Available online at www.sciencedirect.com
SCIENCE DIRECT®
Contact Lens & Anterior Eye 26 (2003) 11–16
Contact Lens & Anterior Eye
www.elsevier.com/locate/clae

Soft contact lens extended wear affects corneal epithelial permeability: hypoxic or mechanical etiology?

Meng C. Lin [a,*], Gemma N. Soliman [a], Min J. Song [a], J. Patrick Smith [a], Carolin T. Lin [a], Ying Q. Chen [b], Kenneth A. Polse [a]

[a] *School of Optometry, University of California, Berkeley, CA 94720-2020, USA*
[b] *Department of Biostatistics, University of California, Berkeley, CA, USA*

Abstract

Contact lens extended wear increases the permeability of epithelium to sodium fluorescein (P_{dc}). The exact mechanism is not known. However, changes in P_{dc} likely result from either corneal hypoxia or mechanical trauma, or both. We explored the effects of one-night continuous wear with either high- or low-*Dk*/*t* soft lenses on P_{dc}. The results show that corneal epithelial barrier function decreases significantly with both lens groups. We also observed that Asian eyes had higher P_{dc} after overnight wear compared to non-Asian and that for both Asian and non-Asian eyes, the elimination of corneal hypoxia did not prevent changes in epithelial permeability.

Keywords: Extended wear; Cornea; Ethnicity; Asian; Epithelial permeability

1. Introduction

Clinicians and researchers often assume that most of the ocular complications associated with soft lens extended wear (SCLEW) result from contact lens-induced hypoxia [1–8]. Recently, a silicone-hydogel (SH) co-polymer soft lens, which provides sufficiently high oxygen transmissibility (*Dk*/*t*) to avoid corneal hypoxia during closed-eye lens wear, has been approved for 30 days of continuous wear [9–13]. Although these high oxygen-permeable lenses have eliminated contact lens-induced corneal hypoxia, they are not without several worrisome complications. For example, reports of adverse responses include superior epithelial arcuate lesions (SEALs), corneal erosions, papillary conjunctivitis, acute red eye, infiltrative keratitis, and peripheral ulcers [14–19]. More recently, there have been reports of microbial keratitis [20]. These clinical findings suggest that there must be factors in addition to hypoxia that can lead to contact lens associated morbidity.

We hypothesize that SH lenses mechanically alter epithelial integrity, which then provides the necessary environment for contact lens-related adverse events to occur. To test this hypothesis, it is necessary to compare epithelial barrier function before and after closed-eye lens wear of conventional and SH lenses.

We have refined a technique to assess indirectly epithelial barrier function by measuring the rate at which sodium fluorescein (NaF) penetrates into the stroma (P_{dc}, nm/s) [21]. In a normal cornea, the epithelium has a high resistance to penetration of hydrophilic dye and therefore an increase in the penetration rate provides evidence of reduced epithelial barrier function. Previous works have shown that 1 h of closed-eye hypoxic lens wear increases corneal epithelial permeability; however, neither hypoxia alone (e.g. no lens wear), open-eye lens wear, nor 1 h of closed-eye wear with high-*Dk* lenses alters P_{dc} [22–24]. If mechanical factors alone can alter epithelial integrity, it is necessary to have longer testing periods with closed-eye lens wear.

In this current study, we test our mechanical hypothesis by measuring changes in epithelial permeability on a group of subjects who were randomly allocated to one night of overnight lens wear of either a high- or low-oxygen-permeable lenses. The data from this study may provide additional information about the etiology of extended wear complications and also offer some potentially important clues about the types of lens design that may be needed to avoid adverse events associated with extended wear. In addition, we also stratified our data based on ethnicity to examine whether corneal epithelial permeability after overnight lens wear differs between Asians and non-Asians.

* Corresponding author. Tel.: +1-510-642-7215; fax: +1-510-643-8987.
E-mail address: mlin@spectacle.berkeley.edu (M.C. Lin).

1367-0484/03/$ – see front matter
PII: S1367-0484(02)00088-7

2. Methods

2.1. Subject recruitment and randomization

All subjects were recruited from the campus of University of California at Berkeley; all were successful soft lens wearers with no history of ocular complications. As part of the eligibility examination, lenses were fitted on prospective subjects. Lens-fitting acceptance included good centration, movement, and adequate comfort (35 or above on a scale from 0 to 50, where 50 = no lens awareness). Of 170 prospective participants, 108 subjects met the eligibility requirements and were scheduled for both baseline afternoon (p.m.) and overnight (a.m.) epithelial permeability measurements. A full explanation of the study procedures was given to each subject, and informed consent was obtained. This study observed the tenets of the Declaration of Helsinki and was approved by the University of California, Berkeley, Committee for Protection of Human Subjects.

Blocked randomization was used to ensure that the number of subjects and the eye to be measured first (the patched eye) were equally distributed in each study group to control for possible bias due to systematic differences between right and left eyes or due to measurement sequence.

2.2. Soft lens material

Subjects were randomly allocated to either PureVision® (balafilcon; 36% H_2O; 8.6 mm; 14.0 mm; 110*Dk*/*t*) or Acuvue® lenses (etafilcon A; 58% H_2O; 8.8 mm; 14.0 mm; 33*Dk*/*t*).

2.3. Instrumentation

A Fluorotron Master® automated scanning fluorophometer was used to perform all scans. The device passes a 100-nm bandwidth of blue light that coincides with the absorption spectrum of NaF and has been more fully described elsewhere [21]. For each measurement, a computer-driven stepper motor performed a 5–8 s scan along the optical axis of the eye, beginning at the tear film and passing through the cornea into the anterior chamber. The instrument generated a single profile of the combined tear film and corneal fluorescence, and the area under this fluorescence profile is proportional to the fluorescein mass encountered along the scan path. The rate of the dye penetration was estimated using a mathematical model described in an earlier study [21].

2.4. Procedures

The effect of overnight eye closure on epithelial permeability to fluorescein (P_{dc}) was measured on 108 subjects by comparing an afternoon (p.m.) P_{dc} measurement of open-eye to a P_{dc} assessment after 8 h of overnight wear (a.m. measurement). For the p.m. P_{dc} measurement, which provided the baseline permeability values, subjects reported to the laboratory when the eyes had been open a minimum of 4 h after awakening, and there had been no prior contact lens wear for at least 72 h. Following a brief slit-lamp examination to verify that the anterior segment of the eye was normal, P_{dc} measurements were made using the procedure outlined below. At the completion of the p.m. visit, subjects were dispensed the study lenses (low-*Dk*/*t* etafilcon A or high-*Dk*/*t* balafilcon lenses) with lens powers that provide the best corrected visual acuity. Subjects were then instructed to wear the lenses at bedtime and to sleep while wearing their study lenses for 8 h with a patch placed over one of the eyes according to the randomization scheme. For the a.m. visit, subjects were required to return to the laboratory within 2 h of awakening the following morning with the patch and lenses in place. The a.m. P_{dc} measurements were taken immediately after the patch and lenses were removed.

For both the p.m. and a.m. visits epithelial permeability was obtained as follows: after corneal fluorescent scanning, a micropipette was used to deliver 2 μl of 0.35% NaF onto the central superior bulbar conjunctiva of the subject's eye which was previously patched. The subject then closed and rolled the eye to distribute evenly the NaF. The eye was then scanned within 1 min of dye instillation and the same procedure repeated on the other eye. The two eyes were alternately scanned every 2 min for the next 20 min and then thoroughly rinsed with non-preserved sterile saline. Corneal fluorescence was measured again and P_{dc} estimates were obtained using a method described previously [21].

A thorough slit-lamp examination was done after each permeability assessment. To classify corneal staining we adopted the Mandell grading system [25]. The presence of corneal staining with fluorescein was graded on a 1–4 scale, where punctate staining of fewer than 5 points was graded as 1; 5–10 points as grade 2; 11–25 points as grade 3; and more than 26 points as grade 4 system. Subjects exhibiting more than 5 punctate stains in the central cornea were excluded from the analysis to avoid an overestimate of the P_{dc}. Subjects who exhibited central staining of >grade 1 at the p.m. visits were not scheduled for the a.m. visits and were dismissed at the completion of the slit-lamp examination.

2.5. Statistical methods

One-way analysis of variance (ANOVA) was first employed to assess the difference in subjects' age and their lens powers between the two study lens groups. The values of P_{dc} were transformed by the natural logarithm (ln) function before the analysis to stabilize the within-subject variability of P_{dc} and to induce greater symmetry of data distribution between the two eyes [21]. The effect of 8-h overnight lens wear was assessed using Student's *t*-test for each eye in both lens groups. The experimental design allowed us to estimate the relative effects of lens groups, visits, eyes, and ethnicity on the corneal epithelial barrier function, using linear regression models. Random effects analysis was employed on

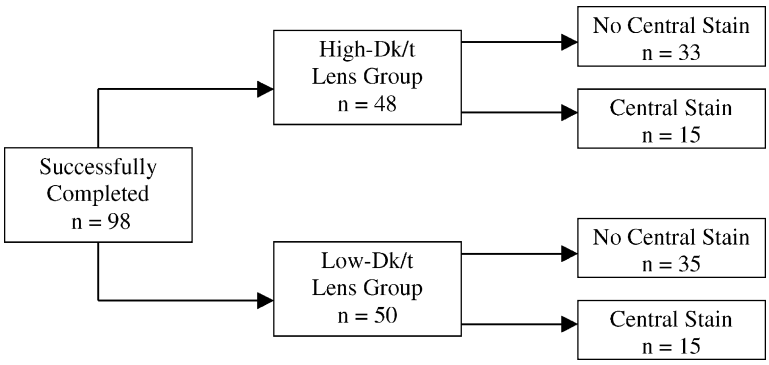

Fig. 1. Outcomes of subjects who successfully completed both baseline (p.m.) and overnight (a.m.) measurements.

repeat measurements. Analyses were performed using JMP V4 and STATA 6.0 statistics and data analysis software.

3. Results

A total of 108 subjects completed both baseline (p.m.) and overnight (a.m.) visits. However, data from 10 subjects were excluded from analysis due to negative P_{dc} values, which could not be transformed to natural logarithm. These negative estimates of the P_{dc} were likely a result of a lower post-rinse stromal fluorescence compared to the background fluorescence for the same eye due to variation in alignment of the subject between readings. Fig. 1 is a flow chart describing the various outcomes of the remaining 98 subjects. Of the 98 subjects, 30 developed central fluorescein staining (i.e. >grade 1) following overnight lens wear. For these 30 subjects, the P_{dc} measurements were analyzed separately from those 68 subjects without central staining (i.e. >grade 1) because of the confounding effect of central stain on the P_{dc} values.

Table 1 provides the demographic information of subjects in each lens group. For subjects without central staining, there was no difference in age ($P = 0.716$) between lens groups, and the average lens power worn in high-*Dk*/*t* lens group was −0.61 D significantly higher than for those in the low-*Dk*/*t* group ($P = 0.0461$). Subjects who exhibited central staining following overnight wear did not show a significant difference in either age ($P = 0.647$) or lens power ($P = 0.266$) between lens groups.

Table 2 shows $\ln P_{dc}$ values after 8-h overnight wear for the 68 subjects who did not develop central staining from either the high- or low-*Dk*/*t* lenses. For these subjects, there was a significant overnight change in P_{dc} in each eye (e.g. patched and unpatched) for both lens types. However, the low-*Dk*/*t* lenses showed greater changes in P_{dc}, an increase of 47 and 66% for patched and unpatched eyes, respectively, compared to 32 and 53% in the high-*Dk*/*t* lens group. Epithelial permeability measurements of the unpatched eyes, which on average had been open for less than 2 h, showed more overnight change in P_{dc} compared to the patched eyes in both lens groups.

Table 3 stratifies P_{dc} values for the non-staining group (Table 2) into Asian and non-Asian eyes. We stratified the P_{dc} data because previous works have shown that Asian eyes demonstrate differences in certain lens performance characteristics such as post-lens tear thickness, lens movement, and tear mixing [26,27]. The data in Table 3 show that the overnight change in P_{dc} for the Asian eyes was greater compared to non-Asian eyes for both balafilcon and etafilcon A lenses. For example, the increase in P_{dc} in the patched eye for the Asian group was 45 and 77% for the balafilcon and etafilcon A lenses, respectively, whereas the non-Asian group showed a modest change of 22 and 18% increase. In

Table 1
Demographic information in each lens group for subjects who either showed no central stain at both baseline (p.m.) and overnight (a.m.) visits or exhibited central stain in one of the eyes after 8-h overnight wear

	Balafilcon	Etafilcon A
Without central corneal stain ($n = 68$)		
Gender (M:F)	16:16	19:17
Age (mean ± S.D.)	22 ± 4	22 ± 3
Lens power (mean ± S.D.)	−4.26 ± 1.54	−3.65 ± 1.95
With central corneal stain ($n = 30$)		
Gender	5:10	2:13
Age (mean ± S.D.)	20 ± 2	20 ± 2
Lens power (mean ± S.D.)	−3.71 ± 2.06	−4.33 ± 2.18

Table 2
The values of natural logarithm of epithelial permeability ($\ln P_{dc}$) for subjects who exhibited no central corneal staining

	Patched	Unpatched
Balafilcon ($n = 33$)		
$\ln P_{dc}$ at baseline (p.m.)	−2.991	−2.862
$\ln P_{dc}$ at overnight (a.m.)	−2.712	−2.438
P-value	0.031	0.005
Etafilcon A ($n = 35$)		
$\ln P_{dc}$ at baseline (p.m.)	−2.918	−2.779
$\ln P_{dc}$ at overnight (a.m.)	−2.534	−2.271
P-value	0.005	0.001

Unit for $\ln P_{dc}$ is nm/s.

Table 3
Data from Table 2 stratified based on ethnic groups

	Patched	Unpatched
Non-Asian		
Balafilcon ($n = 14$)		
$\ln P_{dc}$ at baseline (p.m.)	−3.069	−2.919
$\ln P_{dc}$ at overnight (a.m.)	−2.871	−2.550
P-value	0.0344	0.155
Etafilcon A ($n = 16$)		
$\ln P_{dc}$ at baseline (p.m.)	−2.840	−2.800
$\ln P_{dc}$ at overnight (a.m.)	−2.677	−2.360
P-value	0.456	0.090
Asian		
Balafilcon ($n = 19$)		
$\ln P_{dc}$ at baseline (p.m.)	−2.974	−2.828
$\ln P_{dc}$ at overnight (a.m.)	−2.601	−2.338
P-value	0.034	0.015
Etafilcon A ($n = 19$)		
$\ln P_{dc}$ at baseline (p.m.)	−2.984	−2.761
$\ln P_{dc}$ at overnight (a.m.)	−2.413	−2.197
P-value	0.0007	0.0005

The Asian group consisted of Chinese, Japanese, Korean, Taiwanese, and South Pacific Islanders, while the non-Asian group consisted of Hispanics and Caucasians.

the unpatched eye, Asian eyes had an increase of 63 and 76% in P_{dc} for the balafilcon and etafilcon A lenses, respectively, compared to non-Asians who had 45 and 55% increase in P_{dc}, respectively.

To assess the relative contributions of the available and relevant predictors, we used random effect analysis on the data of the 68 subjects who showed no significant central corneal staining. We first constructed a model including all variables including age, gender, EYE (patched versus unpatched), LENS GROUP (low-*Dk*/*t* versus high-*Dk*/*t* lenses), VISIT (a.m. versus p.m.), and ETHNICITY (non-Asian versus Asian). Table 4 shows the results of the final model, suggesting that while adjusting for all other variables, $\ln P_{dc}$ values after one-night soft lens wear were 11% higher in the unpatched eyes compared to patched ($P = 0.0028$), 6% higher in the low-*Dk*/*t* lenses than in the lenses that provided normoxia ($P = 0.0623$), 12% higher in the Asian subject than non-Asian ($P = 0.0210$), and 25% higher in the morning visit than the baseline p.m. visit ($P = 0.0043$).

Table 4
Predictors of corneal epithelial permeability on the natural log scale ($\ln P_{dc}$, nm/s) among 68 subjects who showed no central corneal staining, using linear regression models with random effect analysis

Predictor	Regression coefficient	Standard error	P-value
EYE	−0.1043	0.0346	0.0028
LENS GROUP	0.0649	0.0347	0.0623
VISIT	0.2271	0.0787	0.0043
ETHNICITY	0.1156	0.0498	0.0210
ETHNICITY × VISIT	0.1994	0.1407	0.1576

The point estimate of the interaction term between VISIT and ETHNICITY was not significant ($P = 0.1576$).

Of the 30 subjects whose P_{dc} measurements were excluded from the data analysis due to central corneal stain, 18 were Asians (9 wore low-*Dk*/*t* lenses), 11 non-Asians (6 wore low-*Dk*/*t* lenses), and 1 of unidentified ethnicity. We do not know the significance of central corneal staining (e.g. are those individuals who show staining following overnight wear more at risk for adverse clinical events?). To answer this clinical question, a prospective clinical trial would have to be completed. The results of random effect analysis on these data ($n = 29$) suggested marginally significant differences in the severity of corneal stain between Asian and non-Asian cornea. Specifically, the difference was most pronounced in the superior corneal zone of the unpatched eyes ($P = 0.078$) and in both inferior ($P = 0.052$), and superior corneal zones ($P = 0.064$) of the patched eyes.

4. Discussion

The results of this study suggest that increased epithelial permeability associated with SCLEW is mechanical in origin. Although corneal hypoxia appears to augment the effect of lens wear on P_{dc}, the elimination of lens-induced hypoxia does not prevent alteration in the corneal epithelial barrier function. For example, the overnight P_{dc} was higher in the low-*Dk*/*t* lens group compared to high-*Dk*/*t*, although approximately the same number of subjects (e.g. 30%) in each lens group developed central corneal staining of the similar level of severity. It is possible that the greater hypoxic load and increased anaerobic metabolism from wearing the low-*Dk* etafilcon A lenses causes more retained debris (e.g. cell death, metabolic byproducts) compared to the high-*Dk* SH lenses and thereby leads to more mechanical trauma once the eye is opened.

It is of particular interest that for both soft lens types, the unpatched eye, which had been open for up to 2 h, showed a greater change in P_{dc} compared to the patched eye. This result seems at first paradoxical, as we might expect more recovery in an eye that has been open for a longer period of time before the measurement. In fact, a similar study on RGP lenses did show that the unpatched eye had lower permeability changes compared to the patched eye [28]. We suggest that this apparently contradictory difference in P_{dc} between RGP and SCL overnight wear is due to the more efficient tear mixing of RGP lenses compared to SCL lenses, thereby allowing elimination of debris from under the lens almost immediately after eye opening, so that little if any mechanical trauma occurs to the epithelium.

We also have found that the Asian eye had substantially greater increase in P_{dc} compared to non-Asians. This finding is in agreement with the results obtained from our earlier study in which Asians wearing RGP lenses for overnight wear also were more prone to greater increase in P_{dc} than were non-Asians [28]. These reported differences

are conservative estimates of the differences between Asian and non-Asian eyes, as we found it necessary to exclude more Asians from the data analysis because of central epithelial cell loss following overnight wear (only subjects who showed no corneal staining after overnight wear were included in the P_{dc} data analysis). It is likely that the higher P_{dc} in the Asian eyes is due to the tighter lids and narrow palpebral aperture, leading to more mechanical force on the cornea during lid closure. If this is true, it may be possible that Asians are more susceptible to contact lens-associated keratopathy. Some investigators now believe that silicon-hydrogel lens complications (e.g. SEALs) may have a mechanical basis due to high lens modulus (i.e. relatively less flexible lens material) compared to the standard soft lenses. These mechanically induced ocular complications may be closely related to the relationship between ocular parameters and the contact lens, which in turn affects lens performance and thereby the integrity of the corneal epithelium. This means that a lens with the same design and material may perform differently on eyes of different ocular characteristics. Since the differences in ocular anatomy between Asians and non-Asians are primarily involved in the lid structures, it is possible that this presumed tighter upper lids of the Asian eyes make them more susceptible to the mechanically induced adverse effects after wearing the newly-developed silicon hydrogel lenses. Therefore, to assess the safety of extended wear with a new lens material or design, it is important and useful to control carefully for ethnic background and ocular characteristics to examine accurately the effects of lens wear on the ocular health.

In conclusion, we suggest one possible mechanism responsible for increased P_{dc} caused by soft lenses, as summarized in Fig. 2. During sleep there is a build-up of debris under the contact lens. Upon eye opening, the debris in the post-lens tear film is not quickly removed because of the inefficient tear mixing. When normal blinking resumes, the debris sandwiched between the lens and cornea is mechanically agitated against the epithelium with each lens movement. Ultimately, for some lens wearers, depending on the lens material and ocular parameters, this repeated mechanical agitation alters epithelial cell integrity, leading to adverse clinical events.

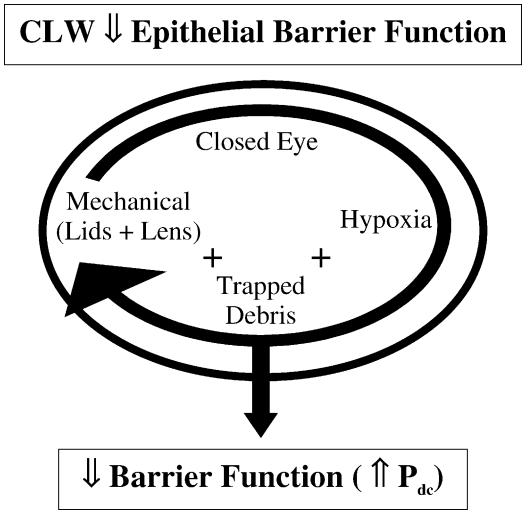

Fig. 2. The proposed mechanism responsible for the altered corneal epithelial barrier function.

Acknowledgements

Grant/financial support for this study was provided by Bausch & Lomb—Global Vision Care.

References

[1] Holden BA, Sweeney DF, Vannas A, et al. Effects of long-term extended contact lens wear on the human cornea. Invest Ophthalmol Vis Sci 1985;26(11):1489–501.
[2] Kenyon E, Polse KA, Seger RG. Influence of wearing schedule on extended-wear complications. Ophthalmology 1986;93(2):231–6.
[3] Polse KA, Brand RJ, Cohen SR, et al. Hypoxic effects on corneal morphology and function. Invest Ophthalmol Vis Sci 1990;31(8):1542–54.
[4] Cohen SR, Polse KA, Brand RJ, et al. Stromal acidosis affects corneal hydration control. Invest Ophthalmol Vis Sci 1992;33(1):134–42.
[5] Bonanno JA, Polse KA. Corneal acidosis during contact lens wear: effects of hypoxia and CO_2. Invest Ophthalmol Vis Sci 1987;28(9):1514–20.
[6] Polse KA, Decker M. Oxygen tension under a contact lens. Invest Ophthalmol Vis Sci 1979;18(2):188–93.
[7] Holden BA, Mertz GW. Critical oxygen levels to avoid corneal edema for daily and extended wear contact lenses. Invest Ophthalmol Vis Sci 1984;25(10):1161–7.
[8] Ren DH, Petroll WM, Jester JV, et al. The relationship between contact lens oxygen permeability and binding of *Pseudomonas aeruginosa* to human corneal epithelial cells after overnight and extended wear. CLAO J 1999;25(2):80–100.
[9] Lin MC, Graham AD, Polse KA, et al. The effects of 1-h wear of high-*Dk* soft contact lenses on corneal pH and epithelial permeability. CLAO J 2000;26(3):130–3.
[10] Fonn D, du Toit R, Simpson T, et al. Sympathetic swelling response of the control eye to soft lenses in the other eye. Invest Ophthalmol Vis Sci 1999;40(13):3116–21.
[11] Alvord L, Court J, Davis T, et al. Oxygen permeability of a new type of high *Dk* soft contact lens material. Optomol Vis Sci 1998;75(1):30–6.
[12] Keay L, Sweeney DF, Jalbert I, et al. The microcyst response to high *Dk*/*t* silicone hydrogel contact lenses. Optomol Vis Sci 2000;77:582–5.
[13] Covey M, Sweeney DF, Terry RL, et al. Hypoxic effects on the anterior eye of high *Dk* soft contact lens wearers are negligible. Optomol Vis Sci 2001;78:95–9.
[14] Holden BA, Stephenson A, Stretton S, et al. Superior epithelial arcuate lesions with soft contact lens wear. Optomol Vis Sci 2001;78(1):9–12.
[15] O'Hare N, Naduvilath T, Sweeney D, et al. A clinical comparison of limbal and paralimbal superior epithelial arcuate lesions (SEALs) in high *Dk* EW. Invest Ophthalmol Vis Sci 2001;42(4):S595.
[16] O'Hare N, Naduvilath T, Jalbert I, et al. Supeiror epithelial arcuate lesions (SEALs): a case control study. Invest Ophthalmol Vis Sci 2000;41(4):S386.

[17] Dumbleton K, Fonn D, Jones L, et al. Severity and management of contact lens related complications with continuous wear of high-*Dk* silicone hydrogel lenses. Optomol Vis Sci 2000;77(12s):216.
[18] Dumbleton K. Adverse events with silicone hydrogel continuous wear. Contact Lens Ant Eye 2002;25(3):137–46.
[19] Skotnitsky C, Jalbert I, O'Hare N, et al. Case reports of three atypical infiltrative keratitis events with high *Dk* soft contact lens wear. Cornea 2002;21(3):318–24.
[20] Lim L, Loughnan LS, Sullivan LJ, et al. Microbial keratitis associated with extended wear of silicone hydrogel contact lenses. Br J Ophthalmol 2002;86:355.
[21] McNamara NA, Fusaro RE, Brand RJ, et al. Measurement of corneal epithelial permeability to fluorescein. A repeatability study. Invest Ophthalmol Vis Sci 1997;38(9):1830–9.
[22] McNamara NA, Polse KA, Fukunaga SA, et al. Soft lens extended wear affects epithelial barrier function. Ophthalmology 1998;105(12): 2330–5.
[23] McNamara NA, Chan JS, Han SC, et al. Effects of hypoxia on corneal epithelial permeability. Am J Ophthalmol 1999;127(2):153–7.
[24] Lin MC, Han SC, Polse KA, et al. Etiology of contact-lens-induced changes in epithelial barrier function. Invest Ophthalmol Vis Sci 2000;41(4):S389.
[25] Mandell RB. Slit Lam classification system. J Am Optomol Assoc 1987;58:198–201.
[26] Lin MC, Duong A, Polse KA. The effect of ethnicity on soft lens tear mixing. ARVO abstract. 2002.
[27] Lin MC, Polse KA. The effects of Bse curve radius of soft lenses and subject characteristics on the post-lens tear thickness. CLAO J 2003;29(1S).
[28] Lin MC, Graham AD, Polse KA. The impact of rigid contact lens extended wear on corneal epithelial barrier function. Invest Ophthalmol Vis Sci 2002;43(4):1019–24.