treatment decreased significantly myopic errors within A{+/-}10A{degrees} (M: $-0.06 A{\pm}0.43$, 0A{degrees}), but caused significant relative myopic shifts in the A{+/-}10-30A{degrees} zone (e.g., M shift: $-1.73 A{\pm}1.44D$, 20A{degrees}), with relatively little change beyond A{+/-}30A{degrees} of eccentricity (e.g., M shift: $-0.49 A{\pm}1.52D$, 35A{degrees}). The M and J45 components showed good repeatability at all eccentricities while the repeatability of the J180 component decreased significantly beyond A{+/-}30A{degrees} after OrthoK treatment, presumably due to the high irregularity of the cornea in this transition zone. Conclusions The Grand Seiko WR-5100K autorefractor with add-on fixation bar allows reliable measurement of peripheral refractive errors out to 30A{degrees} eccentricity in OrthoK-treated subjects. If peripheral relative hyperopia is a risk factor for the progression of myopia, as speculated by others, then OrthoK is a plausible myopia control treatment, given that they are significantly reduced by this treatment.

Swarbrick, H.A. and J.H. Yoon

Posterior Corneal Shape Changes in Overnight Orthokeratology

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Purpose To investigate posterior corneal shape changes in overnight orthokeratology (OK) over 14 nights wear of reverse geometry rigid gas-permeable (RGP) contact lenses. Methods Eighteen young adult subjects (19-32 yrs) with low myopia ($<-4.00D$) and astigmatism ($<1.50D$) were fitted with OK lenses (BE; Capricornia Contact Lens, Brisbane, Australia) in Boston XO material (nominal Dk/t 46). Lenses were worn overnight only for 14 days. Another group of 10 subjects (19-32 yrs) with low astigmatism ($<1.50D$) wore J-Contour conventional RGP lenses (Capricornia Contact Lens) in Boston XO material (nominal Dk/t 56) for one night. Corneal topographic data using the Medmont E300 topographer (Medmont, Camberwell, Australia), and total corneal thickness using the Holden-Payor optical pachometer across the horizontal meridian were measured at baseline and 8-10 hours after lens removal on Days 1, 4, 7 and 14 of overnight OK lens wear, and after one night of RGP lens wear. Posterior corneal apical radius of curvature R_o and asphericity Q were calculated using an in-house program based on the anterior corneal ellipsoid curve and corneal thickness. Repeated measures ANOVA with protected post hoc paired t-tests was used to compare changes from baseline with a critical p-value of 0.05. Results Myopia reduced from $-2.64 {\pm} 0.99D$ (mean ${\pm}$ SD) to $-0.39 {\pm} 0.49D$ over 14 days of overnight OK lens wear. In the OK lens-wearing eyes, there were no statistically significant changes in posterior R_o ($p > 0.141$) over the lens-wearing period. However

there were significant increases in posterior Q on days 4 ($p=0.007$) and 7 ($p=0.002$). In the conventional RGP lens-wearing eyes, there were no significant changes of either posterior Ro or Q after overnight lens wear. ConclusionsThe results of this study demonstrate that overnight OK lens wear does not cause flattening of the central posterior corneal curvature, at least in the first two weeks of lens wear. This supports the current hypothesis that the OK refractive effect is achieved primarily through remodelling of the anterior corneal layers. Changes in posterior corneal asphericity towards an oblate shape implicates mid-peripheral corneal changes in the response to OK lens wear.

Yoon, J.H. and H.A. Swarbrick

Posterior Corneal Shape Changes With Overnight Corneal Edema in Rigid Conventional and Orthokeratology Lens Wear

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PurposeTo evaluate the influence of overnight corneal edema on posterior corneal shape during sleep, and conventional and orthokeratology (OK) rigid gas-permeable (RGP) lens wear. MethodsEighteen young adult subjects (19-32 yrs) with low myopia ($<-4.00D$) and astigmatism ($<1.50D$) were fitted with reverse geometry OK lenses (BE; Capricornia Contact Lens, Brisbane, Australia) in Boston XO material (nominal Dk/t 46). Lenses were worn overnight only for 14 days. A separate group of 10 subjects (19-32 yrs) wore J-Contour conventional RGP lenses (Capricornia Contact Lens) in Boston XO material (nominal Dk/t 56) for one night in one eye only. Posterior corneal apical radius of curvature (Ro; mm) and asphericity Q were calculated using an in-house program based on the anterior corneal ellipsoid curve measured using the Medmont E300 topographer (Medmont, Camberwell, Australia) and corneal thickness measured with the Holden-Payor optical pachometer across the horizontal meridian. Data were collected at baseline and within 1 hr of eye opening. Repeated measures ANOVA with planned comparisons was used to compare changes from baseline, with a critical p-value of 0.05. ResultsIn the non-lens wearing eye there were no changes in posterior Ro or Q after sleep. In the conventional RGP lens-wearing eyes, there was significant flattening of posterior Ro ($p=0.001$) and significant increases (towards oblate) in posterior Q ($p=0.001$) after overnight lens wear. In the OK lens-wearing eyes, myopia reduced from $-2.64 \{+/-\} 0.99D$ (mean $\{+/-\}$ SD) to $-0.39 \{+/-\} 0.49D$ over 14 days of overnight OK. There was significant steepening of posterior Ro in the morning on days 7 and 14 ($p<0.001$). Moreover, there were significant increases in posterior Q on days 1 ($p<0.001$) and 4 ($p=0.011$). In contrast, there was a significant decrease in posterior Q on day 14 ($p=0.013$). ConclusionsThe findings of this study are consistent with previous research demonstrating inhibition of central edema in overnight OK, but a normal edema response in the mid-periphery. Analysis relative to a fixed 8mm chord demonstrates that the cornea swells in a posterior direction with overnight edema.

Clark, C., J. Shen, P. Soni, and L. Thibos

Peripheral Refractive Error With Spherical, Multifocal, and Orthokeratology Correction

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PurposePeripheral refractive error has been hypothesized to be a stimulus for myopia progression. We have shown that when the central vision of a myope is corrected with soft contact lenses, the peripheral refractive error tends towards hyperopia which may be the stimulus for local compensatory eye growth. Hence, it is important to understand the effects of various corrective devices on the peripheral refractive error. The purpose of this study is to determine the effect of currently available corrective methods on central and peripheral refraction along the horizontal visual field. Methods8 subjects with refractive error in the range of -1.00 to -5.00 participated in this investigation. The Hartmann-Shack technique was used to measure the central and peripheral refractive error at $5\{\text{degrees}\}$ intervals out to $\{+/-\}35\{\text{degrees}\}$ in the nasal and temporal periphery along the horizontal meridian in uncorrected and corrected eyes. Corneal topographical data was collected before, with and after lens wear. The refractive and corneal topographical data was collected with spherical contact lenses, back surface aspheric multifocal contact lenses, and after orthokeratology treatment. ResultsCentral and peripheral refractive error at baseline and with the spherical contact lenses was consistent with previous results showing a tendency to higher degree of hyperopic refractive error in the periphery for myopes. Multifocal contact lenses showed a mild myopic shift in refractive error between $15\{\text{degrees}\}$ temporal and nasal, but returned to baseline further into the periphery. Peripheral refractive error showed a decrease in hyperopia and increase in myopia following orthokeratology treatment. Corneal topography showed a correlation with changes noted in peripheral refractive changes up to $15\{\text{degrees}\}$ temporal and nasal. ConclusionsContact lenses show a potential for correcting peripheral refractive error. Back surface aspheric multifocal contact lenses show a potential for peripheral correction, but may not adequately correct peripheral refractive error at this time. Orthokeratology was better at correction of the periphery. Corneal topography offers a potential way to monitor changes in the peripheral refractive error which may be improved with off axis topography.

Gifford, P. and H.A. Swarbrick

Time Courses of Corneal Topographic Changes in the First Week of Overnight Hyperopic Orthokeratology

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PurposeTo investigate the time course of refractive and corneal topographic changes in overnight hyperopic orthokeratology (OK) lens wear, over a 7-day lens-wearing period. **Methods**Ten subjects (age 20 to 33 years) were fitted with bi-aspheric rigid lenses designed for hyperopic OK (Capricornia Contact Lens Pty Ltd), in one eye only. The fellow eye acted as a non lens wearing control. Lens specifications were matched to provide the same post lens tear profile in all subjects. The lenses were worn overnight only over a 7-day period and changes in subjective refraction, corneal apical radius and asphericity (Medmont E-300) were measured. The dimensions of the steepened treatment area were measured from the topography plots using standard techniques. Repeated-measures ANOVA with post-hoc paired Student t-tests were employed to compare changes from baseline, with a critical p-value of 0.05. **Results**Most refractive change occurred after the first night of hyperopic OK lens wear ($1.03\{\pm\}0.25\text{D}$), reaching $1.45\{\pm\}0.35\text{D}$ by day 7 ($p<0.01$). Retention of refractive effect at the end of the day improved with increasing nights of lens wear ($0.64\{\pm\}0.25\text{D}$ on day 1 vs $1.18\{\pm\}0.44\text{D}$ on day 7, $p<0.01$). Most corneal topographic change also occurred after the first night of lens wear, with increasing effect towards day 7 (change in apical radius: $-0.13\{\pm\}0.03\text{mm}$ increasing to $-0.18\{\pm\}0.07\text{mm}$, $p<0.01$; change in asphericity Q: $-0.36\{\pm\}0.07$ increasing to $-0.52\{\pm\}0.18$, $p<0.01$). Both horizontal and vertical treatment zone dimensions increased during the day on day 1 (H: $+0.42\{\pm\}0.39\text{mm}$, V: $+0.42\{\pm\}0.41\text{mm}$, $p<0.05$) and day 7 (H: $+0.31\{\pm\}0.32\text{mm}$, V: $+0.92\{\pm\}0.61\text{mm}$, $p<0.05$). **Conclusions**The time course of refractive and corneal topographic change in hyperopic OK is analogous to myopic OK. Most of the change in refractive and topographic variables occurs on day 1, with regression of effect during the day, but greater retention of effect by day 7. Interestingly, throughout the day while lenses were not worn, the treatment zone dimensions increased. Further research is indicated to establish the mechanisms underlying this unexpected effect, and to define the timeframe to reach the endpoint of hyperopic OK treatment.

Hiraoka, T., C. Okamoto, F. Okamoto, *et al.*

Influence of Decentered Treatment of Orthokeratology on Ocular Higher-Order Wavefront Aberrations

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PurposeTo investigate the relation between decentration of corneal central flattened area after orthokeratology and ocular higher-order wavefront aberrations. **Methods**Subjects were 46 eyes of 23 patients undergoing overnight orthokeratology for myopia. Mean age was $24.2\{\pm\}3.3$ years (range 21 to 33), and mean spherical equivalent before treatment was $-2.38\{\pm\}0.98\text{D}$ (range -1.00 to -4.00). Decentration of central flattened area was determined by computerized videokeratography (TMS-4, Tomey). On the instantaneous power map at 3-month follow up visit, sixteen points were plotted along an equi-refractive-power line surrounding the central flattened area. On the basis of these plotted points, an approximate ellipse and its center were determined using a data analysis software (MATLAB(R), Cybernet systems). The degree of decentration was calculated as the distance between the center of the ellipse and the center of the entrance pupil. Simultaneously, ocular higher-order aberrations for a 4-mm pupil were measured using the Hartmann-Shack aberrometer (KR-9000PW, Topcon), and the relationship between the decentration and higher-order aberrations was analyzed. **Results**The decentration was $0.85\{\pm\}0.51\text{mm}$ (range 0.17 to 2.05), which significantly correlated with 3rd order aberration (RMS) (Pearson, $r=0.662$, $p<0.0001$) and 4th order aberration (RMS) ($r=0.566$, $p<0.0001$). The decentration also showed significant correlation with the amount of myopic correction ($r=0.332$, $p=0.0269$). **Conclusions**The larger the decentration of orthokeratology treatment was, the greater the induction of ocular higher-order aberrations was. These changes depended on the amount of myopic correction. For better optical quality of the eye, the fitting and centration of the treatment lens should be strictly performed, and large myopic correction should be avoided in orthokeratology practice.

Lum, E., J. Kim, L. Lin, *et al.*

Corneal Topographic Correlates of Refractive Error Change in Orthokeratology

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PurposeTo investigate differences in corneal topographic variables for two different targeted refractive error corrections in overnight orthokeratology (OK) lens wear, over an 8-day lens-wearing period. **Methods**Thirteen subjects (age 21 to 27 years) were fitted with reverse-geometry lenses for OK (MeniconZ CRT; Paragon Vision Sciences, Arizona, USA) in both eyes. Lenses in matched designs and fittings but different targeted refractive error corrections (-1.00DS and -4.00DS) were worn overnight only in the two eyes over an 8-day period. Changes in subjective refraction, corneal apical radius and asphericity (Medmont E-300) were measured. The diameter of the treatment zone was measured from the topography plots using standard techniques. Paired Student t-tests were employed to compare changes from baseline between the

two targeted corrections, with a critical p-value of 0.05. Results After eight days of overnight OK lens wear, there were statistically and clinically significant differences between the two eyes (-1.00DS versus -4.00DS target refractive correction) for changes in refraction (best vision sphere; -1.32 ± 0.49 D vs. -2.54 ± 0.97 D; $p < 0.01$), corneal apical radius (0.20 ± 0.04 mm vs. 0.42 ± 0.13 mm; $p < 0.001$) and asphericity Q (0.17 ± 0.13 vs. 0.28 ± 0.14 ; $p < 0.01$). There was no significant difference between the two eyes in the treatment zone diameter along the horizontal (4.95 ± 0.65 mm vs. 5.09 ± 0.55 mm; $p > 0.05$) or vertical (5.13 ± 0.54 mm vs. 5.43 ± 0.76 mm; $p > 0.05$) meridians. Conclusions Differences in targeted refractive error correction in overnight OK do not appear to influence the size of the treatment zone in the short term, over the range of myopic corrections studied. This challenges traditional thinking which assumes that treatment zone diameter decreases as the refractive error correction increases. Analysis of more complex aspects of corneal shape and power changes across the treatment zone appears to hold the key to explaining differences in refractive outcomes in overnight OK.

Matsubara, M., S. Takeda, K. Mukai, and Y. Ishii

PMMA, Medium- or High-Dk RGP Orthokeratology Extended Wear; Histological Outcomes in Rabbit Corneas After One Week Extended Wear

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Purpose To determine the relationship between hypoxia and redistribution of epithelial cells with different Dk orthokeratology lens (OK lens) wear by comparing the histological effect on the rabbit corneal epithelium. Methods Rabbits ($n=18$) were fitted with either a Dk 0 (PMMA), 33 or 95 OK lens and sacrificed after one week of continuous wear. HE, PAS and enzyme staining were performed on corneal tissues obtained from them. Results Redistribution of epithelial thickness was found in every cornea regardless of Dk values. At the area corresponding to the alignment curve zone of OK lens, the epithelium was thick with increased layers as many as 10 to 12. Epithelial edema was not observed. Central epithelium was very thin or detached in Dk 0 group. PAS staining showed decreased glycogen granules in basal cells in Dk 0 group whereas no change was found in other groups. Lactic dehydrogenase and alkaline phosphatase showed slightly strong stainings, but there was no difference among the groups. Conclusions No conspicuous histological changes after adapted 1 week continuous wear of OK lens with Dk 33 or 95 suggest the good potential of epithelial adaptation to orthokeratology.

Tsukiyama, J., Y. Miyamoto, S. Higaki, *et al.*

Changes in the Anterior and Posterior Radii of the Corneal Curvature and Anterior Chamber Depth by Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2007. 48(5): p. 5384-.

Purpose To investigate the mechanism for the refractive effect of orthokeratology using measurements of the anterior and posterior radii of the corneal curvature and anterior chamber depth with PentacamTM analysis system. Methods Subjects were 9 women (18 eyes, mean age 29.6 ± 3.8 years) with low to moderate myopia. All subjects were recruited to a 53-week trial of overnight orthokeratology using RD-171K lens (hexafoconA). After wearing orthokeratology lenses overnight, subjects were examined at daytime. With PentacamTM analysis system, subjects were examined in 2, 4, 8, 12, 24, 36, and 53 weeks for the assessment of the anterior and posterior radii of the corneal curvature and the anterior chamber depth. Results Myopic refractive error significantly reduced (ANOVA, $p < 0.001$). The refractive error was -2.85 ± 0.46 D at the base line and significantly reduced to -0.28 ± 0.65 D in 2 weeks (Bonferroni/Dunn post-hoc test, $p < 0.01$). A significant correlation was observed between the amount of change in central anterior radius of corneal curvature and the change in the refractive error at the 24 weeks (Pearson correlation coefficient, $r=0.57$, $p < 0.05$). However, in any weeks, no significant differences were seen in either the central posterior radius of corneal curvature (ANOVA, $p=0.55$) or the anterior chamber depth (ANOVA, $p=0.69$). Conclusions Overnight orthokeratology lens wear alters the anterior corneal shape rather than the posterior radius of corneal curvature and the anterior chamber depth. This suggests that the primary factor behind the refractive effect of orthokeratology is change in the anterior corneal shape rather than the overall corneal bending.

Berntsen, D.A., G.L. Mitchell, and J.T. Barr

Changes in Refractive Error-Specific Quality of Life After Overnight Contact Lens Corneal Reshaping

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Purpose: To determine the effect of Corneal Refractive Therapy (CRT) on refractive error-specific quality of life. Methods: The National Eye Institute Refractive Error Quality of Life Instrument (NEI RQL-42) was administered to 20 myopic patients (mean spherical equivalent -3.11 ± 0.96 D) between the ages of 18 and 39 years both before and 1 month after being successfully fitted with Paragon CRT lenses. High- and low-contrast best-corrected visual acuity (BCVA) and higher-order aberrations were also measured. Scores for the 13 NEI RQL-42 subscales were calculated and a Wilcoxon Sign Rank test was used to determine whether there was a significant change in each of the subscale scores. Results: Statistically significant

changes were found in 3 of the 13 NEI RQL-42 subscales. Significant improvements in subscale score were found for the symptoms (mean {+/-} SD; 10.18 {+/-} 10.57, $p = 0.0007$) and dependence on correction (43.13 {+/-} 27.42, $p < 0.0001$) subscales. A significant reduction was found in the glare subscale (-32.50 {+/-} 35.22, $p = 0.001$). No significant changes were found in the clarity of vision, expectations, near vision, far vision, diurnal fluctuations, activity limitations, worry, suboptimal correction, appearance and satisfaction with correction subscales. Conclusions: CRT may improve a patient's perception of their visual independence, decrease the amount of ocular symptoms they report, and increase symptoms of glare. The increase in patient reported glare is likely due to measured increases in higher-order aberrations after CRT, especially spherical aberration under mesopic and scotopic conditions.

Calossi, A., M. Romano, F. Romano, and G. Ferraioli

Overnight Orthokeratology Flattening the Cornea Without Direct Compression of the Center

Invest. Ophthalmol. Vis. Sci., 2006. 47(5): p. 100-.

Purpose: One of the concerns in orthokeratology is central epithelial thinning induced by a direct compression of the optical zone of the cornea. We think it is possible to produce central flattening, by affecting the periphery of the cornea, and we designed a lens geometry that would aid the displacement of peripheral epithelium towards the optical zone. Our biomechanical hypothesis is that the central flattening might be secondary to a mid-peripheral steepening, induced by a displacement of the epithelium that results from a proper compression in the peripheral alignment zone of this lens. **Methods:** We fitted 28 eyes of 14 myopic patients (ranging from -1.00 to -4.25 D sph, and astigmatism up to 1.00 D) with an hexa-curve reverse geometry design that attempts to mold the periphery of the cornea with a minimum compression in the centre (hexafocon-A material). Assessment criteria included UCVA, BCVA, manifest refraction, ultrasound pachymetry, corneal topography, and biomicroscopy. These data were collected at baseline, and then after one night, one week, two weeks, one month, and three months of overnight lens wear. All the examinations were performed in the morning immediately after lens removal and repeated in the evening of the same day. **Results:** The cornea responded rapidly with significant ($p < 0.05$) central corneal flattening and improvement in visual acuity after the first night of contact lens wear. By the end of one week, all corneal and visual changes had reached a maximal level and remained stable during the day. These changes were sustained at the following visits. After the first molding, the fluorescein pattern showed a clearance under the center of the lens that demonstrated a minimal central touch. Biomicroscopy showed no significant ocular adverse events. The average pre-treatment CCT was 533 +/- 31 micron. During the period of the study, ultrasound pachymetry did not show any significant change in the central thickness of the cornea (repeated measures ANOVA: $p = 0.978$), both in the morning and in the evening (Bonferroni/Dunn post-hoc test: $p > 0.414$). **Conclusions:** The absence of change found in the central pachymetry suggests that this overnight contact lens design can successfully flatten the cornea without direct compression of the center. The absence of change in CCT during the day seems to exclude a masking effect due to edema. Contrary to our finding, the majority of previous studies reported that orthokeratology caused epithelial and total central corneal thinning. This difference could be caused by differing lens geometry and differing lens behavior during overnight.

Lu, F., T. Simpson, L. Sorbara, and D. Fonn

Moldability of the Ocular Surface in Response to Local Mechanical Stress

ARVO 2006 Annual Meeting, 2006.

Purpose: To determine the moldability of the ocular surface by examining the acute effects of local mechanical stress on optical performance, corneal shape and corneal/epithelial thickness after corneal refractive therapy for myopia and hyperopia (CRT® and CRT®H).

Methods: 20 ametropes (spherical equivalent: -2.08 ± 2.31 D) wore CRT® and CRT®H lenses in a random order on one eye (randomly selected). The lenses were worn for three separate time periods of 15min, 30min and 1 hour (randomly ordered, with each time period taking place on a separate day). Refractive errors, aberrations, corneal topography, and corneal/epithelial thickness (using OCT) were measured before and after the lens wear. The measurements were performed on the control eyes at the 1 hour visit only. **Results:** With both CRT® and CRT®H lens wear, significant changes occurred in many parameters from the 15min time point. Refractive error, total aberration and defocus decreased after CRT® lens wear (all $p < 0.05$) and increased after CRT®H lens wear from baseline (all $p < 0.05$). Astigmatism did not change (both $p > 0.05$). Higher order aberration (HOA), including spherical aberration (SA) and coma, increased after CRT® and CRT®H lens wear (all $p < 0.05$) from baseline, but the signed SA shifted from positive to negative after CRT®H lens wear ($p < 0.05$). The central cornea flattened and the mid-periphery steepened after CRT® lens wear, whereas the central cornea steepened and mid-periphery flattened after CRT®H lens wear ($p < 0.05$). The central cornea swelled less than the mid-periphery after CRT® lens wear ($p < 0.05$), whereas the central cornea swelled more than the mid-periphery after CRT®H lens wear ($p < 0.05$). The central epithelium was thinner than the mid-periphery after CRT® lens wear ($p < 0.05$) and thicker than the mid-periphery after

CRT®H lens wear ($p < 0.05$). Optical performance and corneal curvature did not change from baseline in the control eyes (all $p > 0.05$).

Conclusions: CRT® lenses for myopia and hyperopia induce significant structural and optical changes in as little as 15min. The cornea is a highly moldable tissue.

Papas, E.B., A. Petznick, F. Stapleton, and Q. Garrett

Involvement of Matrixmetalloproteinase-9 (MMP-9) and Tissue Inhibitor of Matrixmetalloproteinase-1 (TIMP-1) During Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2006. 47(5): p. 117-.

Purpose: Despite the increase in the popularity of orthokeratology, the mechanisms by which corneal flattening occur are poorly understood. We hypothesise that upon initial wear of orthokeratology lenses, the mechanical stress may induce corneal epithelial cells to release MMP-9 and a disturbance of the tightly regulated ratio between MMP-9 to its inhibitor, TIMP-1, might lead to central corneal flattening. This study was to investigate the involvement of MMP-9 and TIMP-1 during orthokeratology. Methods: In the randomised and controlled clinical trial study, five subjects wore orthokeratology (Ortho-K) lens in one eye leaving the fellow eye as a control for the time periods of 1, 3, 7 and 15 hours. At the end of lens wear, the tears were collected for the measurement of MMP-9 or TIMP-1 expression using ELISA. The activity of MMP-9 was determined using gelatin zymography. Corneal topography was measured to confirm corneal flattening. Results: Ortho-K lens wear caused significant corneal flattening ($p < 0.01$). A greater amount of MMP-9 and greater amount of MMP-9 activity were found in the tears of lens wearing eyes than control eyes. Furthermore, both the amount and the activity of MMP-9 in the tears increased with the length of lens wear. There was no difference in TIMP-1 expression between lens wearing or control eyes, and no difference in TIMP-1 expression regardless of lens wear duration. Conclusions: A trend toward increasing MMP-9 expression during orthokeratology lens wear was found, suggesting that epithelial cell migration from the central cornea to the mid-periphery mediated by MMP-9 activity may be one of the mechanisms for orthokeratology.

Romano, M.R., A. Calossi, F. Romano, and G. Ferraioli

Intra-Ocular Pressure After Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2006. 47(5): p. 2391-.

Purpose: To investigate the influence of overnight orthokeratology on intra-ocular pressure (IOP). On one hand we could suppose an increase of IOP caused by the continue overnight pressure of the contact lens on the cornea, on the other hand we could have falsely low IOP readings due to the variation in corneal biomechanics as observed in corneal refractive surgery. Methods: We fitted 28 eyes of 14 myopic patients aged from 17 to 44 years with a baseline spherical equivalent ranging from -1.00 to -4.25 D, and astigmatism up to 1.00 D with a hexa-curve reverse geometry lens design (ESA ortho-6) in hyper-Dk gas-permeable material (Boston XO, hexafocon-A). Assessment criteria included UCVA, BCVA, manifest refraction, ultrasound pachymetry, corneal topography, biomicroscopy and Goldmann applanation tonometry. These data were collected at baseline, and then after one night, one week, two weeks, one month, and three months of overnight lens wear. All the examinations were performed in the morning immediately after lens removal and repeated in the evening of the same day. Results: The cornea responded rapidly with significant ($p < 0.05$) central corneal flattening and improvement in visual acuity after the first night of contact lens wear. By the end of one week, all corneal and visual changes had reached a maximum level and remained stable during the day. These changes were sustained at the following visits. Biomicroscopy showed no significant ocular adverse events. With this lens design, there was no significant change in central pachymetry. The average pre-treatment IOP was 13.6 ± 1.9 mmHg. The analysis of variance showed no statistically significant IOP variation during all the period of the study (repeated measures ANOVA: $p = 0.096$). After the first week of treatment Goldmann tonometry showed that IOP readings tend to be lower (1.57 mmHg), but this difference was not statistically significant (Bonferroni/Dunn post-hoc test). At each visit, there was no difference between the morning and evening IOP readings (Bonferroni/Dunn post-hoc test). Conclusions: These minimum changes found in IOP reading during the period of the study suggests that this overnight contact lens design can successfully flatten the cornea without an increasing risk of glaucoma. The absence of significant change in IOP during the day seems to exclude a masking effect, due to the overnight compression of the cornea, on IOP measurement errors induced by corneal variation.

Stillitano, I.G., A. Hofling-Lima, P. Schor, *et al.*

Wavefront-Guided Corneal Reshaping Analysis

Invest. Ophthalmol. Vis. Sci., 2006. 47(5): p. 62-.

Purpose: To analyze wavefront-guided changes of lower-order and higher-order optical aberrations (HOA) after corneal reshaping by overnight orthokeratology (ortho-k) for low to moderate myopia and low myopic astigmatism correction. Methods: Twenty randomly eyes (10 patients) exhibiting sphere from wavefront -1.00D to -3.63D and astigmatism up to -1.59D were prospectively analyzed during pre-test and after 1, 8, 30,

90 nights of customized ortho-k lens therapy (Be Free, Mediphacos Ltda, Belo Horizonte, Brazil). Wavefront measurements of lower and HOA deviate into Zernike polynomials were determined for pupil size of 6.5 mm and performed by the LADARWave Shack-Hartmann aberrometer (Alcon Laboratories). Optical aberrations were quantitatively analyzed using RMS (root mean square) coefficient values. Data on sphere, cylinder, defocus, total RMS, HOA RMS, spherical aberration and total coma (T-coma), horizontal (H-coma) and vertical coma (V-coma) were collected. Results: Ortho-k significantly reduced the mean sphere refraction from wavefront: -2.04 ± 0.76 D (baseline) to $+0.34 \pm 0.74$ D (180 nights) ($P < 0.0001$, paired t test). The main change occurred between 1 and 8 nights follow-up (-1.17 ± 0.17 D). The mean cylinder did not change. Total RMS and defocus continued decreasing up to 90 nights. HOA RMS increased up to 8 nights from 0.39 ± 0.10 μ m to 1.04 ± 0.27 μ m but did not significantly change between 30 and 90 nights. T-coma increased 2.0-fold. H-coma increased up to 8 nights to the positive direction in the right eyes and to the negative direction in the left eyes and remained unchanged. V-coma fluctuated significantly to the negative direction in both eyes. Spherical aberration increased 10.0-fold up to 8 nights and remained unchanged ($p < 0.05$). Conclusions: Wavefront-guided ortho-k with Be Free was found to be effective and stable after 8 nights for HOA, particularly coma and spherical aberration. The lower-order optical aberrations continued decreasing during 90 nights follow-up. Wavefront analysis made it possible to map a profile of the whole eye during ortho-k corneal reshaping.

Swarbrick, H.A. and E. Lum

Lens Dk/t Influences the Clinical Response in Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2006. 47(5): p. 110-

Purpose: To investigate the influence of lens Dk/t on the clinical response to overnight orthokeratology (OK) lens wear over a 2-week lens-wearing period. Methods: Eleven subjects (age 20 to 39 years) were fitted with reverse-geometry lenses for OK (BE; Capricornia Contact Lenses, Brisbane, Australia) in both eyes. Lenses in matched designs and fittings but different materials (Boston EO; nominal Dk/t = 26, and Boston XO; nominal Dk/t = 46) were worn overnight only in the two eyes over a 2-week period. Changes in logMAR visual acuity (Test Chart 2000 Pro), subjective refraction, corneal apical radius and asphericity (Medmont E 300), and central stromal thickness (Holden-Payor optical pachometer) were measured. Repeated measures ANOVA and protected post hoc paired t-tests were employed to compare changes from baseline between the two lens materials, with a critical p-value of 0.05. Results: Throughout the study, there was a clinically and statistically significant difference in outcomes between the two lens materials (ANOVA, $p < 0.001$). After two weeks of overnight OK lens wear, changes from baseline with the EO lenses were significantly less than with the XO lenses for logMAR visual acuity (-0.72 ± 0.37 vs. -0.83 ± 0.41 ; $p < 0.05$), refraction (best vision sphere; $+2.34 \pm 0.61$ D vs. $+2.78 \pm 0.71$ D; $p < 0.05$), corneal apical radius (0.36 ± 0.08 mm vs. 0.48 ± 0.11 mm; $p < 0.001$) and asphericity Q (0.26 ± 0.08 vs. 0.37 ± 0.08 ; $p < 0.001$). After the first overnight OK lens wear, central stromal edema was greater for EO lenses compared to XO lenses (27 ± 36 μ m vs. 10 ± 31 μ m; $p = 0.05$), but overnight edema was reduced after two weeks for both lens materials (8 ± 25 μ m vs. -1 ± 33 μ m; $p > 0.05$). Conclusions: An increase in lens Dk/t appears to increase the clinical effects of overnight reverse-geometry lens wear over the medium term. This suggests that the stroma plays an important role in the corneal changes induced by overnight OK. It also adds further support to the recommendation that high Dk materials should be used for overnight OK, not only to provide physiological advantages, but also to optimize clinical outcomes.

Choo, J.D., P.J. Caroline, B.A. Holden, *et al.*

Soft Contact Lenses Can Induce Orthokeratology-Like Topographical Changes

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2062-

Purpose: Traditionally, orthokeratology has relied on rigid contact lenses to achieve the desired corneal reshaping effects. However, recent work has shown that soft lenses worn everted (inside out) can create similar changes to the corneal surface. The purpose of this study was to examine the topographical changes associated with the wearing of everted soft lenses of various designs and powers. Methods: One subject was used in this study. CIBA Focus Night and Day (lotrafilcon-A) 24% water lenses with base curves of 8.4mm, diameters of 13.8mm and powers of +6.00D, -0.25D, -6.00D and -10.00D were each everted and placed on one eye of the subject. Also evaluated were two custom soft lenses made in the Benz-G5X, (hioxifilcon-A) 59% water material with a base curve of 8.15mm, a diameter of 14.5mm and powers of -20.00D and -30.00D. The subject wore each of the everted lenses overnight for 6.5 hours and separately during the day for 6.5 hours. Each wearing period was separated by an appropriate period of non-lens wear to allow the cornea to return to baseline. All lens fits were evaluated with Fluoresoft 0.35% and photographed. The topographical changes between baseline and post-lens removal were analysed using the Medmont topographer. Results: Soft contact lenses worn everted resulted in corneal topographic changes generally consistent with traditional rigid lens orthokeratology; soft lenses worn without inversion resulted in very small topographic changes. Everted lenses of higher minus power showed more distinct Fluoresoft patterns and greater amounts of corneal topographic changes. For example, a -10D everted lens gave up to

2.50D of central flattening during daily wear, while a -20D everted lens gave up to 5.40D of central flattening. By comparison, the -10D lens produced 1.30D of flattening during overnight wear. The higher minus lenses were also found to induce a mid-peripheral ring of epithelial erosion. The Fluoresoft patterns of all everted lenses compare favourably with pressure profile patterns obtained mathematically using finite element analysis. Conclusions: It appears that everted soft contact lenses are capable of inducing significant changes in corneal topography, with daily wear resulting in greater topographic changes than overnight wear. Further work must be done to help understand these changes to develop a predictable and effective way of using soft contact lenses for corneal reshaping.

Evans, S.R., A. Ho, and J.D. Choo

Orthokeratology-Like Effects of Everted Soft Contact Lenses: A Mechanical Model

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2059-.

Purpose: Recent work has shown that soft contact lenses (SCLs) can produce corneal reshaping when worn everted (inside-out). Orthokeratology traditionally relies on rigid contact lenses to reshape the cornea. The purpose of this study is to examine the mechanisms by which everted SCLs produce similar effects. **Methods:** Finite-element analysis (FEA) was used to simulate the eversion of various SCLs, and their on-eye pressure profiles. The model uses 500-1500 axisymmetric planar elastic elements, depending on lens shape. The lenses were a simple generic design in a range of powers (-30, -20, -10, -6, plano and +6 dioptres) and elastic moduli (0.2, 1.0 and 2.0 MPa). First, the everted lenses are compared off-eye, since the internal stresses produced by eversion may be important on-eye. Secondly, each lens is pressed against a rigid cornea by imposing a uniform constant 'eyelid pressure' of 200 Pa, in order to derive an estimate for the on-eye pressure profile. The changes in internal stress produced by pressing the everted lens onto the eye are analysed, and the on-eye pressure profiles are compared to those of right-side-in lenses. **Results:** On eye, all high minus lenses showed a low-pressure area near the optic zone margin, and high pressures (>800 Pa) in the mid-periphery. In the central zone, pressure is nearly independent of power for minus-powered lenses (around 300 Pa), while the +6D lens showed central pressure of about 550 Pa. The pressure pattern compares favourably with images obtained clinically using Fluoresoft 0.35%. The everted pressure profiles are in dramatic contrast to those of non-everted lenses. The effect of lens modulus is to adjust the position and magnitude of peaks in the pressure profile for a given power. For example, a -10D lens with a modulus of 1.0 MPa gives a central treatment zone of 3 mm, while a modulus of 2.0 MPa gives a central treatment zone of 5.5 mm. The difference between the off-eye (equilibrium) and on-eye (non-equilibrium) stress states of everted lenses show an alternating pattern of 'push-down' and 'spring-off' forces which modify the pressure profile. On-eye performance of an everted lens is thus different to that of an identically shaped lens without prestressing. **Conclusions:** Both geometry and stress preload play a role in the on-eye performance of everted SCLs. The position of pressure peaks and stand-off zones compare well with clinical results. FEA provides a useful tool for the analysis of everted lenses, whose shape and preload states would be difficult to determine otherwise.

Kamei, Y., K. Cassar, J. Shen, and P.S. Soni

Short-Term Corneal Changes in Closed Eye Condition With Orthokeratology Lenses

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2060-.

Purpose: To determine the short-term corneal curvature and refractive changes with CRT and Contex OK orthokeratology lenses. **Methods:** Both eyes of 10 subjects were fitted, using the fitting guidelines provided by the manufacturer, with CRT(R) and Contex OK orthokeratology lenses. Each lens design was worn by each subject for 60 minutes. The eyes were closed and covered with a mask and the subject was asked to rest in a quiet, dark room. Uncorrected visual acuity (UVA), spherical (SPH) and spherical equivalent (SPE) refractive correction, central flat (FK) and steep (SK) curvature were measured before and after lens wear. A three week wash-out period was used in between the tests with the two designs. **Results:** Results: The average UVA, SPH, SPE, FK and SK readings before using CRT(R) and Contex OK lenses was 0.9 (\pm 0.34) LogMAR, -3.63 (\pm 1.74) D, -3.89 (\pm 1.72) D, 44.05 (\pm 1.32) D, and 44.86 (\pm 0.88) D. Post treatment with CRT(R) and Contex OK orthokeratology lenses the UVA, SPH, SPE, FK and SK was 0.71 (\pm 0.36) LogMAR, -2.99 (\pm 1.84) D, -3.28 (\pm 1.74) D, 43.48 (\pm 1.43) D, and 44.24 (\pm 0.98) D and 0.64 (\pm 0.31) LogMAR, -2.85 (\pm 1.72) D, -3.17 (\pm 1.69) D, 43.59 (\pm 1.3) D, and 44.22 (\pm 0.94) D respectively. There was a statistically significant ($p=0.001$) difference in the data collected prior to and after each of the lenses were worn. While there is no statistical difference between the refractive and corneal responses to the two lens designs, the Contex OK lens consistently demonstrated a greater change. **Conclusions:** The data shows that on the average, the two lenses produced significant but similar refractive and corneal change when used under a short-term closed eye conditions.

Lu, F., T.L. Simpson, L. Sorbara, and D. Fonn

The Relationship Between the Treatment Zone Diameter With Visual and Optical Performance in Hyperopic Corneal Refractive Therapy Lens Wearers

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2057-.

Purpose: To investigate the stability of the treatment zone (TZ) after one night of hyperopic Corneal Refractive Therapy (CRT(R)H) lens wear and to determine the association between the TZ with visual and optical performance. Methods: Paragon CRT(R)H lenses (Dk=100) were fit on one eye of 20 ametropes (mean{+/-}SD spherical equivalent: -2.09{+/-}2.53D) with no lens on the contralateral eye (randomly selected). High/Low contrast visual acuity (HCVA/LCVA), refractive error, aberrations (LADARWaveTM), and corneal topography were measured at baseline, and immediately after lens removal and 1, 3, 6, 12 hours later on the following day. The TZ was defined by the change in curvature from negative to positive and vice versa, using the tangential difference map from the Atlas TM and Orbscan II TM corneal topographers. Root mean square (RMS) wavefront errors and zernike coefficients of spherical aberration (SA) were collected using 4.5mm pupils. Results: During the day, the central steepened zone (CSZ, {+/-}SE) was statistically constant (both $p \geq 0.118$) and was 2.50{+/-}0.11mm using the Atlas and 3.30{+/-}0.18mm using the Orbscan. During the same period, the total treatment zone (TTZ) ranged from 7.18{+/-}0.13mm to 6.65{+/-}0.24mm using Atlas, from 6.11{+/-}0.10mm to 5.82{+/-}0.13mm using the Orbscan (both $p \leq 0.011$). There was a positive correlation between CSZ and signed SA using Orbscan ($r=0.676$, $p=0.002$); there were negative correlations between TTZ and RMS SA using Atlas and CSZ and HCVA/LCVA using Orbscan ($r = -0.480$ [-]0.584, all $p \leq 0.044$). There were also marginal correlations between TTZ and signed SA and LCVA using Orbscan ($r=0.432$, $p=0.073$; $r=-0.441$, $p=0.067$). Conclusions: CSZ was approximately constant after one night of CRT(R)H lens wear, while TTZ reduced. The treatment zone concept (both central and total) is a useful indicator of visual and optical performance of CRT(R)H lens wear.

Matsubara, M., S. Takeda, T. Hirowatari, *et al.*

Histological Findings of Rabbit Cornea Produced by an Orthokeratology Lens

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2058-.

Purpose: To report the topographical epithelial changes histologically after the use of orthokeratology lens (ortho-K lens) in rabbit cornea. Methods: An ortho-K lens (target reduction; -3.0 diopter) was continuously inserted into right eyes of white rabbits. Eyes were enucleated after 4 weeks, and served to histological examination using hematoxylin-eosin staining and electron microscopic study. Left eyes were used as controls. Results: Panoramic view of cornea showed apparent topographical changes of epithelial thickness corresponding to portions of Ortho-K lens. In the area that corresponds to the base curve zone, epithelial layers showed almost normal configuration. In the reverse curve zone, epithelium was thick with 7 to 9 layers. Epithelial layers were thinnest in the alignment curve zone. Electron microscopic study revealed slightly increased proteoglycans in deep stroma at the center. Epithelial cells in any area showed no abnormal staining pattern. Conclusions: Continuous wear of Ortho-K lens gives topographical epithelial changes in thickness.

Minavi, A., N. Leach, and W. Miller

Reverse Geometry Lenses: Are Changes in Corneal Epithelium Responsible for Myopia Reduction?

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2055-.

Purpose: To investigate central and peripheral corneal epithelial changes in neophyte orthokeratology patients after three months of treatment. Methods: Confocal microscopy (ConfoScan3) and ultrasonic pachymetry (Sonogage Corneo-Gage Plus 2) were used to obtain baseline central and peripheral corneal epithelium thickness (CET, PET) measurements on 8 healthy myopic subjects (28 + 4 years; 6 females and 2 males) with a mean spherical equivalent refractive error of -2.31 + 0.89 D; range -1.50 to -4.38 D. Both eyes were fit according to protocol with CKRTM (Boston Equalens II; Dk/t= 85) reverse geometry gas permeable lenses and patients were instructed to wear the lenses overnight for three months. Central measurements were taken with the patient in primary gaze and peripheral measurements were taken inferiorly with the subject in superior gaze (28° above primary gaze). All measurements were repeated after one and three months of continuous lens wear. One eye was chosen for statistical analysis. Measurements were compared using 2-tailed t-tests using the Bonferroni correction factor for multiple comparisons. Results: While individual differences were observed, average mean differences (AMD) between baseline, one month and three month CET and PET measurements showed no statistical difference with the ConfoScan3 or with the Sonogage instruments ($p > 0.05$). For the ConfoScan3, CET and PET at one month was 7.5 + 17.2 {micro}m (AMD + SD) and 2.9 + 17.3 {micro}m and at three months 0 + 10.73 and 4.6 + 15.83 {micro}m respectively. As for the Sonogage, AMD for CET and PET at one month was -1.8 + 2.7 and 0.2 + 0.1 {micro}m; at three months - 0.4 + 0.96 and 0.1 + 0.79 {micro}m respectively. All subjects showed significant myopia reduction ($p < 0.05$) at the one month visit and maintained this reduction during the three month visit. Conclusions: Our findings show that myopia reduction after orthokeratology does not appear to be a result of epithelial change as reported by other investigators. It is possible that structural changes within the cornea

are not detectable by the methods used. Differences in instrument sensitivity and/or operator error may also partially explain our findings.

Sorbara, L., F. Lu, D. Fonn, and T. Simpson

Topographic Keratometric Effects of Corneal Refractive Therapy for Hyperopia After One Night of Lens Wear

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2061-.

Purpose: To examine the topographical corneal shape change across the horizontal meridian after one night of wearing CRTTM corneal reshaping contact lenses for the correction of hyperopia. Methods: Twenty participants wore a CRTTM HDS 100 contact lens in one eye designed to reduce hyperopia. The other eye served as the control. The lens was worn during 8 hours of sleep. Topography and refractive error was measured using the Humphrey Atlas™ corneal topographer the night prior to lens insertion, immediately after lens removal on the following morning and 1, 3, 6 and 12 hours afterwards. Recovery data was gathered 28 hours later. Topographic changes were measured over a 6-8mm chord in 1mm steps. Results: There were significant differences in corneal curvature over time; the central cornea was steepened by 0.85{+/-}0.67D (range 0.00 to 2.20D) and at the mid-periphery (3mm temporal from the centre) the cornea flattened 1.70{+/-}1.11D (range 0.00 to 4.30D) in experimental eyes (both p=0.000) compared to baseline, while no change was found in control eyes (p=0.139). The central corneal steepening regressed over time 50% centrally and 56% mid-peripherally. (both p=0.000) and did not recover to baseline after 12 hours. At the 28 hour (post-discontinuation) visit, the central cornea recovered to baseline, although it was still steeper (approx. 0.12D) and the mid-periphery was still flatter by 0.25D representing a 98% recovery (both p>0.05). Conclusions: After one night of lens wear, the CRTTM for Hyperopia lens wearing eye showed a moderate although significant central steepening which translates into hyperopic correction. The shape of the cornea did not recover to baseline at 12 hours after one night, but, recovered after 28 hours of no lens wear.

Stuebiger, N., M. Ronecker, R. Michels, and H. Specht

The Effects of Overnight Orthokeratology Lens Wear

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2054-.

Purpose: Overnight orthokeratology (Ortho-K) is a method for temporarily eliminating myopia. A special geometry of rigid gas permeable (RGP) lenses (double reverse back curve) enables transformation of the cornea to a flatter form. The aim of our study was to evaluate the effectiveness of Ortho-K for treatment of myopia, to evaluate possible pathologic corneal alterations and changes of the intraocular pressure (IOP). Methods: A group of 20 volunteers (m:f=9:11) with a mean age of 25.92 {+/-} 5.86 years were included in our study. Both eyes were fitted with Ortho-K lenses, and uncorrected visual acuity, refractive correction, corneal curvature and corneal changes, including measurements of corneal endothelial alterations, were achieved. The control group consisted of 6 volunteers, who have worn glasses as vision correction. Neither group exhibited any eye disease or any pathological symptom at the beginning of the study. Results: Before fitting the Ortho-K lenses, the wearing group had a mean spherical correction (oculus dexter/oculus sinister) of -2.06/-2.25 {+/-} 0.90/0.84 diopter (D), a mean uncorrected vision of 0.64 {+/-} 0.31 (visus logmar) and a mean central corneal radius of 7.78/7.77 {+/-} 0.31/0.30 mm. After one week of wearing contact lenses the majority of the volunteers had such a good response, that no statistical difference in visual acuity between the two groups was detectable (the mean spherical correction was +0.14/-0.02 {+/-} 0.25/0.14 D, the mean uncorrected vision was -0.12 {+/-} 0.06 and the mean central corneal radius was 8.09 / 8.08 {+/-} 0.35/0.34 mm). Corneal irritations which occurred at the beginning of the study in the wearing group included corneal staining (40%, Grading scale 1.1), acute corneal edema (10%), microcysts (5%). Problems with halos were frequently noticed (90%), but the wearers get accustomed to that. The study was completed after a mean observation period of 8 months and, . At that time no corneal edema could be observed, and in the whole observation period no corneal endothelial alterations, no infectious corneal complications, in none of the volunteers IOP changes occurred, and altogether, five volunteers discontinued the study from the wearing group. Conclusions: Overnight orthokeratology, as an alternative to refractive corneal surgery, is a very safe method for temporarily eliminating minor myopia. We achieved in our study stable remaining visual changes for all waking hours of the day, which allow patients enjoy excellent device-free vision.

Swarbrick, H.A., J. Jayakumar, W. Co, *et al.*

Overnight Corneal Edema Can Modulate the Short-Term Clinical Response to Orthokeratology Lens Wear

Invest. Ophthalmol. Vis. Sci., 2005. 46(5): p. 2056-.

Purpose: To investigate the influence of overnight corneal edema on the clinical response to overnight orthokeratology lens wear. Methods: Twelve young adult subjects (age 20 to 25 years) were fitted with reverse-geometry lenses for orthokeratology (BE; UltraVision, Brisbane, Australia) in both eyes. Matched design lenses in Boston ES (nominal Dk/t = 8) and Boston XO materials (nominal Dk/t = 45) were worn in the two eyes for eight hours overnight. A separate overnight trial was conducted to examine corneal changes in

the absence of lens wear in the contralateral eye. LogMAR visual acuity, apical corneal radius (ro, mm; Medmont E-300 topographer) and corneal eccentricity (e; Medmont) were measured before and immediately after overnight lens wear. The overnight corneal edema response was monitored using optical pachometry. Changes from baseline were examined using ANOVA and post hoc protected t-tests, with a critical p-value of 0.05. Results: Overnight central corneal edema averaged 11.5 {+/-} 5.8% and 3.3 {+/-} 3.7% in the ES and XO lens-wearing eyes respectively (ES > XO; p < 0.001), compared to 2.4 {+/-} 2.1% with no lens wear. Despite the matched reverse-geometry lens designs, changes in unaided visual acuity and corneal topography were much less evident in the ES lens-wearing eyes compared to those wearing the XO material (change in logMAR VA: -0.09 {+/-} 0.25 vs. -0.33 {+/-} 0.16, p < 0.001; change in ro: 0.02 {+/-} 0.06 vs. 0.18 {+/-} 0.11 mm, p < 0.001; change in e: 0.00 {+/-} 0.09 vs. -0.19 {+/-} 0.13; p < 0.001). No significant differences in these clinical outcomes were found between ES lenses and no lens wear. Conclusions: High levels of overnight corneal edema appear to limit the clinical effects of overnight reverse-geometry lens wear, at least in the short term. This suggests that the use of high Dk materials for overnight orthokeratology not only provides physiological advantages, but may also optimize clinical outcomes.

Berntsen, D.A., J.T. Barr, and G.L. Mitchell

Higher-Order Aberration Changes After Corneal Refractive Therapy (CRT)

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1543-.

Purpose: Corneal Refractive Therapy (CRT, Paragon Vision Sciences) utilizes gas permeable reverse return zone design contact lenses to reshape the cornea to achieve a reduction in myopia. The Complete Ophthalmic Analysis System (COAS, WaveFront Sciences), a Hartmann-Shack wavefront sensor, is used to measure the effects of corneal reshaping with CRT on higher-order aberrations of normal human eyes. Methods: The aberration profiles of sixteen myopic subjects (-1.25 D to -5.00 D, mean -2.72 D {+/-} 0.96 D) between the ages of 21 and 37 were measured in the morning using the COAS. Subjects were correctable to 20/20 and free of ocular disease. Patients were then fit with CRT lenses in each eye. One month after the CRT lens fit was finalized, the patient's aberration profile was again measured in the morning. The COAS was used to measure each dilated eye 8 times at both the baseline and one month visit. The right eye of each subject was selected and the average higher-order RMS wavefront error (3rd to 6th order) at each visit was calculated for a 5 mm pupil diameter and included in the analysis. A Wilcoxon Sign Rank Test was used to determine if the difference between the baseline and one month measurements was significantly different from zero (i.e. whether CRT resulted in a significant change in higher-order aberrations). An analysis of higher-order aberration change was repeated including only even order Zernike coefficients in the RMS error calculation (spherical-like aberrations) and again using only odd order Zernike coefficients in the RMS error calculation (coma-like aberrations). Results: The mean sphere component of the refractive error changed from -2.72 D {+/-} 0.96 D to +0.55 D {+/-} 0.39 D with an average change of +3.27 D {+/-} 0.88 D. Total higher-order RMS error (in microns) increased from 0.1484 {+/-} 0.0387 (mean {+/-} SD) to 0.3173 {+/-} 0.1066 with an average increase of 0.1689 {+/-} 0.1196 (p=0.001, Wilcoxon Sign Rank Test). Even order RMS error (spherical-like aberrations) increased from 0.0768 {+/-} 0.0249 to 0.2277 {+/-} 0.0975 with an average increase of 0.1508 {+/-} 0.1114 (p=0.001, Wilcoxon Sign Rank Test). Odd order RMS error (coma-like aberrations) increased from 0.1252 {+/-} 0.0368 to 0.2110 {+/-} 0.0807 with an average increase of 0.0857 {+/-} 0.0824 (p=0.003, Wilcoxon Sign Rank Test). Conclusions: CRT results in an overall increase in the higher-order aberrations of the eye. While significant increases in both spherical-like and coma-like aberrations were measured, spherical-like aberrations appear to contribute more to the increase in higher-order aberrations than do coma-like aberrations.

Choo, J.D., P.J. Caroline, D.D. Harlin, and W. Meyers

Morphologic Changes in Cat Epithelium Following Overnight Lens Wear with the Paragon CRT Lens for Corneal Reshaping

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Purpose: Corneal reshaping with contact lenses (orthokeratology) has been found to be a safe and effective technique in correcting patients with low to moderate degrees of myopia. At this time, the exact forces and mechanisms responsible for the topographical changes seen in overnight corneal reshaping are poorly understood. This study was undertaken to better understand how the procedure works and exactly which corneal tissues are involved in the process. Methods: Thirteen cats of the same age, gender, species and weight were used in this study. One animal served as a control with no lens wear. The remaining 12 animals were fitted with specially designed Paragon CRT lenses for the correction of myopia in the right eye and hyperopia in the left eye. The lenses were worn for periods of 4, 8, 24 and 48 hours and 7 and 14 days. The animals were euthanised at the above scheduled time periods and the corneal tissue stained with H&E, PAS and Alcian Blue for histologic evaluation and measurement. Five measurements of epithelial thickness were taken with the Image Pro-Plus Measurement Software and averaged. Results: The control eyes revealed an average central epithelial thickness of 37.65 microns and mid-peripherally, 3.0 mm from centre of 37.89 microns. The right eyes of the animals (fitted for the correction of myopia) showed a progressive central

thinning from 34.08 microns at 4 hours to 11.85 microns at 14 days. Over the same time period, there was a subsequent thickening of the mid-peripheral epithelium from 49.61 microns at 4 hours to 55.20 microns at 14 days. The left eyes (fitted for the correction of hyperopia) showed progressive thickening of the central epithelium from 58.03 microns at 4 hours to 80.86 microns at 14 days and progressive mid-peripheral thinning from 42.75 at 4 hours to 13.02 at 14 days. Conclusions: The results of this study show a progressive, time related change in epithelial thickness associated with the wearing of the Paragon CRT lenses for overnight corneal reshaping. Eyes wearing lenses for the correction of myopia showed significant central epithelial thinning with a proliferation of cells mid-peripherally. Eyes wearing lenses for the correction of hyperopia showed the opposite pattern with central epithelial thickening and mid-peripheral thinning. Further ultra-structure studies will be necessary to determine the exact mechanism of these changes. Additionally, further research into the role of stromal restructuring will need to be investigated.

Guo, Y., T. Nguyen, S. Soni, and G. Wison

Cell Shedding in Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1581-.

Purpose: Orthokeratology produces a reduction in myopia by reshaping the cornea with specially designed rigid gas-permeable contact lenses. Central thinning of the corneal epithelium has been suggested to be one possible mechanism behind the refractive changes. Thinning could be accomplished by removal of cells from the epithelium or by redistribution within the tissue. In our study the effect of overnight orthokeratology lenses on the exfoliation of cells from the corneal epithelial surface was investigated. Methods: Ten healthy subjects between the ages of 18 and 37 years with myopia [\leq] 4.00D and astigmatism [\leq] 1.50D were fitted with either BE or Contex orthokeratology lenses. The lenses were worn overnight and removed during the day. The whole course of lens wear was about one month for each subject. Baseline data were collected for the week before lens wear. After 2 weeks and 4 weeks of orthokeratology lens wear cells were collected and counted again. A final collection was made after the cornea and refraction had recovered to baseline after discontinuing lens wear (usually 1 to 2 weeks). All the cell collections were made at 4 pm using flexible hydrogel contact lenses. Four insertions and removals were performed in each eye. After removal of the hydrogel lens, cells were washed from the back of the lens into a beaker. Cells from the two eyes were counted separately following fluorescent staining with acridine orange and Hoechst. Results: The refractive error was reduced significantly at day 1 and then stabilized after 1 week. The average baseline cell counts were 93 ± 19 (mean \pm SEM) for nucleated cells and 209 ± 103 for cell ghosts. No significant differences were found in the counts of cell ghosts at different time points ($p > 0.05$, ANOVA). However, the average counts for nucleated cells dropped significantly at 2 weeks (39 ± 7) from the baseline (93 ± 7), and recovered to the baseline level again by 4 weeks ($p < 0.05$, ANOVA). Conclusions: An increase in cell shedding from the epithelial surface is unlikely to be the explanation of thinning of the epithelium in orthokeratology. It is hypothesized that morphological restructuring of individual cells might be responsible for the short-term changes in epithelial thickness reported in orthokeratology.

Haeussler, K., B. Hard*, R. Michels, and N. Stuebiger

The effects of overnight orthokeratology lens wear: visual and corneal changes

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1570-.

Purpose: Overnight orthokeratology (Ortho-K) is a method for temporarily eliminating myopia. A special geometry of rigid gas permeable lenses (double reverse back curve) enables transformation of the cornea to a flatter form. The aim of our study was to evaluate the efficacy of Ortho-K for treatment of myopia and to evaluate pathologic corneal alterations. Methods: The study was performed with a group of 20 volunteers. Both eyes were fitted with Ortho-K lenses, and uncorrected visual acuity, refractive correction, corneal curvature and corneal changes, including measurements of corneal endothelial alterations, were achieved. The control group consisted of 5 volunteers, who have worn glasses as vision correction. Neither group exhibited any eye disease at the beginning of the study. Results: Before fitting the Ortho-K lenses, the wearing group had a mean spherical correction (oculus dexter/oculus sinister) of $-2.06/-2.25\pm 0.90/0.84$ D, a mean uncorrected vision of 0.64 ± 0.31 (visus logmar) and a mean central corneal radius of $7.78/7.77\pm 0.31/0.30$ mm. One week after initiation of the study the majority of the volunteers had such a good response, that no statistical difference in visual acuity between the two groups was detectable. Corneal irritations which occurred at the beginning of the study in the Ortho-K wearing group included corneal staining (40%, Grading scale 1.1), corneal edema (10%), microcysts (5%). Problems with halos were frequently noticed (90%), but the wearers get accustomed to that. The study was completed after a mean observation period of 4 months. At that time the mean spherical correction had changed significantly to $+0.14/+0.02\pm 0.25/0.14$ D, the mean uncorrected vision was -0.12 ± 0.06 D and the mean central corneal radius was $8.09/8.08\pm 0.35/0.34$ mm. After 4 months no corneal edema could be observed, and in the whole observation period no corneal endothelial alterations, and no infectious corneal complications occurred. Other corneal findings were reduced corneal staining (25%, Grading scale 0.5) and a reduced number of microcysts in the above mentioned volunteer. Altogether, 5 volunteers discontinued the study from the wearing group and 1 volunteer

in the control group was discontinued for retinal bleeding. Conclusions: Overnight orthokeratology, as an alternative to refractive corneal surgery, is a very safe method for temporarily eliminating minor myopia.

Hiraoka, T., Y. Matsumoto, F. Okamoto, *et al.*

Corneal higher-order aberrations induced by overnight orthokeratology

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1548-.

Purpose: Orthokeratology is defined as the temporary reduction of myopia by the application of specifically designed rigid contact lenses. The temporary reduction in myopia and improvement of unaided vision were achieved by flattening the corneal curvature with a flat-fitting rigid contact lens. However, modification of the corneal shape to correct myopia can cause undesirable side effect on visual performance. We evaluated corneal higher-order aberration induced by overnight orthokeratology for myopia. Methods: Sixty-four eyes of 39 patients undergoing overnight orthokeratology for myopia were examined. Inclusion criteria were uncorrected visual acuity of 20/20 or better after treatment and minimum follow-up of 3 months. Mean age was 15.6 {+/-} 6.2 years (range 11 to 37). Mean spherical equivalent before treatment was -2.60 {+/-} 1.13 D (range -0.75 to -5.25). Videokeratography data were obtained with computerized videokeratography (TMS-2N, Tomey). Higher-order aberrations of the cornea were calculated from the height data for 3-, 4-, and 6-mm pupils. Results: By orthokeratology, coma-like aberration (3rd order RMS) significantly increased for 3-mm ($P < 0.0001$, paired t-test), 4-mm ($P < 0.0001$), and 6-mm ($P < 0.0001$) pupils. Similarly, spherical-like aberration (4th order RMS) increased significantly by the treatment for 3-mm ($P = 0.0001$), 4-mm ($P < 0.0001$), and 6-mm ($P < 0.0001$) pupils. Increases in the coma-like and spherical-like aberrations showed significant positive correlations with the amount of myopic correction for 3-mm (Pearson correlation coefficient, $R = 0.452$, $P = 0.0001$ for coma-like aberration, $R = 0.381$, $P = 0.0017$ for spherical-like aberration), 4-mm ($R = 0.478$, $P < 0.0001$, $R = 0.484$, $P < 0.0001$), and 6-mm ($R = 0.499$, $P < 0.0001$, $R = 0.455$, $P = 0.0001$) pupils. Conclusions: Corneal higher-order aberrations significantly increased even in clinically successful orthokeratology cases. The increases in the higher-order aberrations correlated with the magnitude of myopic correction. Although the influence of these changes on visual function should be further studied, correction of high myopia by orthokeratology might affect visual performance.

Jackson, J.M., T. Bildstein, J. Anderson, *et al.*

Short-Term Corneal Changes with Corneal Refractive Therapy (CRT)

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1547-.

Purpose: To evaluate changes in visual acuity, corneal topography, and corneal thickness after short periods of CRT lens wear. Methods: Twenty eyes of 10 subjects were analyzed. One eye was randomly selected to wear the CRT lens, while the other served as a control. After baseline examination, the test eye was fit with the CRT lens. Subjects wore the lens for intervals of 10 minutes, 30 minutes, and 60 minutes. After each period, the lens was removed and a masked examiner measured unaided high contrast LogMAR VA, corneal topography (Humphrey Atlas), and ultrasound pachymetry (Corneogage II) for both eyes. The results were compared to the same values measured at the baseline examination prior to lens wear using repeated-measures ANOVA. Results: Visual acuity improved in the test eyes ($p < 0.001$, ANOVA) after 30 minutes (0.2 +/- 0.02 LogMAR mean improvement), but did not change over time in the control eyes ($p = 0.48$, ANOVA). Apical corneal radius flattened significantly in the test eyes ($p < 0.001$, ANOVA) after 10 minutes (0.05 +/- 0.02 mm mean change), but did not change in the control eyes ($p = 0.979$, ANOVA). Total central corneal thickness did not change significantly in either group ($p = 0.021$ test eyes; $p = 0.053$ control eyes, ANOVA). Central epithelial thickness did not change significantly in either group ($p = 0.242$, test eyes; $p = 0.624$, control eyes, ANOVA). Conclusions: Previous studies using other orthokeratology lens designs have found significant changes in acuity, topography, and corneal thickness after 10 minutes of lens wear. This study, using the CRT design, shows similar results, but acuity changes took longer to achieve and pachymetry changes did not occur. The lack of corneal thickness changes may be attributable to the ultrasound instrument used for this study.

Jayakumar, J. and H. Swarbrick

Age is a significant contributing factor in the short-term corneal response to orthokeratology lens wear

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Purpose: To investigate the effect of age on the response to short-term (one hour) open eye orthokeratology (OK) lens wear. Methods: Subjects were divided into two groups comprising young adults (group I, $n = 18$, mean age 24.3 {+/-} 3.9 years) and older adults (group II, $n = 18$, mean age 43.9 {+/-} 5.3 years). Subjects wore reverse geometry lenses (BE; UltraVision Pty Ltd, Brisbane, Australia) under open-eye conditions for one hour in one eye only. Changes in unaided visual acuity were measured using a logMAR chart, changes in corneal asphericity and apical radius were measured with the Medmont corneal topographer, and changes in central corneal, stromal and epithelial thickness were measured with the Holden-Payor optical pachometer. Two-tailed paired Student t-tests were employed to compare changes before and after

orthokeratology and independent samples Student t-tests were used to compare between the two groups, with a critical p-value of 0.05. Results: After one hour of open eye wear, statistically significant changes from baseline ($p < 0.05$) were found in both subject groups for unaided visual acuity, corneal asphericity, apical corneal radius and central corneal and epithelial thickness. No significant changes were found in central stromal thickness. Comparisons between groups revealed statistically significant differences ($p < 0.05$) in the improvement in unaided visual acuity (group I: 0.61 ± 0.29 , group II: 0.15 ± 0.12 logMAR units), flattening of apical corneal radius (group I: 0.15 ± 0.09 , group II: 0.05 ± 0.06 mm), decrease in corneal asphericity (group I: 0.20 ± 0.13 , group II: 0.09 ± 0.09) and decrease in central corneal thickness (group I: -5.7 ± 3.6 , group II: -2.6 ± 5.7 μm) and epithelial thickness (group I: -9.8 ± 10.7 , group II: -2.6 ± 3.7 μm). Conclusions: Corneal and visual changes found in this study confirm previous reports on the effects of short-term OK lens wear. Older lens wearers show a reduced or delayed response to reverse geometry lens wear.

Kollbaum, P.S. and A. Bradley

Optical Signature, Structural Mechanism, And Chronology Of Corneal Refractive Therapy (crt)

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1541-.

Purpose: The purpose of this experiment was to determine the optical signature and chronology of eyes wearing Paragon CRT contact lenses, and determine how these relate to the structural mechanism.

Methods: Three myopic patients were fit with CRT lenses. Following the first night, 1 week, and 1 month of nightly lens wear, repeated whole eye aberrations (COAS) and corneal aberration measurements (ORBSCAN) were acquired hourly from the time of eye opening (8 am) until bedtime (9 pm). Measurements were also taken on one of these subjects when ceasing treatment, on the first through fourth day following discontinuing wear, and then again at 1, 2, 3, and 4 weeks. Wavefront variances were calculated and retinal images simulated for 3mm and 5mm pupil sizes. Results: As expected, after wearing the lenses myopia was decreased from -3.49 ± 0.80 D at baseline to -0.52 ± 0.24 at 1 month. However, with this decrease in myopia, spherical aberration increased from $+0.07 \pm 0.05$ D at baseline to a maximum of $+0.32 \pm 0.05$ D after 7 days, and then leveled off to $+0.19 \pm 0.07$ at 1 month. Over this same initial 7 day period, a 1 D reduction in anterior corneal curvature resulted in a 1 D reduction in myopia. However, following this time a further reduction in myopia occurred, while anterior corneal curvature remained the same. Anterior and posterior corneal curvature changes occurred at roughly the same rate initially, and showed a similar regression throughout the day. However, following 3 weeks of lens wear, the posterior curvature remained roughly constant throughout the day, however the anterior curvature still regressed slightly. Correspondingly, aberrations were initially less stable throughout the day, showing an increase in myopic defocus of -0.043 D/hr. at day 1, but became more stable by 1 week (-0.033 D/hr.), and even more stable at 1 month (-0.023 D/hr.). Conclusions: In agreement with published reports of acuity data, if the lenses are worn nightly for two weeks, CRT can provide an effective method of myopia correction, which is quite optically stable throughout the day. However, an increase in spherical aberration can accompany the reduction in myopia, especially initially. The structural mechanism appears to be complex, involving an initial corneal stromal reshaping, compounded by further longer term epithelial changes.

Ladage, P.M., N. Yamamoto, and H.D. Cavanagh

Confocal microscopy of the rabbit corneal surface following orthokeratology lens wear.

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1535-.

Purpose: The aim of this study is to examine the effects on the cornea of reversed geometry orthokeratology lens wear (OK) in the rabbit using in vivo confocal microscopy. Methods: 12 NZW rabbits (3-3.5kg) were used for this study and treated according to the ARVO statement for the use of animals in ophthalmic and vision research. Partial membranectomy was performed on all rabbits 1 week prior to confocal microscopy. Baseline control values for corneal epithelial thickness, stromal thickness and corneal epithelial surface cell size were determined for the central and peripheral (temporal) cornea. One week later, one randomly chosen eye was fitted at 10:00am with either a RGP control lens (Menicon Z, Menicon Co. Ltd., Japan) or a reverse geometry OrthoK lens designed for the rabbit eye and made of the same material as the control lens. A handheld slitlamp, blue light and a wratten #12 filter were used to assess the fit on each rabbit. Following 24-hours lens wear, the same eye of each rabbit was scanned again with the confocal microscope. Results: Compared to baseline values, both RGP and OK lenses significantly thinned the central epithelium by respectively 9.8% ($p = 0.001$) and 6.4% ($p = 0.03$). Peripherally a 1% (RGP) and 4% (OK) increase in thickness was found, albeit not statistically significant with the current sample size. Central cell size increased significantly by 5.3% (RGP) and 29% (OK) while peripherally 8.1% (RGP) and 1.6% (OK) decreases were seen. Stromal thickening was comparable for both lenses. Conclusions: This study demonstrates that the rabbit model can be used to study orthokeratology lens wear as it exhibits rapid thinning of the central epithelium and a trend to peripheral thickening similarly to the human. The large and prompt increase in cell size suggests that the central pressure of the OK lens is compressing the central corneal epithelial surface cells, flattening them in the lateral directions; very likely this effect will also occur in the human patient.

Lu, F.H., T. Simpson, L. Sorbara, *et al.*

The relationship between the treatment zone diameter and visual, optical and subjective performance in CRTTM lens wearers

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1576-.

Purpose: To investigate the stability of the treatment zone (TZ) during Corneal Refractive Therapy over one month of lens wear, and to determine the relationship between the treatment zone diameter (TZD) and visual performance. **Methods:** 23 myopic subjects wore Corneal Refractive Therapy (CRTTM HDS, Dk=100) lenses overnight and removed their lenses on awakening. High/Low contrast visual acuity, subjective visual performance using an analogue scale, refractive error, aberrations (LADARWaveTM), and corneal topography were measured at baseline, immediately after lens removal on the first day and 14 hours later and these were repeated on day 4, 10 and 28. The TZD was defined by the change in curvature from negative to positive and vice versa, using the tangential difference map from the Atlas TM topographer. **Results:** The average diameter (\pm SE) of the flat zone ranged from 3.11 \pm 0.13mm to 3.61 \pm 0.09 mm, and from 7.40 \pm 0.15mm to 7.91 \pm 0.12mm for the total (steep+ flat) zone over the study duration. The flat zone became significantly smaller ($p<0.001$), while the overall diameter remained constant ($p=0.886$) throughout the day. From day 4 onwards, the overall TZD was constant (all $p>0.116$), but the flat zone diameter was only stable from day 10 onwards ($p=0.449$). There were significant positive correlations between the TZD and the achieved prescription, subjective vision and spherical aberration ($r=0.743-0.926$, all $p<0.05$). There were significant negative correlations between the total zone diameter and high/low contrast visual acuity ($r=-0.913$, $p=0.002$; $r=-0.918$, $p=0.001$). There were also negative correlations between the flat zone diameter and high/low contrast visual acuity ($r=-0.652$, $p=0.080$; $r=-0.701$, $p=0.053$). **Conclusions:** The CRTTM TZ changed during the first 10 days. Its diameter was associated with visual acuity, achieved prescription, spherical aberration, and subjective vision. The TZ is a useful indicator of visual, optical and subjective performance of CRTTM lenses.

Mitsui, I. and Y. Yamada

Safety and Effectiveness of Advanced Orthokeratology as an additional treatment after Refractive Surgeries

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1574-.

Purpose: Orthokeratology (Ortho-K) is known as non-invasive technique to reduce myopia and astigmatism. When refractive errors still remained or re-appeared after refractive surgeries, Ortho-K can be another option as an additional procedure to correct irregularity of corneal surface from keratoectasia. **Methods:** Ortho-K was indicated for twenty-three eyes of thirteen patients after refractive surgeries such as LASIK, PRK, and RK. The average of their Uncorrective Visual Acuity (UCVA) after surgeries was 20/30 or worse, and mean spherical equivalent (SE) was -2.42D (range -0.75 to -3.75D). They were followed at least two years wearing of Advanced Ortho-K lenses. The follow up examinations on auto-refraction, auto-keratometry, uncorrected and corrected visual acuity, intra-ocular pressure, corneal endothelium, corneal thickness and curve, and corneal shape were performed. **Results:** 95% of the patients improved in UCVA up to 20/20 or better, 86% of them improved up to 20/15 or better, and 76% of them improved up to 20/10. The mean SEs improved to -1.20 \pm 1.02D during six months, -1.03 \pm 0.83D during one year, and -0.73 \pm 0.64D during two years. Astigmatism also slightly decreased. Ophthalmologic examinations showed no abnormalities including flap formation, intra-ocular pressure, and endothelium. **Conclusions:** Advanced Ortho-K technique was evaluated to be safe and effective enough to correct refractive errors still remained or re-appeared after refractive surgeries.

Potapova, N.V., G. Wang, S. Haji, *et al.*

Corneal topography and wavefront analysis in CRT patients.

Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 2857-.

Purpose: To evaluate the visual outcome, corneal topography changes and wavefront analysis in normal myops after CRT, corneal reshaping contact lenses worn only at night to provide good uncorrected visual acuity (UCVA) during the day. **Methods:** Thirty nine eyes were fitted with Paragon CRT contact lenses which were worn nightly. Before and after CRT fitting, uncorrected visual acuity was measured, corneal topography with Holladay Diagnostic Summary, EyeSys 2000 Videokeratoscope and wavefront analysis with Marco 3DWave were performed. To evaluate the visual outcome, refractive yield (achieved/attempted correction) was calculated, accounting for distance or monovision. Pre-fitting the mean spherical equivalent (SE) was -2.7D \pm 1.03D (n=39 eyes). **Results:** UCVA improved in all patients. Before the CRT fit 70% of patients had UCVA of 20/200 or worse. One month after the fit the mean refractive yield was 96.76%. At 1 month, mean Q value increased from -0.08 to 0.38 ($p=0.0004$), PCA and CUI showed no significant changes. Topographic mean regular astigmatism decreased from 0.846 before fit to 0.762 ($p=0.32$) at 1 month after the fit, and so did irregular astigmatism (from 0.025 to 0.023, $p=0.85$). Wavefront analysis showed increased in RMS (root mean square) for HOA (higher order aberrations) up to sixth order from mean RMS of 0.151 before the fit to

0.26 at 1 month after the fit. However, during the follow-up period all the RMS values were within normal limits (less than 0.50). Mean for the vertical coma changed from -0.0077 before the fit to 0.0739 at 1 month after the fit, mean for horizontal coma changed from 0.06 to 0.045, mean for vertical trefoil changed from -0.054 to 0.038 and mean for horizontal trefoil changed from 0.092 to 0.136. Conclusion: CRT lenses are effective in improving uncorrected visual acuity. CRT appears to significantly change cornea from prolate to oblate while corneal quality is maintained. CRT increases the amount of higher order aberrations, but the RMS number stays within normal limits. Comparison with myopic LASIK will be presented.

Sorbara, L., F. Lu, R. Kort, *et al.*

Topographic Keratometric Effects of Corneal Refractive Therapy After One Month of Lens Wear
Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1580-

Purpose: To examine the topographical corneal shape change over a horizontal chord after one month of wearing CRTTM corneal reshaping contact lenses. Methods: Twenty three participants wore CRTTM HDS 100 contact lenses in both eyes while sleeping. Topography was measured using the Humphrey Atlas™ corneal topographer the night prior to lens insertion, immediately after lens removal on the following morning and 1, 3, 7 and 14 hours afterwards at days 1, 4, 10 and 28 and after a 72 hour washout period of no lens wear. Topographic changes were measured over a 6-8mm chord in 1mm steps. Results: There were significant differences in corneal curvature over time ($p=0.000$), day ($p=0.000$) and at various corneal locations ($p=0.000$). The central positions flattened and the mid peripheral positions steepened throughout the month of the study. The mean ($\{+/-\}$ sd) change in curvature centrally and at 3mm temporal from the centre was $-1.54\{+/-\}1.59D$ and $2.31\{+/-\}2.26D$ respectively, immediately after lens removal, at Day 1 and $-2.76\{+/-\}1.52D$ and $4.08\{+/-\}2.41D$ at Day 28 respectively. On Day 28, after 14 hours, there was little regression noted compared to the morning, 18% centrally and 29% mid-peripherally. At the 72 hour (post-discontinuation) visit, the cornea did not recover to baseline, the central cornea was still flatter (approx. 0.75D, 69% recovery) and the mid-periphery was still steeper by the same amount, representing a 77% recovery. Conclusions: After one month of lens wear, the CRTTM lens wearing eyes showed a significant topographic shift. The shape of the cornea did not recover to baseline at 14 hours after one month or after a 72 hour recovery period, indicating that the change in shape can be maintained.

Yamamoto, N., P.M. Ladage, and H.D. Cavanagh

Pseudomonas aeruginosa binding to the rabbit corneal surface following orthokeratology lens wear.
Invest. Ophthalmol. Vis. Sci., 2004. 45(5): p. 1582-

Purpose: Previous studies have shown that contact lens wear causes an increase in Pseudomonas aeruginosa (PA) binding to the corneal epithelial surface. The aim of this study is to examine the effect of reversed geometry Orthokeratology lens wear on bacterial binding. Methods: 12 NZW rabbits (3-3.5kg) were used for this study and treated according to the ARVO statement for the use of animals in ophthalmic and vision research. Partial membranectomy was performed on all rabbits 1 week prior to lens fitting. One randomly chosen eye was fitted at 10:00am with either a RGP control lens (Menicon Z, Menicon Co. Ltd., Japan) or a reverse geometry OrthoK lens designed for the rabbit eye. Following 24-hours lens wear, rabbits were sacrificed. The eyeballs were enucleated and immediately placed in 0.5ml 1.0×10^7 CFU/ml bacterial solution (ATCC 27853). After incubation (30min.), the epithelium with adherent bacteria was scraped and cultured for 24-hours. Colony-forming unit method was used to quantify the data per eye. All PA-binding steps were carried out by a masked observer. Results: PA-binding in the RGP lens group was $0.93\{+/-\}0.37$ and $1.69\{+/-\}0.59$ 105 CFU for respectively the control and lens wearing eyes ($p=0.130$). OK group: $1.17\{+/-\}0.81$ (control) and $2.76\{+/-\}0.77$ (OK lens) 105 CFU ($p=0.003$). PA-binding with the OK lens was significantly higher than the RGP ($p=0.014$). Conclusions: In the rabbit, OK overnight lens wear showed a statistically significant increase in bacterial binding to the corneal epithelium while the RGP control lens did not, even though both lenses are made from the same hyper O2 material. Human studies on bacterial binding on exfoliated corneal epithelial cells are needed to determine whether this PA increase also occurs in the human.

Alharbi, A.A., H.A. Swarbrick, and D. La Hood

Overnight Orthokeratology Lens Wear Suppresses the Overnight Central Corneal Edema Response
Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3704-

Purpose: To investigate the overnight corneal edema response during overnight orthokeratology (OK). Methods: Eighteen young adult myopic subjects wore BE reverse geometry lenses in Boston XO material (nominal Dk/t 45 ISO units) on an overnight wearing schedule for 1 month. A further 10 subjects wore conventional RGP lenses of slightly higher Dk/t in one eye only on an identical schedule. Corneal thickness (total, stromal and epithelial) in the center, midperiphery and periphery was measured with the Holden-Payor optical pachometer in the morning after lens removal (am) and following 8-10 hours of no lens wear (pm), after 1, 4, 10 and 30 nights of wear. Changes from baseline (%) for OK (right eye only), RGP and no-lens eyes were compared by repeated-measures ANOVA and protected t-tests. Results: On Day 1 (am), central

corneal edema averaged 1.5 {+/-} 0.6%, 6.5 {+/-} 0.9% and 2.7 {+/-} 0.8% in the OK, RGP and no-lens eyes respectively (OK<RGP, p<0.01; OK<no-lens, p<0.01, unpaired t-tests). The central stroma swelled significantly less in OK than in RGP eyes (p<0.001, ANOVA), and less than with no lens wear (p<0.001, ANOVA) throughout the study. Conversely, levels of overnight edema consistent with Dk/t were found on Day 1 in the midperiphery (3.5mm from apex) and periphery (5.0mm) for both OK and RGP lenses. An overall trend suggesting adaptation of the overnight edema response was found in the midperiphery and periphery (p<0.01, regression test). Recovery to baseline stromal thickness in the evening (pm) was demonstrated for RGP eyes, and for OK eyes in the central and peripheral cornea. As reported previously, the midperipheral stroma in OK eyes showed significant residual thickening after Day 4 (p<0.001, ANOVA). Conclusions: Overnight wear of reverse geometry OK lenses suppressed the central stromal edema response. Normal overnight edema levels, consistent with Dk/t, were found in the corneal midperiphery and periphery. Adaptation of the edema response occurred with continuing overnight lens wear. We postulate that central pressure exerted by the flat-fitting base curve of the OK lens acts as a "clamp" to locally suppress central corneal swelling.

Hiraoka, T., A. Furuya, F. Okamoto, *et al.*

Quantitative Evaluation of Corneal Regular and Irregular Astigmatism in Subjects Undergoing Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3685-.

Purpose: Orthokeratology is defined as the temporary reduction in myopia by the programmed application of rigid gas-permeable contact lenses. Development of new reverse geometry contact lens designs has led to a renewed interest in this field. However, the influence of this procedure on corneal topography has not been studied in detail. We conducted the current prospective study to quantitatively assess changes in corneal regular and irregular astigmatism in subjects undergoing overnight orthokeratology. Methods: Fifty-nine eyes of 36 patients undergoing overnight orthokeratology for myopia were examined. Inclusion criteria were uncorrected visual acuity of 20/20 or better after treatment and minimum follow-up of 3 months. Mean age was 15.9 {+/-} 6.3 years (range 11 to 37). Mean spherical equivalent before treatment was -3.15 {+/-} 1.13D (range -1.25 to -5.75). Videokeratographic data were obtained with computerized videokeratography (TMS-2N, Tomey). Using Fourier series harmonic analysis, topography data were decomposed into spherical component, regular astigmatism, asymmetry (tilt or decentration), and higher order irregularity. These data were calculated for 3-mm and 6-mm pupils. Results: By orthokeratology, regular astigmatism significantly increased for both 3-mm (p=0.0177, paired t-test) and 6mm (p=0.0039) pupils. Similarly, asymmetry component increased significantly by the treatment for 3-mm (p<0.0001) and 6-mm (p<0.0001) pupils. No significant changes were observed in higher order irregularity (p=0.2772, 0.0811). The amount of myopic correction significantly correlated with asymmetry for 3-mm (Pearson r=0.44, p=0.0004) and 6-mm (r=0.65, p<0.0001) pupils, but not with regular astigmatism (r=0.15, p=0.2705) (r=0.14, p=0.2860). Conclusions: Even in patients who acquired good uncorrected visual acuity by means of orthokeratology, asymmetry as one of the irregular astigmatism components increased considerably. The magnitude of myopic correction correlated with the increases in asymmetry component. Future studies are needed to investigate the exact influence of corneal irregular astigmatism on patients' daily vision after overnight orthokeratology.

Jackson, J.M., M.J. Rah, L.A. Jones, *et al.*

Baseline Corneal Eccentricity as a Predictor for Refractive Error Change in Overnight Orthokeratology: Results from the LOOK Study

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3289-.

Purpose: Predicting success for an individual patient undergoing ortho-k remains a clinical challenge. Some studies have reported that the amount of baseline corneal eccentricity is a predictive factor for change in refraction attainable, while others have not found this relationship. This relationship is evaluated using data from the Lenses and Overnight Orthokeratology (LOOK) study. Methods: Data for 39 right eyes and 38 left eyes were evaluated; this includes patients who were and were not successfully treated. Subjects were examined at time of lens removal (AM visits) and 6 hours after lens removal (PM visits). Corneal topography, LogMAR VA, refraction, and slit-lamp exam were performed at each visit. Linear regression analysis was performed to determine if there was a relationship between baseline eccentricity values and the amount of refractive error change attained. Results: Mean SEQ refractive error was -2.00 +/-0.92 OD and -2.07 +/-0.82 OS; mean baseline e-value was 0.41 +/-0.14 OD and 0.43 +/-0.12 OS. Mean SEQ change in refraction was +2.08 +/-1.10 OD and +2.16 +/-1.16 OS. Linear regression analysis showed no significant relationship between baseline eccentricity and amount of SEQ refraction change when baseline SEQ was controlled for (adjusted r-square 0.41 OD, p=0.086; 0.46 OS, p=0.162). Conclusions: While some studies have found a predictive value for baseline eccentricity values, these findings do not support that hypothesis. This could be caused by a variety of factors, including different methods and algorithms used by topographers to measure eccentricity data.

Lu, F.H., L. Sorbara, R.A. Kort, *et al.*

Topographic Keratometric Effects of Corneal Refractive Therapy After One Night of Lens Wear

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3699-.

Purpose: To compare the extent of the corneal shape change topographically over a horizontal 6-8mm chord after a single night of wearing CRTTM corneal reshaping contact lenses to wearing control (alignment) lenses and also to compare data collected using OrbscanTM II and AtlasTM corneal topographers.

Methods: Twenty study participants wore CRTTM HDS 100 contact lenses in one eye and control lenses (tetracurve design) of the same material in the contralateral eye, overnight. Measurements were performed at baseline on the night prior to lens insertion, immediately after lens removal on the following morning and at 20 and 60 minutes and 3, 6 and 12 hours later. Topographic changes were measured over a 6-8mm chord in 1mm steps. Results: There were significant differences in corneal radius of curvature between the two lenses ($p=0.0058$) and at various corneal locations ($p=0.0000$). The mean change in curvature centrally and at the 3mm mid-peripheral point was $-1.49\{\pm\}0.73D$ and $1.96\{\pm\}2.10D$ respectively, for the CRT lens and $-0.37\{\pm\}0.40D$ and $-0.15\{\pm\}0.92D$ for the control lens immediately after lens removal. There were significant changes of shape over time ($p=0.0043$), but the 12 hour measurements were still significantly different from baseline ($p=0.0005$). There were strong and significant correlations ($r=0.84-0.99$, all $p<0.05$) between OrbscanTM II and AtlasTM data topographically, except at the first nasal (1mm) location ($r=0.75$, $p=0.052$). Conclusions: Despite only a single night of lens wear, the eye wearing the CRTTM design had significant topographic keratometric changes compared to the control lens. The shape of the cornea did not recover to baseline values at 12 hours, indicating that the change in shape can be maintained. This work was supported by grants from Paragon CRTTM Inc and the Canadian Foundation for Innovation (CFI).

Oguri, A. and M. Nishimura

Advanced Orthokeratology for Japanese Patients with High Myopia

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3290-.

Purpose: To evaluate the visual results of Advanced Orthokeratology (Ortho-K) to treat Japanese patients with high myopia. Methods: The enrollment criteria of this study were: patient having myopia whose Ortho-K treatment was started after August 2001 at Jyoto eye clinic; spherical equivalent (SE) range from -6.0 to -9.0 diopters (D); a follow-up examination every 1 to 3 months for at least 1 year; no ocular disease except myopia. Eight eyes of 5 patients, with mean age of 28.2, were conducted. The mean SE was $-7.22D$. The full custom rigid gas-permeable (RGP) contact lenses (CL) were designed for each eye. Uncorrected visual acuity (UCVA) was 0.06 or worse in all cases. The patients wore the RGP lens for approximately 9 hours per day in the waking and/or sleeping time. The follow up examinations were performed in the morning (10am to 12am). Results: The mean SEs were $-3.92\{\pm\}1.21D$ at 1month, and $-0.84\{\pm\}0.73D$ at 1 year. The average UCVA change is shown on Fig.3, and it was $0.81\{\pm\}0.46$ at 1 year after the treatment. A UCVA of 1.0 (20/20) or better was obtained in 3/8 cases (37.5 %) at that time. No severe complications occurred during the follow up period. Conclusions: Although Advanced Ortho-K takes a longer time to receive a patient's satisfaction in UCVA than refractive surgery, it was found to be safe and effective enough in the treatment of refractive errors for high myopia in this study. Longer follow-up is necessary for long-term results. This method deserves further investigation as one of the treatments of choice in refractive therapy.

Rodriguez, G., J.M. Merayo-Llodes, and OK Study Group

Effectiveness of Orthokeratology to Reduce Dependence of Glasses and Contact Lenses Wear and Modulate Refraction

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3702-.

Purpose: To validate Orthokeratology (OK) with two specific contact lenses like a method to reduce dependence of glasses and contact lenses. Methods: After an informed consent, 74 eyes from 37 subjects (mean age of 29 yrs, range 18 to 50) with myopia equal or less than 3.00D and astigmatism equal or less than 1.00D (mean refraction: sph= $-1.92D$, cyl= -0.51 , Uncorrected Visual Acuity (UCVA)=0.23) were fitted with OK lenses (Conoptica(R) and Lenticon(R)). Before study, 17 patients were contact lenses wears (soft=15, RPG=4, PMMA=1). The lenses were worn during the day and removed during the night. Data were collected before and 3, 6, 9 and 12 months after treatment. UCVA and Refraction was measured after remove lenses. A questionnaire about satisfaction, quality of vision, comfort and easy handle was filled in each visit. Results: Mean parameters of fitted lenses were R=8.48mm, Periphery band Closure= 4.5D, diameter=10.2mm, Refraction=1.5D. Lenses were worn a mean of 7.7 hours at 7 days per week. Only 6 patients ended study (follow-up= 12 months), 6 followed 9 months, 5 followed 6 months and 4 patients followed 3 months. 17 patients left study during the period of adaptation. One patient was taken out of study because of adverse event. Main reasons for left study were: bad VA (7 patients), discomfort (5) and unstable refraction (2). All patients who referred discomfort were soft contact lenses wears. In patients who followed in the study mean refraction after treatment was sph= $-0.31D$, cyl= $-0.14D$ and UCVA=0.76. Satisfaction in these patients was good. In a scale of 1 to 10, patients pointed Comfort= 7.97, Quality of vision= 8.65 and easy handle= 9.13. Conclusions: Orthokeratology is an alternative method to reduce the dependence of use

of glasses and contact lenses and modulate refraction in mild myopia. The most satisfied patients are those who don't wear contact lenses before or patient who wear RGP and who don't need a perfect Vision. However a great percentage of patients drop up of the study due to the strictly program of adaptation.

Shum, P.

Control of Myopia by Using Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3718-.

Purpose: Most of the myopia is due to the axial length elongation of the eyeball. The cycloplegic agent has been using for the control of myopia for over two decades but the effect is not remarkable. Overnight orthokeratology is a method to reduce the myopia by flattening the corneal curvature with a rigid gas permeable contact lens. Some studies reported that the hard contact lenses may have an effect on the control of myopia. In this study, we want to investigate whether the progression of myopia will be retarded by using the overnight orthokeratology. Methods: There were 27 cases (54 eyes) involved in the study group and 61 cases (122 eyes) in the control group respectively. The ratio of sex, age and the period of follow up were matching each other. The autorefractometry, autokeratometry, intraocular pressure and ultrasonic biometry were performed before and after wearing the rigid gas permeable contact lenses. The mean age was 11 years old and the mean observation time was 18 months. Results: The myopia was decreased by 1.46 +/- 0.22 D (Mean +/- SEM) in the study group but increased by 0.90 +/- 0.08 D in the control group. The axial length was increased by 0.21 +/- 0.06 mm in the study group and 0.44 +/- 0.03 mm in the control group respectively. The vitreous length was increased by 0.28 +/- 0.05 mm in the study group and 0.40 +/- 0.03 mm in the control group respectively. Those differences were significant statistically. Conclusions: As the myopic progression is mainly due to the vitreous length elongation, we concluded that the overnight orthokeratology may have the effect on the control of myopia.

Subramaniam, S.V., E.S. Bennett, B. Morgan, and V. Lakshminarayanan

Comparison of Overnight Orthokeratology in RGP and Non-RGP Wearers

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3713-.

Purpose: Extended wear of RGP lenses has been associated with minor corneal shape changes, particularly a reduction in corneal eccentricity. This raises a question whether RGP lens wear affects the outcome of orthokeratology (OK), the process in which specially designed rigid lenses are used to correct low myopia by flattening the cornea. The objective of the study is to compare the refractive outcome of overnight OK in RGP and non-RGP wearers and identify the predictors. Methods: The RGP and non-RGP wearing groups consisted of seven and eight subjects respectively, a total of 15 subjects (30 eyes) in the age range of 18 to 42 years with myopia ranging from -0.50 to -4.50D. The average baseline myopia was -2.33D in non-RGP group and -2.71D in RGP group. RGP wearers were asked to discontinue lens wear 3 weeks prior to the study. Each subject was fit with BE OK lenses (Precision Optics) using Mountford's sag fitting approach. Apical radius, eccentricity and sag were measured via the Medmont corneal topographer and entered in the BE software. The suggested lens parameters were then calculated for each eye. The diagnostic lens fit was initially assessed one night after wearing the lens before the final lens was ordered. The goal was to achieve a Bull's eye fluorescein pattern was ensured. The subjects were advised to wear the lenses every night for about 8-10 hours. Visual acuity, subjective refraction, topography and slit lamp examination were performed at each weekly visit for a period of one month. Results: The average decrease in myopia was -2.64D in the non-RGP group and -2.34D in the RGP group. Since the attempted flattening of curvature depends on the baseline error, the myopia reduction in the two groups cannot be directly compared. Regression analysis shows an R2 of 87% for the non-RGP group and 14.4% for the RGP group. This shows that greater degree of variance in myopia reduction is explained by baseline error in the non-RGP group. In order to identify more predictors to explain the difference, multiple regression was performed with baseline myopia and eccentricity as variables. Eccentricity results in a significant R2 change in the RGP group accounting for 61.8% of the variance in myopia reduction. Conclusions: For the range of refractive errors considered in the study, eccentricity seems to be a better predictor for the RGP group compared to baseline error while in the non-RGP group, greater reduction was achieved in higher refractive errors.

Tahhan, N., F. Sarfraz, N. Raad, *et al.*

Orthokeratology and the Eyelid

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3714-.

Purpose: Our aim was to determine the relation between eyelid tension and refractive effects in orthokeratology (orthok) and the effect of lid position (open vs closed) on lens centration. Methods: Thirteen Caucasian and 13 Asian subjects were randomly fitted with BE and ABE (Capricornia Australia) reverse geometry contact lenses in one random eye. Subjects wore the lens for one hour with the eyes open. After one week of no lens wear, they wore the lens again for one hour with their eyes closed. Upper eyelid tension was measured objectively using a custom designed eyelid tensiometer. Refraction and Eyesys (version 4.2) corneal topography measurements were taken at baseline and after each period of lens wear. Lens

centration on the open eye and topography treatment zone centration after both open and closed eye lens wear was evaluated. Data were analysed using Student's t-tests and Pearson correlation. Results: There were no significant differences between either lens centration and treatment zone centration in the open eye nor in treatment zone centration in open vs closed eye for either Asian or Caucasian groups. There were no significant differences in eyelid tension between the groups (Asian 22.1 + 4.6mN vs Caucasian 20.9 + 5.7mN). No correlation was found between lid tension measurement and refractive change ($r=0.15$, $p=0.45$). There was no significant difference between Asian and Caucasian eyes in the amount of myopic reduction with either closed or open eye lens wear. Refractive changes in Asian eyes were significantly lower with closed eye wear compared to open eye wear ($0.52 + 0.49D$ vs $0.87 + 0.36D$ respectively, $p<0.05$), but refractive change with open and closed eye mode did not differ significantly in the Caucasian group ($1.04 + 0.71D$ open eye vs $0.88 + 0.49D$ closed eye, $p=0.41$). Conclusions: The results suggest that practitioners can assume that lens centration during eye closure will be similar to that in the open eye. There was no demonstrable relationship between lid tension and myopic reduction with orthok. This suggests lid forces play a less significant role than those of the tear film with orthok therapy.

Walline, J.J., M.J. Rah, and L.A. Jones

Children's Overnight Orthokeratology Investigation (COOKI) Pilot Study

Invest. Ophthalmol. Vis. Sci., 2003. 44(5): p. 3288-.

Purpose: There is no published literature regarding overnight corneal reshaping with reverse geometry contact lenses for temporary myopia reduction in children. A case series of children fitted with these contact lenses can provide much needed information. The ultimate goal of the COOKI Study is to examine the effects of overnight corneal reshaping contact lenses on myopia progression in children, but the primary aim of this COOKI Pilot Study is to investigate the safety and efficacy. Methods: Children between 8 and 11 years old were fitted with Corneal Refractive Therapy contact lenses (Paragon Vision Sciences, Mesa, AZ). They were examined in the morning and at least six hours later one day, one and two weeks, and one, three, and six months after dispensing the contact lenses. At each visit, uncorrected logMAR visual acuity, manifest refraction, corneal topography, and slit lamp examination were performed. We report results from the right eyes only. Results: We enrolled 29 children and 11 have been examined at six months to date. The mean (\pm SD) age was 10.4 (\pm) 0.99 years, 65.5% were female, and 48.3% were Caucasian. Four did not finish: two contact lens fits were not acceptable, and two discontinued for reasons unrelated to vision or comfort. Prior to contact lens wear, the mean uncorrected logMAR visual acuity was +0.68 (\pm) 0.22 (Snellen 20/96), and the mean spherical equivalent refraction was -2.50 (\pm) 1.37 D. At six months, the uncorrected visual acuity in the afternoon was +0.15 (\pm) 0.22 (Snellen 20/28), and the spherical equivalent refraction was -0.26 (\pm) 0.81. Six hours after removal of the contact lenses, the visual acuity improved by 0.01 (\pm) 0.10 (one letter), and the spherical equivalent refraction became more myopic by -0.24 (\pm) 0.78 D. At the six-month visit, 72.7% and 11.1% of the children exhibited any corneal staining at the morning and afternoon visits, respectively. No children experienced an adverse event during the course of the study. Conclusions: Overnight corneal reshaping is a safe, efficacious means of temporary myopia reduction in children.

Mita, T., Y. Ishii, K. Mukai, *et al.*

Histological Change of Cornea by Using Orthokeratology Lens

Invest. Ophthalmol. Vis. Sci., 2002. 43(12): p. 4119-.

Purpose: To investigate the histological and topographical changes after use of orthokeratology lens. Methods: After being studied corneal topography, twelve white rabbits wore orthokeratology lens (Euclid Systems Co, USA) on the left eyes for 8 hours daily. Eyes were enucleated after 2, 7, 14 days and 1 month, and served to histological examination. Results: After 7-14 days, epithelial layer were slightly thin in the center of the cornea (6 mm apical zone) with HE staining. In intermediate zone, epithelial layer was thick and getting thin toward corneal limbus. PAS staining showed no abnormal distribution of glycogen granules or their producing cells. After 1 month, there was no further change in epithelial and stromal configuration. Bulbar conjunctiva showed no abnormality throughout the study. Conclusion: Orthokeratology lens gave the change in the distribution of epithelial thickness. No functional variation was found in both epithelial and stromal layer.

Nguyen, T., S. Soni, D. Carter, and T. Biehl

Corneal Changes Associated With Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2002. 43(12): p. 3092-.

Purpose: To examine the changes in corneal curvature and thickness associated with reverse geometry orthokeratology lenses over a 3-month treatment period. Methods: 16 eyes from 8 subjects (21 to 43 yrs) with myopia less than 3.00D and astigmatism less than 1.00D were fitted with reverse geometry OK lenses (OK B & D Series, Contax Inc., Sherman Oaks, CA). The lenses were worn overnight and removed during the day. Data was collected once before treatment (baseline) and then at 0, 4, 8, and 12 hrs following the removal of OK lenses after overnight wear at 1 day, 1 wk, 1 mo, and 3 mos. Corneal topography and corneal

thickness were measured using Orbscan. Epithelial, stromal and total corneal thickness of the right eye was determined using confocal microscopy. Keratometry measurements were made with a standard keratometer. Results: The corneal curvature in the horizontal meridian showed a statistically significant flattening of 1.22D on Day 1, 0 hr ($p < 0.05$). At 4 hr, the curvature change was reduced to 0.68D and remained relatively the same throughout the day. These changes were not statistically significant at $p < 0.05$. By 1 wk, the corneal curvature flattened significantly by 1.91D at 0 hr and 1.47D at 12 hrs. These changes were stable for the remainder of the study. For all test visits, the mean central corneal thickness measured by Orbscan increased by approximately 20 microns at 0 hr. and returned to baseline at 4 hrs and was not significantly altered thereafter. At 0 hr, the epithelial thickness decrease by 17.77 microns, and by 12 hrs, the difference was reduced to 14.70 microns. These reductions are statistically significant at $p < 0.05$. At 0 hr, the stromal thickness increase by 40.1 microns, and by 12 hrs, the difference was reduced to 23.60 microns. These changes were not statistically significant at $p < 0.05$. At 0 hr, the total corneal thickness increased by 23.56 microns (not statistically significant at $p < 0.05$), thereafter, there was very minimal increase in total corneal thickness. Conclusion: The change in horizontal keratometry measurements at all visits showed statistically significant correlation ($r = .61$, $p < 0.05$) with the change in refractive error. The small or absence of change in total corneal thickness shown with Orbscan and confocal microscopy can be explained by a decrease in central corneal epithelial thickness accompanied by increase in stromal thickness. We believe that a portion of the increase in total central corneal thickness at 0 hr is the result of edema following sleep.

Oguri, A. and I. Mitsui

Results of Advanced Orthokeratology for Medium Myopia in Japan

Invest. Ophthalmol. Vis. Sci., 2002. 43(12): p. 3093-.

Purpose: To evaluate the visual results of advanced orthokeratology to treat patients with medium myopia in Japan. Methods: A retrospective study of 71 eyes of 36 patients, with mean age of 22.6 (range 7-57), whose spherical equivalent (SE) range was -2.0 to -4.0 diopters (D), was conducted. The mean SE was -3.1 {+/-} 0.5D. The same orthokeratologist designed custom rigid gas-permeable (RGP) contact lenses for all patients. The subjects were followed at least 1 month using only one designed lens for each eye. Uncorrected visual acuity (UCVA) was 0.3 or worse in all cases. The patients wore the RGP lens for approximately 9 hours per day. The follow up examinations were performed in the morning (10am to 12am). Results: All eyes obtained improvement in UCVA after the treatment. After 1 week of follow up, the 70.3% of subjects was 0.6 or better in UCVA and the mean SE was -1.8 {+/-} 0.8D. After 1 month, the 86.9% of them was 0.6 or better and the mean SE was -1.4 {+/-} 0.8D. No severe complications occurred during the follow up period. Conclusion: Advanced orthokeratology, even using only the first designed lens, was found to be safe and enough effective in the treatment of refractive errors for medium myopia in Japan. This method deserves further investigation as one of the treatments of choice in refractive therapy. Longer follow-up is necessary for long-term results.

Rah, M., M. Bailey, L. Jones, *et al.*

Changes in High and Low Contrast logMAR Visual Acuity with Overnight Orthokeratology

Invest. Ophthalmol. Vis. Sci., 2002. 43(12): p. 3095-.

Purpose: The difference between unaided logMAR high and low contrast visual acuity was evaluated to determine whether low contrast visual acuity changes at a different rate than high contrast visual acuity over time in a sample of overnight orthokeratology patients. In previous reports in the literature, traditional soft contact lenses, PRK, and LASIK have all been shown to reduce contrast sensitivity and/or low contrast visual acuity. Methods: Two lens designs were used: the Fargo lens from G.P. Specialists and the CRT lens from Paragon Vision Sciences. Subjects were examined at the time of lens removal (morning) and a minimum of 6 hours later (afternoon) at visits one, three and six months following a baseline examination. Standardized protocols to measure high and low contrast visual acuity using Bailey-Lovie charts were used for study outcome measures. Unaided visual acuity was recorded as the number of letters read correctly. This number was converted to logMAR for analysis Results: Comparison n OD OS Morning Visits Baseline to One Month 46 0.017 +/- 0.184 -0.006 +/- 0.176 Baseline to Three Months 31 -0.019 +/- 0.162 -0.011 +/- 0.197 Baseline to Six Months 27 -0.036 +/- 0.162 0.004 +/- 0.195 Afternoon Visits Baseline to One Month 44 -0.024 +/- 0.223 -0.022 +/- 0.198 Baseline to Three Months 31 0.005 +/- 0.202 -0.011 +/- 0.159 Baseline to Six Months 27 -0.003 +/- 0.274 0.010 +/- 0.290 Baseline to One Year 10 0.028 +/- 0.156 0.106 +/- 0.160 No significant changes were found for any of the above comparisons. Conclusion: Low contrast visual acuity does not improve at a different rate than high contrast visual acuity with overnight orthokeratology.

Soni, P. and T. Nguyen

Which Corneal Parameter, Anterior Corneal Curvature, Posterior Corneal Curvature, or Corneal Thickness is Most Sensitive to Acute Changes With Reverse Geometry Orthokeratology Lenses

Invest. Ophthalmol. Vis. Sci., 2002. 43(12): p. 3086-.

Purpose: The purpose of this investigation is to determine which one of the major corneal parameters (anterior corneal curvature, posterior corneal curvature and corneal thickness) is the most sensitive to change under acute application of reverse geometry orthokeratology lenses (OrthoK lenses). **Methods:** Nineteen, non-selected, eyes were fitted with OrthoK lenses that were on the average 1D flatter than the central horizontal Keratometer reading. The lenses were worn for 60 minutes. Pre and post corneal parameters were evaluated with the Orbscan topographical system and visual acuity was documented using Bailey-Lovie high contrast distance acuity charts. **Results:** There is significant flattening of central anterior cornea (1.01D, $p=0.0003$) following lens wear, with a tendency for greater flattening towards the nasal cornea. At 1.5 mm from the center there is no difference between the pre and post corneal curvatures. However significant steepening is noted (nasal -0.95D, $p=0.0004$; temporal-0.93D, $p=0.0077$) beyond 2.5 mm both nasally and temporally. In general no significant difference is found in the posterior curvature or corneal thickness following lens wear, except a tendency for cornea to thicken nasally from 1.5 to 3.0 mm (approximately 7 μ m, $P=0.04$) is noted. Uncorrected visual acuity on the average improved from 0.603 to 0.428 logMAR units ($p=0.0322$) following 60 minutes of lens wear. The average reduction in refractive error (0.80D, $p, =0.0001$) following lens wear correlates well with the anterior corneal curvature change. **Conclusion:** The anterior corneal curvature is the most sensitive parameter to an acute change induced by a reverse geometry orthokeratology lenses. The refractive error reduction closely parallels the anterior corneal flattening.