A polarographic oxygen electrode was used to measure the oxygen transmissibility of seven contact lenses of varying water content and center thickness. A similar electrode was used to measure the oxygen uptake following wear of these same contact lenses for both the open- and closed-eyelid conditions on five young healthy subjects. Linear regression revealed a strong correlation between oxygen transmissibility and equivalent oxygen percentage (EOP) values for both the open- and closed-eyelid conditions. This strong correlation between these two oxygen parameters shows both are useful in predicting the oxygen tensions across the tear-epithelial interface during contact lens wear. Invest Ophthalmol Vis Sci 25:1451-1453, 1984

Different methodologies can be used to study the oxygen transmission properties of contact lenses. A physiologic method is the equivalent oxygen percentage (EOP) technique developed by R. M. Hill. A physical method is the technique of measuring the oxygen transmissibility of a contact lens developed by Fatt and St. Helen. Recently, Efron and Carney correlated oxygen transmissibility and EOP values on human corneas. They found only a mild correlation for the open-eyelid case (r = 0.68) and a poor correlation for the closed-eyelid case (r = 0.30). The purpose of this study is to unify the two approaches or suggest reasons that might account for the differences.

**Materials and Methods.** A micropolarographic (25 µm cathode diameter) system, described earlier, was used to measure the oxygen flux across the tear-epithelial interface of five healthy young adults (average age: 26.2 years; range: 24–32 years) following various test conditions of relative oxygen deprivation. The conditions consisted of a five minute wearing of each of the contact lenses listed in Table 1 for the open- and closed-eyelid conditions. Five minutes have been shown to be more than ample time for the tears and corneal epithelium to reach a new oxygen tension steady state. Each condition was repeated four times per subject. In addition, the two control conditions of 21% O₂ (no relative oxygen deprivation) and 0% O₂ (anoxia) were measured for each test condition. The average time lapse between lens removal and polarographic electrode reservoir contact was approximately 1 sec. The 140-40 mmHg segments of the probe reservoir exhaustion records were used for rate comparisons (units of mmHg/sec) throughout; because both the time constant of the instrument and the measured corneal responses are exponential, the time constant for instrument response was subtracted from each measurement before analysis.

The “EOP calibration curve” relating the relativized corneal responses of contact lens induced oxygen deprivation to an oxygen percentage was measured on each individual subject. Briefly, this procedure involved measuring the corneal oxygen response to thirteen different mixtures of oxygen, the balance nitrogen, after being passed over the subject’s cornea for 5 min. The gas was humidified by being first bubbled through a saline bath at room temperature. The relativized corneal responses of oxygen deprivation (“relative flux” or “relative oxygen uptake response”) were calculated by the method of Hill as discussed by Roscoe and Wilson.

**Table 1. Lenses used in the study**

<table>
<thead>
<tr>
<th>Lens</th>
<th>Water Content</th>
<th>Base Curve</th>
<th>Overall Diameter</th>
<th>Center Thickness</th>
<th>Dk/L, (cm/sec)</th>
<th>Dk/L, (ml O₂/ml • mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gelflex</td>
<td>36%</td>
<td>+6.00 D; 7.40 mm</td>
<td>0.36 mm ± 0.02 (N = 3); Dk/L, 3.49 ± 0.48 (cm/sec) (ml O₂/ml • mmHg) (N = 7)</td>
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<tr>
<td>2. Aquaflex</td>
<td>42.5%</td>
<td>−1.00 D; vault III; center thickness, 0.24 mm ± 0.006 (N = 3); Dk/L, 4.28 ± 0.69 (cm/sec) (ml O₂/ml • mmHg) (N = 8)</td>
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<td></td>
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</tr>
<tr>
<td>3. Hydrocurve II</td>
<td>45%</td>
<td>−1.00 D; base curve, 8.9 mm; overall diameter, 14.5 mm; center thickness, 0.10 mm ± 0.01 (N = 3); Dk/L, 7.33 ± 0.58 (cm/sec) (ml O₂/ml • mmHg) (N = 8)</td>
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</tr>
<tr>
<td>4. Permalens</td>
<td>71%</td>
<td>−1.00 D; base curve, 8.0 mm; overall diameter, 13.5 mm; center thickness, 0.30 mm (N = 3); Dk/L, 10.39 ± 1.24 (cm/sec) (ml O₂/ml • mmHg) (N = 10)</td>
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<tr>
<td>5. Soflens O₃</td>
<td>38.6%</td>
<td>−2.00 D; center thickness, 0.305 ± 0.028 mm; Dk/L, 13.67 ± 0.75 (cm/sec) (ml O₂/ml • mmHg) (N = 6)</td>
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</tr>
<tr>
<td>6. Hydrocurve II</td>
<td>55%</td>
<td>−0.50 D; base curve, 8.3 mm; overall diameter, 14.5 mm; center thickness, 0.09 mm ± 0.01 (N = 3); Dk/L, 13.69 ± 1.71 (cm/sec) (ml O₂/ml • mmHg) (N = 10)</td>
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<td></td>
</tr>
<tr>
<td>7. Silsoft</td>
<td>0%</td>
<td>−3.00 D; base curve, 7.50 mm; overall diameter, 11.3 mm; center thickness, 0.20 mm ± 0.008 (N = 3); Dk/L, 23.09 ± 1.22 (cm/sec) (ml O₂/ml • mmHg) (N = 8)</td>
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</tr>
</tbody>
</table>

Note: Dk/L numbers should be multiplied by 10⁻⁹ to give the appropriate values. All lenses were measured at 35°C.
Table 2. Oxygen transmissibility* and EOP values (\%) for the open- and closed-eyelid conditions

<table>
<thead>
<tr>
<th>Oxygen transmissibility</th>
<th>Open-eyelid EOP</th>
<th>Closed-eyelid EOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 3.49</td>
<td>2.49 ± 0.31</td>
<td>0.21 ± 0.16</td>
</tr>
<tr>
<td>2. 4.28</td>
<td>2.80 ± 0.36</td>
<td>0.25 ± 0.03</td>
</tr>
<tr>
<td>3. 7.33</td>
<td>4.34 ± 1.09</td>
<td>0.92 ± 0.20</td>
</tr>
<tr>
<td>4. 10.39</td>
<td>5.58 ± 1.78</td>
<td>1.24 ± 0.13</td>
</tr>
<tr>
<td>5. 13.69</td>
<td>10.38 ± 1.19</td>
<td>1.62 ± 0.14</td>
</tr>
<tr>
<td>6. 13.67</td>
<td>7.89 ± 1.69</td>
<td>1.35 ± 0.11</td>
</tr>
<tr>
<td>7. 23.09</td>
<td>17.93 ± .93</td>
<td>4.38 ± 0.04</td>
</tr>
</tbody>
</table>

* Dk/L numbers should be multiplied by \(10^{-9}\) to give the appropriate units listed in Table 1.

Each EOP value is the mean of 20 measurements; standard deviations are also listed.

The oxygen transmissibility of each of the contact lenses was measured on a Schema Versatae apparatus as described by Wilson. Briefly, the lens was removed by plastic tweezers from its vial, which had been placed in a 35°C water bath and gently placed on the polarographic electrode. A cotton-tip applicator was used to remove any excess saline on the lens' surface. The temperature of the lens while on the electrode was maintained at 35°C by a heat lamp and monitored by a thermistor placed adjacent to the edge of the lens. When the decline in electrode current output appeared asymptotic, the value was recorded and used to calculate the lens' Dk/L value in units of \((\text{cm/sec}) (\text{ml O}_2/\text{ml} \cdot \text{mmHg})\). By measuring the oxygen transmissibility directly, relative ranking of each lens to the others is assured.

Some controversy exists as to the efficacy of using this apparatus to measure the oxygen transmissibility of silicone and "ultrathin" lenses, so they have been treated separately in the results. The transmissibility of the silicone lens used in this study was measured by the technique suggested by Fatt and Chaston; the ultrathin lens was measured in a manner similar to the other hydrogel lenses.

This study was approved by the Institutional Review Board of the University of Alabama in Birmingham.

Results. Table 2 lists the average EOP values for the open and closed eyelid as a function of contact lens oxygen transmissibility. Table 3 lists the results of linear regression analysis for the first five lenses listed in Table 2. The oxygen values of the silicone and ultrathin lenses were not included in the analysis because of their "questioned" oxygen transmissibility values. Figure 1 illustrates the two best fit lines relating oxygen transmissibility to EOP values for both the open- and closed-eyelid conditions.

Discussion. Several conclusions may be made from these results. First, oxygen transmissibility and EOP values appear to be well correlated for both the open- and closed-eyelid cases. The higher correlations found in this study compared with the Efron and Carney study may be contributed, in part, to the use of more accurate oxygen values.

Table 4. Comparison of predicted EOP values for the open eyelid for the same oxygen transmissibility* values used in this study

<table>
<thead>
<tr>
<th>Oxygen transmissibility</th>
<th>EOP†</th>
<th>EOP‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 3.49</td>
<td>0.53</td>
<td>1.96</td>
</tr>
<tr>
<td>2. 4.28</td>
<td>0.73</td>
<td>2.57</td>
</tr>
<tr>
<td>3. 7.33</td>
<td>1.45</td>
<td>4.76</td>
</tr>
<tr>
<td>4. 10.39</td>
<td>2.17</td>
<td>6.93</td>
</tr>
<tr>
<td>5. 13.69</td>
<td>2.95</td>
<td>9.32</td>
</tr>
<tr>
<td>6. 23.09</td>
<td>5.16</td>
<td>16.06</td>
</tr>
</tbody>
</table>

* Dk/L numbers should be multiplied by \(10^{-9}\) to give the appropriate units listed in Table 1.
† EOP = 2.36 \times 10^8 (Dk/L) – 0.280; (N = 40, r = 0.95, P < 0.001) (Novicky and Hill).
‡ EOP = 7.17 \times 10^8 (Dk/L) – 0.50; (N = 20, r = 0.96, P < 0.001) (Roscoe and Wilson, this study).
oxygen data points (11 versus 3) in the derivation of the “average EOP calibration equation” and direct measurement of contact lens oxygen transmissibility. These high correlations between these two oxygen quantifying parameters show both are useful in deriving models of tear–corneal epithelial oxygen tensions during contact lens wear.

This correlation also compares favorably with the findings of Novicky and Hill 10 and Fatt and Chaston 11 who found a similarly high correlation (r = 0.95) between oxygen transmissibility and EOP values for the open-eyelid case. However, Table 4 shows their model predicts much smaller EOP values for the same Dk/L values used in this study. Possible reasons for this difference include species variation (rabbit versus human corneas), static (no blinking) versus dynamic (blinking) conditions and different sample sizes (N = 40 versus N = 20).

Secondly, inspection of Figure 1 shows the measured oxygen parameters of the silicone and “ultra-thin” contact lenses are close to both best-fitted lines. In fact, recalculated r values with these lenses were 0.98 and 0.96 for the open- and closed-eyelid conditions, respectively. This suggests that the “functional” oxygen transmissibility values of these lenses, ie, that value while the lens is worn on the cornea, is closely approximated by those values measured on the Schema Versatae apparatus. This supports the conclusions of Fatt and Chaston. 8,9

Finally, the EOP closed-lid values for the two Hydrocurve lenses used in this study may be compared. The paired Student’s t-test reveals these EOP values are significantly different at the 95% confidence level. The values also appear to be physiologically significantly different; the Hydrocurve 55% water content lens’ closed-lid EOP value almost approaches the classical Polse-Mandell criterion, which may confirm physiologically the clinical practice of using the Hydrocurve 55% water content lens instead of the 45% lens in extended wear situations.

Key words: oxygen transmissibility, equivalent oxygen percentage (EOP), contact lenses, corneal physiology, oxygen measurement methodology

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References

Preservative Alteration of Corneal Permeability in Humans and Rabbits
Neal L. Burstein

Isotonic, neutral buffered solutions of benzalkonium chloride or chlorhexidine digluconate were applied topically to one eye of rabbits or human subjects. Contralateral control eyes received phosphate buffered saline as placebo. One-half hour later, the tear film of both eyes was loaded with nonpreserved sodium fluorescein. Anterior chamber fluorescence levels were measured at 1 hr intervals to determine corneal permeability changes attributable to preservative action. In rabbits, corneal permeability increased with rising preservative concentration. Benzalkonium chloride 0.01% increased anterior chamber fluorescence level 1.8 (±0.2 SEM) times over control eyes, while chlorhexidine digluconate 0.01% caused 1.5 (±0.2 SEM) to one ratio of fluorescence in treated/untreated eyes. In human subjects, neither preservative produced significant permeability change at 0.01% concentration. However, benzalkonium chloride 0.02% caused 1.23 (±0.08 SEM) permeability increase. The results support the hypothesis that rabbits are more