The amount of initial corneal swelling and the time course of corneal deswelling were measured after overnight wear of several types of hard and hydrogel lenses. Deswelling occurred in the right eye with the lens still on the cornea. In the left eye the lens was removed at eye opening and left off the cornea during deswelling. For lenses of equal nominal oxygen transmissibility, hard lenses initially induced greater corneal swelling than hydrogel lenses after overnight wear. The rate of deswelling during the first 15 min after hard lens wear was significantly greater than a comparable time period after hydrogel lens wear both with the lenses on and off the eye during deswelling. After the initial 15 min of eye opening, no significant difference in the deswelling rates with hard or hydrogel lenses could be shown under either deswelling condition. Invest Ophthalmol Vis Sci 27:20–23, 1986

Extended wear, in the hydrogel lens form, is enjoying increasing popularity as more knowledge and better materials become available. The problems associated with it, however, including decreased lens life, physiological insult to the cornea, and lack of an optimal correction for the astigmat still prevent it from achieving total acceptance. Recently, more permeable hard lenses have been developed making them feasible for both daily and extended wear. However, these lenses, like their hydrogel counterparts, also induce overnight corneal swelling and potential corneal insult. The purpose of this study is to compare the overnight swelling response of the cornea to hard and hydrogel extended wear contact lenses of various permeabilities.

Materials and Methods

Two subjects, adapted to both hard and hydrogel lenses, were fitted with four brands of hard gas permeable contact lenses and four brands of hydrogel lenses. Informed human consent was obtained from each subject prior to lens fitting. The lenses used in this study and their permeabilities and transmissibilities based upon harmonic average center thicknesses are listed in Table 1. All lenses had transmissibilities of at least $8 \times 10^{-9}$ (cm × ml O$_2$/sec × ml × mm Hg) which was judged tolerable for at least short-term extended wear. Both subjects wore each of the 8 lens types in both eyes continuously for 3 days. At least 24 hr were allowed to elapse between each wearing period. On the last night of wear for each brand, both eyes of the subjects were loosely taped shut. In the morning the subjects, with eyes still shut, were transported to the OSU Contact Lens Research Laboratory. Their eyes were untaped, the lenses were removed, and the central corneal thickness of each eye was measured with a Diagnostic Concepts Electronic Digital Pachometer (San Diego, CA). Immediately after these initial measurements were taken, the right lens was reinserted. The left lens was not replaced. Corneal thickness measurements were recorded at 0, 5, 10, 15, 30, 45, 60, 75, 90, 120 and 150 min after the eyes were opened. This procedure was repeated for all eight lens types. In addition, the same procedure was followed for each subject on one occasion without overnight or subsequent contact lens wear (control condition).

Results

Figure 1 shows the average corneal swelling caused by each lens immediately upon eye opening plotted against lens transmissibility. The best fit natural logarithmic regression curve was drawn through the hard and hydrogel lens points.

Deswelling during Lens Wear

Figure 2 (solid lines) shows the averaged deswelling time course while the lens remained on the eye during the initial 2.5 hr for the hard and hydrogel lenses used in this study. The average amount of initial swelling measured was similar for the hard and hydrogel lenses (hard = 11.5%, hydrogel = 12.1%). Once the eye was opened and the deswelling process began, however, the amount of corneal swelling remaining was consistently greater with the hydrogel compared to that caused by

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Table 1. Oxygen permeability and transmissibility of contact lenses

<table>
<thead>
<tr>
<th>Lens</th>
<th>Dk (× 10⁻¹⁰)</th>
<th>Dk/L_ave*</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard lenses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental HCL</td>
<td>62</td>
<td>39</td>
</tr>
<tr>
<td>Paraperm EW</td>
<td>56</td>
<td>36</td>
</tr>
<tr>
<td>Optacyl K</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Silicon</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Average</td>
<td>38.5</td>
<td>24</td>
</tr>
<tr>
<td>hydrogel lenses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B &amp; L 04</td>
<td>8.4</td>
<td>15</td>
</tr>
<tr>
<td>WJ D3X4</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Hydrocurve II 55%</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>CooperVision Permaflex</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Average</td>
<td>18.6</td>
<td>17</td>
</tr>
</tbody>
</table>

* Since the thickness of the lenses varied among the subjects due to power differences, the Dk/L_ave values are averages of all lenses used of each brand.
† Dk by personal communication with N. Stoyan 1984.

The estimated rate of deswelling for both the hard and hydrogel lenses was obtained by fitting a linear regression curve (not shown) through the 0 to 15 min and the 15 to 120 min points of each deswelling curve. The deswelling rate was then calculated as the slope of the line through the appropriate points and is shown in the top of Table 2. A small sample statistical test for differences between population means (df = 6) showed that the rate of deswelling for the hard contact lens was significantly greater (hard P < 0.01) during the first 15 min than during the 15–120-min interval. There was no significant difference in the deswelling rate of the hydrogel lens between the 0–15 min and 15–120-min time period. During the first 15 min after eye opening, the corneal deswelling rate with the hard lens was also significantly greater (P < 0.025) than that with the hydrogel lens during the same time period. For the 15–120-min time period, the deswelling rates for hard and hydrogel lenses were not statistically different. Two and one-half hours after the eyes were opened, neither the hard nor hydrogel lenses allowed the cornea to reach a level of zero-swelling. The average residual swelling was 2.2% for the hydrogel lenses and 1.1% for the hard lenses. When the eyes are taped shut with no lenses worn (control condition), the cornea reached the zero-swelling level in approximately 90 min (see Fig. 2).
Deswelling after Lens Removal

Corneal deswelling after eye opening and lens removal was monitored for 2.5 hr in the left eye of the subjects following the wearing of each lens and also after eye opening without lens wear (control condition). The deswelling curve without lens wear was similar in shape to the curve found during lens wear. As might be expected, the amount of corneal swelling remaining at any particular time (except immediately upon eye opening) was less when the lens was left off the cornea during deswelling (left eye) than when it was worn (right eye). Figure 2 (dashed lines) also shows the average deswelling results for the hard and hydrogel lenses after the lens was removed.

Again a linear regression curve (not shown) was fit through the 0–15-min and the 15–120-min portions of the deswelling curves for all lenses worn on the left eye (no replacement). The slopes of these curves indicate the rates of deswelling and are shown in the bottom of Table 2. As noted with the right eye, the deswelling rate was significantly greater (hard = 20.8%/hr) compared to the 15–120-min interval. Surprisingly, the 0–15-min deswelling rate of the cornea after hard lens wear (20.8%/hr) was significantly greater (P < 0.05) than the rate during the same time period after hydrogel lens wear (10.8%/hr), despite the fact that the initial swelling amounts were nearly identical (hard = 11.5% hydrogel = 10.9%), and no lenses were worn during deswelling. The 15–120-min deswelling rates for the hard and hydrogel lenses after lens removal were not significantly different.

Discussion

Corneal swelling due to contact lens induced hypoxia has been studied for over thirty years. A mechanism for stromal swelling has recently been described by Klyce. He found that epithelial hypoxia increased epithelial lactate production and its release into the stroma. The stromal lactate concentration increased while the stromal NaCl concentration decreased (through dilution). The increased lactate concentration exceeded the dilutional effect on NaCl and stromal edema was produced. Klyce also found that thickness of the epithelium was not affected by hypoxia.

Three aspects of the corneal swelling response after overnight lens wear are studied here: (1) the amount of overnight swelling produced by each lens type immediately upon eye opening; (2) the corneal deswelling response as the eye is opened and the lens is removed (left eye); (3) the corneal deswelling response as the eye is opened and the lens continues to be worn (right eye). This last condition simulates the morning deswelling response to hard and hydrogel extended wear lenses. Four hard lenses, four hydrogel lenses, and the no lens wear condition are evaluated.

An earlier study reported the initial amount of corneal swelling and the deswelling time course of the cornea after removal of several hard and hydrogel lenses worn for 3 hr with the eyes closed. This study extended the period of continuous lens wear to 72 hr and the period of eye closure (during the last night of wear) to approximately 7 to 8 hr.

The level of initial corneal swelling with the hydrogel lens as a function of lens transmissibility is shown in Figure 1. The natural logarithmic regression curve fit by the least square method (r = −.94) if extrapolated, would intersect the 4% swelling level (due to eye closure without lens wear) at approximately a Dk/L(ave) of 84 × 10⁻⁹ (cm × ml O₂)/(sec × ml × mm Hg). This agrees closely with the prediction of Holden and Mertz. Figure 1 also shows the initial swelling values and the natural logarithmic regression curve (r = −.96) for the hard contact lenses used. The swelling curve for the hard lenses falls closely along the hydrogel lens curve at low transmissibility levels. As higher transmissibility levels are measured, however, the initial hard and hydrogel swelling curves deviate considerably. Extrapolation of the hard lens curve shows that a transmissibility value of 159 × 10⁻⁹ (cm × ml O₂)/(sec × ml × mm Hg) would be necessary to maintain overnight swelling at the 4% “no lens” level. If the Dk results correctly represent oxygen permeability, then this deviation may be due to an unusually high measurement of transmissibility in the hard lens. This phenomenon has been previously noted and described as being due to the presence of an interfacial boundary resistance layer of water on the soft lens surface which effectively lowers its transmissibility measurement. Further studies of corneal swelling while wearing lenses of transmissibilities in the 50 to 160 range are necessary to confirm these findings.

Figure 2 shows that although the hard and hydrogel lenses induce similar levels of initial overnight swelling, the cornea deswells faster during and after wearing hard lenses compared to hydrogels. This difference might be attributed to the following: (1) the higher average Dk/L of the hard lenses vs the hydrogel lenses used in this study (hard Dk/L(ave) = 24 × 10⁻⁹; hydrogel Dk/L(ave) = 17 × 10⁻⁹); (2) a difference in the manner in which oxygen is supplied to the cornea between hard lenses (transmissibility + tear pump) and hydrogel lenses (transmissibility + minimal tear pump); (3) a difference in the area of the cornea that becomes swollen with hard and hydrogel lenses due to the difference in diameter of the lenses; and (4) a difference in the anterior-
posterior distribution of the edema caused by hard and hydrogel lens wear.

Analysis of the deswelling rates of the cornea during the wearing of hard and hydrogel lenses (Table 2; top) showed a significant difference during the first 15 min after eye opening. The hard lenses allowed a deswelling rate which is 2.5 times (14.7% per hr vs 5.9% per hr) that with the hydrogel lenses. After the first 15 min however, the deswelling rates of the hard and hydrogel lenses were not significantly different. Any of the three factors mentioned above or a combination thereof may explain this initial deswelling rate difference.

Inspection of the left eye deswelling rates (corneal deswelling without lens wear) in the bottom of Table 2 shows a deswelling rate twice as fast with the hard lenses (20.8% per hr) as with the hydrogel lenses (10.8% per hr) during the first 15 min. This difference cannot be accounted for by transmissibility differences or by the addition of a tear pump to aid deswelling since no lens was worn while deswelling occurred. Although peripheral pachometry was not included in this study, previous investigations have shown that the area of corneal swelling following hydrophilic lens wear is larger than following hard lens wear.8,9 Differences in the area of corneal swelling may have some influence on the speed of deswelling although a mechanism for this effect is not understood.

In summary, the levels of initial overnight corneal swelling induced by hard and hydrogel extended wear lenses were similar in the lower transmissibility range. As lenses with higher transmissibility were worn, however, the hard lens produced higher swelling amounts than did the hydrogel with the same transmissibility. As the eye was opened, the initial rate of deswelling was greater on an eye in which the swelling was induced by a hard lens compared to a hydrogel. After the initial 15 min of deswelling, the rates were nearly equal. These findings were the same with the lens on or off the eye during deswelling.

**Key words:** contact lens, deswelling, cornea, hydrogel, extended wear

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**References**