Influence of Rigid Contact Lens Base Curve Radius on Tear Pump Efficiency

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ABSTRACT
The effects of rigid contact lens base curve radius changes on tear pump efficiency were determined by measuring oxygen uptake on six with-the-rule corneas (with toricities between 0.37 and 1.00 D) under three conditions: (1) normal open eye, (2) after 5 min of static (without blinking) wear of polymethyl methacrylate (non-gas permeable) contact lenses, and (3) after 5 min of dynamic (with blinking once every 5 s) wear of the same lenses. The difference between the oxygen uptake rates measured under static and dynamic conditions provides an index of tear pump efficiency. Each subject wore a series of five lenses: fitted on K and 0.05 or 0.10 mm steeper and flatter than the flattest corneal meridian. The mean diameter of all lenses was 8.8 mm, the optic zone was 7.4 mm, the axial edge lift was 0.09 mm, and all other parameters were constant. The contact lens fitted on K was associated with the greatest central corneal oxygen debt under static conditions, whereas the same lens also provided for the best tear exchange with the blink. In addition, better tear exchange was found to be associated with larger palpebral aperture sizes.

Key Words: contact lens, cornea, oxygen, base curve radius, tear pump efficiency

Many philosophies and techniques of rigid corneal contact lens fitting have continued to evolve over the years. Lenses have become thinner, gas permeable materials have been developed, various peripheral curve and edge designs have been proposed, and numerous lens diameters and corneal/contact lens base curve relationships have been advocated. Most of these methods have proved successful for a certain percentage of patients, yet many patients are unable to be fitted with a given contact lens design. One problem that has persisted through the years is how to provide the individual cornea with an optimum environment, one with an appropriate oxygen content, pH, osmolality, and a minimum of metabolic byproducts.

Blinking plays a very important role in providing oxygen to the cornea of the rigid corneal contact lens-wearing patient by pumping oxygenated tears beneath the lens and clearing debris and metabolic wastes from under the lens. Contact lens designs of appropriate cornea/contact lens base curve relationships, peripheral curve width and radius, overall and optic zone diameters, and edge design should enhance this bulk-flow exchange.

A Clark-type oxygen electrode can be used to evaluate oxygen availability to the cornea. Since Hill and Faut made the first in vivo measurements of oxygen consumption from the atmosphere by the human cornea in 1963, this technique has been used to establish the increase in epithelial oxygen uptake rate after disruption of the anterior oxygen supply. This increased oxygen uptake rate is greater if a gas-impermeable rigid contact lens is worn statically, or without blinking, than if the patient is allowed to blink. Using this technique, the effect of various corneas/contact lens base curve fitting relations on oxygen uptake rate of the cornea can be determined in both static and dynamic conditions. The difference between the oxygen uptake rates measured under static and dynamic conditions provides an index of tear pump efficiency.

Using these techniques, past studies have determined the effects of changes in overall diameter, optic zone diameter, axial edge lift, and blink frequency on tear pump efficiency. In this study, the effects of variations in rigid contact lens base curve radius on the oxygen uptake rate of the cornea and tear pump efficiency will be quantified.

Questions that will be explored here include: (1) Which corneas/contact lens base curve fitting relation results in the maximum corneal oxygen uptake under static conditions? (2) What are the effects of the distribution of the tear pool between the cornea and the various contact lens base curves on the corneal oxygen response? (3) How much reduction in corneal oxygen uptake is achieved with blinking for each cornea/contact lens base curve relationship? (4) Which cornea/contact lens base curve fitting relation is associated with the best tear pump efficiency? (5) Is the influence of palpebral aperture height on tear pump efficiency evident in this study as it has been in previous studies?
METHODS

Subjects

Six subjects participated in the study, four males and two females. They ranged in age from 22 to 27 years, all were in good ocular health, and none had ever worn contact lenses. The flattest corneal meridian fell between 41.37 and 43.87 D (mean, 42.29 D) and corneal toricities ranged from 0.37 to 1.00 D (mean, 0.75 D). The vertical palpebral aperture size ranged from 8.5 to 12.0 mm (mean, 10.5 mm).

Contact Lenses

Contact lenses of polymethyl methacrylate were used in the study for their negligible oxygen permeability, so that oxygen transmission through the lens material itself would not affect the oxygen tension beneath the lens. The overall diameter of all lenses was 8.8 mm, and the optic zone diameter was 7.4 mm. The base curve radius of all lenses was fitted to parallel the flattest corneal meridian of each subject as determined by keratometry (i.e., “on K”). Lenses fitted 0.05 and 0.10 mm steeper and flatter than these were also worn by each subject. The back vertex power of the lenses was −3.00 D, the center thickness was 0.14 mm, and the axial edge lift was 0.09 mm.

Equipment

Corneal oxygen uptake rates were measured with a Clark-type polarographic electrode (25 µm cathode), fitted with a 12 µm thick polyethylene membrane. The system was calibrated at 36°C by alternately placing the electrode in saline baths bubbled with air (for the 155 mm Hg level) and nitrogen (for the 0 mm Hg level). Reduction in oxygen tension with time was determined with a gas analyzer and displayed on a chart recorder as the electrode was placed in gentle tangential contact with the cornea. The segment of the oxygen depletion record between 140 and 40 mg Hg, corrected for the sensor and recorder time constants, was used to indicate the corneal oxygen uptake. Each lens or control condition produced a distinctive oxygen depletion curve, showing the change in partial pressure of oxygen in the probe reservoir per second. Steeper slopes were associated with higher oxygen uptake rates, which indicated a decreased oxygen supply to the cornea.

Procedure

After three practice and instructional sessions, each subject participated in eight data-gathering sessions. The first oxygen uptake measurement of each session was that of the normal, open eye. Afterward, each of the five contact lenses were placed on the eye in random order. During all periods of lens wear and all measurements, the subjects were in an upright, seated position. Each lens was worn first under static conditions (without blinking as the examiner held the subject’s upper lid) for 5 min and then under dynamic conditions (with blinking once every 5 s) for 5 min. Oxygen uptake rates were measured within 1 min after contact lens removal, and 5 min was allowed between oxygen uptake measurement and contact lens placement to assure that baseline oxygen uptake rates were reestablished.

RESULTS

Data from the eight measurement sessions for the six corneas were pooled for the static and dynamic condition data for each cornea/contact lens base curve relation. The data were divided by the mean oxygen uptake rate obtained on the normal open eye to indicate the increases in oxygen uptake that occurred when a contact lens was worn statically or dynamically. Differences between these relativistic静态 and dynamic condition data were calculated for each lens design to indicate tear pump efficiency associated with each design.

The mean oxygen demand response associated with each cornea/contact lens base curve relation for both static and dynamic conditions, as well as the difference data, are listed in Table 1, along with the standard errors of the mean and number of measurements involved. Fig. 1 shows the means and standard deviations for the static condition and dynamic condition. The difference data are shown for each cornea/contact lens base curve fitting relation. The same data for each of the six subjects are summarized in Fig. 2.

Table 2 presents the results of tests of statistical difference among the patient responses to the five cornea/contact lens base curve relations and two wearing conditions. Under static conditions, the oxygen uptake rates associated with the lens fitted 0.10 mm steeper-than-K were significantly lower than all other oxygen uptake rates. Under dynamic

| Table 1. Oxygen uptake rates (mm Hg/s) of 6 human corneas, each observed 8 times, to 5 min of either static or dynamic wear of 5 contact lenses of varying cornea/contact lens base curve fitting relations, relative to the oxygen uptake rate of the normal open eye.* |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cornea/Contact Lens Base Curve Fitting Relation (mm) | -0.10 | -0.05 | +0.05 | +0.10 |
| Static Condition | Mean | 6.67 | 7.18 | 7.74 | 7.14 | 6.99 |
| | SEM | 0.18 | 0.20 | 0.22 | 0.19 | 0.21 |
| | No. | 48 | 48 | 48 | 48 | 48 |
| Dynamic Condition | Mean | 6.28 | 6.23 | 6.21 | 6.17 | 6.08 |
| | SEM | 0.17 | 0.18 | 0.18 | 0.19 | 0.16 |
| | No. | 48 | 48 | 48 | 48 | 48 |
| Difference | Mean | 0.58 | 0.94 | 1.54 | 0.97 | 0.91 |
| | SEM | 0.21 | 0.31 | 0.22 | 0.19 | 0.11 |
| | No. | 48 | 48 | 48 | 48 | 48 |

* Differences between the means of the static and dynamic condition values are also listed, along with the standard errors of the means and number of measurements.

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conditions, there were no significant differences among the oxygen uptake rates associated with the five corneas/contact lens base curve fitting relations. The difference values associated with the on K fit were significantly greater than those associated with all other fits, except for the 0.05 mm flatter-than-K fit.

**DISCUSSION**

**Static Condition Data**

Under static conditions, it can be seen, both from the pooled data in Fig. 1 and the individual data in Fig. 2, that the contact lens base curve that most closely paralleled the flattest corneal meridian, as measured with the keratometer, resulted in the greatest increase in corneal oxygen uptake. In the pooled data, the increase in mean oxygen uptake rate was 7.74 times that of the normal open eye, whereas for the individual data the increase in mean oxygen uptake rates ranged from 6.67 to 9.20 times that of the no-lens condition. Statistical analysis showed that, for the pooled data, the lens fitted on K resulted in significantly higher increases in corneal oxygen uptake than did the steepest lens used. As the contact lens base curve was made steeper or flatter than the cornea, the oxygen uptake rates were less than when the lens was fitted on K. The greatest reduction in corneal oxygen uptake, compared to the uptake associated with the on K fit, occurred with the contact lenses fitted only 0.05 mm steeper or flatter. The volume of the tear reservoir between the contact lens and the cornea influences corneal oxygen uptake, with higher oxygen uptake rates being associated with smaller tear reservoir volumes.

Reductions in corneal oxygen uptake observed with the lenses fitted steeper than the cornea were due to the volume of tears over the central cornea between the contact lens and the cornea. With lenses fitted flatter than the cornea, the central part of the contact lens theoretically remains in contact with the central cornea if the contact lens is well centered. However, slight rocking movements or decentering of the lens could provide oxygenated tears from the annulus of tears in the lens periphery.

**Dynamic Condition Data**

Oxygen uptake rates measured after the dynamic wear of the contact lenses and associated with the various corneas/contact lens base curve relations were not significantly different from one another. The plot of the pooled dynamic condition data produces a straight line with a slope equal to zero. The mean rate of oxygen uptake from the pooled data for the dynamic condition was about six times higher than that of the no-lens condition, with individual mean oxygen uptake rates for the various corneas/contact lens base curve relations ranging from 4.82 to 7.32 times those of the no-lens condition.

**Difference Data**

Differences in the pooled data between oxygen uptake rates measured under static and dynamic conditions were significant for all corneas/contact lens base curve relations, however, indicating that
Figure 2. A comparative summary for each of six human corneas, showing their individual oxygen demands associated with each of five cornea/contact lens base curve fitting relations (ranging from 0.10 mm flatter-than-K to 0.10 mm steeper-than-K in 0.05 mm steps), relative to the nonlens-wearing open-eye demand for the population. Static condition, dynamic condition, and difference data are shown. Each point is the mean of eight measurements.
only 0.37 D of corneal toricity, the least amount of toricity of the subjects, and fitting guidelines have advocated fitting lenses flatter-than-K on near spherical corneas.

**Palpebral Aperture Size and Tear Pump Efficiency**

Fig. 3 displays the relation between the vertical palpebral aperture height and the maximum difference values among the oxygen uptake rates obtained statically and dynamically for each subject. (Cornea/contact lens base curve relation varied somewhat with subject.) For the 8.8 mm overall diameter contact lens used in this study, subjects with larger palpebral apertures had an advantage. The contact lens was able to move well over the cornea, providing the cornea with oxygenated tears. Subjects with narrow palpebral apertures require a

![Figure 3. Tear pump efficiency curve, displaying an increase in the maximum difference between the static and dynamic condition data obtained for each subject with the 8.8 mm overall diameter contact lens with increasing vertical palpebral aperture height.](image-url)
small diameter lens, inasmuch as large lenses are held tightly against the cornea, and movement and tear exchange are restricted. The result confirms the wisdom of conventional fitting guidelines, which suggest that subjects with narrow palpebral apertures be fitted with contact lenses of small overall diameters.

The results of this study have several clinical implications in the design and fitting of rigid contact lenses. It was determined that the highest increases in corneal oxygen uptake were associated with the static wear of the contact lenses fitted on K; however, little difference was found in the increases in oxygen uptake produced by the various corneal/lens base curve relations under dynamic conditions. The best tear pump efficiency was provided by the contact lens base curve fitted on K, suggesting that near alignment fits will provide for greater oxygenation of the cornea and clearance of metabolic wastes and debris. Finally, better tear pump efficiencies were associated with larger palpebral aperture sizes.

REFERENCES

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CONTACT LENS SYMPOSIUM

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