Silicone Hydrogels: Trends in Products and Properties

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INTRODUCTION

Although Silicone hydrogels resemble conventional hydrogels because of the water that they contain, the substantial presence of relatively hydrophobic silicone components leads to many differences in behaviour from that of simple and to high water content hydrogels. In the years since their launch, clinical experience has revealed a combination of characteristic benefits and complications (such as mismatch bulbing and OSSAL folds). The first two silicone hydrogels that became commercially available in the UK (Bausch & Lomb marketed under the trade name PureVision by Bausch and Lomb and Iotrafilcon A marketed as Focus Night & Day by Ciba Vision) had water contents of 35% and 24% respectively. Although both are classified as silicone hydrogels they are based on bulk and surface technologies that are significantly different from each other.

In 2004, a third silicone hydrogel (galofunic A, marketed as ACOVUE ADVANCE) by Johnson & Johnson Vision Care became available. The water content of this lens at 47% is appreciably greater than either of the two initial materials, as are its surface and bulk chemistries. The oxygen permeabilities of these materials remain high and are not significantly less than the 24% water content. Despite that fact, this new appearance to be a trend in silicone hydrogel development to sacrifice higher oxygen permeability for increased moisture content. Evidence for this was initially found in the FDA website, information relating to new USAN names and new approval submissions, which revealed the development of two new silicone hydrogels, senofilcon A (Johnson & Johnson Vision Care) and Iotrafilcon B (CibaVision). These two materials have now been launched as ACOVUE OASYS and O2OPTIX respectively. This will increase the number of commercial silicone hydrogel lenses to five, covering Equilibrium Water Contents from 24% to 47% and oxygen permeabilities (Dk) from 60 Barrers to 140 Barrers. Further details of these materials are contained in Table 1.

This paper compares the dynamic mechanical properties, dynamic wettability, frictional properties and dehydration behaviour these five materials. Although conventional hydrogel behaviour provides one reference point, the human cornea provides another interesting comparator. It is interesting to ask the question: are silicone hydrogels becoming more like the cornea?

METHODOLOGY

Mechanical Properties (Tensile and Dynamic)

Mechanical properties are conventionally measured in tension, in compression or dynamically using an oscillating cyclic load. The dynamic method is more similar to deformation processes found in nature, such as flexing muscles or blinking. The mechanical behaviour of polymer-based tissues is not simple, they reflect the viscoelastic nature of these tissues, and are usually represented by an elastic and a viscous flow component. Valuable information on the mechanical properties of contact lenses is obtained by studying both tensile properties (initial modulus, elongation to break and tensile strength) and dynamic properties (storage and loss modulus as a function of frequency). Tensile properties are measured on miniature dog bone parallel-sided specimens cut directly from contact lenses. The specimen is mounted in the jaws of a Hounsfield HK tensometer with a 10N load cell. Tensile tests are then carried out at a strain rate of 200%/min and at ambient temperature. Spraying with a fine mist minimises dehydration during the test. The values obtained are initial modulus, elongation to break and tensile strength.

Dynamic mechanical properties are measured using a fully automated Bohlin CVO Rheometer coupled with a temperature-controlled unit interfaced to a microcomputer. The dynamic mechanical properties are measured in oscillation using a parallel plate set up with fritted surface on avoid sample slippage during oscillation. Samples are subjected to frequencies of 0.02 - 20 Hz and values of the storage modulus (G") and the loss modulus (G") and the viscous (loss) modulus (G") are then obtained.

Dynamic Vapour Sorption

The dehydration/dehydration dynamics of the samples were measured using an automated dynamic vapour sorption analyser (DVS). At the heart of the DVS system is an ultra-sensitive microbalance which monitors changes in sample mass over a sequence of 50-100 cycles in which the humidity is switched between upper and lower levels of 98 RH and 40 RH. Cycle times of forty minutes at 98 RH followed by two minutes at 40 RH provide an accelerated representation of front surface dehydration enabling both mass loss and regain to be observed and compared.

RESULTS

Table 1: Silicone-Hydrogel Lenses and Properties

<table>
<thead>
<tr>
<th>Proprietary Name</th>
<th>United States Adopted Name</th>
<th>Manufacturer</th>
<th>Water Content</th>
<th>Oxygen permeability (x 10^18)</th>
<th>Tensile Modulus (gPa)</th>
<th>Formaldehyde (ppt)</th>
<th>Initial Advancing Contact Angle (°)</th>
<th>Relative Initial Dehydration Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PureVision</td>
<td>PureVision</td>
<td>Bausch &amp; Lomb</td>
<td>35.5</td>
<td>99</td>
<td>148</td>
<td>0.0</td>
<td>95</td>
<td>1.9</td>
</tr>
<tr>
<td>Focus Night &amp; Day</td>
<td>Focus Night &amp; Day</td>
<td>Bausch &amp; Lomb</td>
<td>47.0</td>
<td>140</td>
<td>238</td>
<td>0.1</td>
<td>80</td>
<td>1.1</td>
</tr>
<tr>
<td>O2OPTIX</td>
<td>O2OPTIX</td>
<td>Ciba Vision</td>
<td>47.0</td>
<td>60</td>
<td>190</td>
<td>0.0</td>
<td>78</td>
<td>1.4</td>
</tr>
<tr>
<td>ACOVUE ADVANCE</td>
<td>ACOVUE ADVANCE</td>
<td>Care CIBA Vision</td>
<td>24.0</td>
<td>60</td>
<td>65</td>
<td>0.0</td>
<td>65</td>
<td>1.5</td>
</tr>
<tr>
<td>ACOVUE OASYS</td>
<td>ACOVUE OASYS</td>
<td>Care CIBA Vision</td>
<td>35.0</td>
<td>103</td>
<td>92</td>
<td>0.0</td>
<td>68</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Figure 1: (above) Method used to hold lens strip for DCA analyses.

Figure 2: (right) Schematic of wettability measurements.

Coeficient of Friction

Principles and Methodology

Frictional properties of the sliding of one solid body over or along another. The magnitude or “level” of friction can be expressed in terms of the coefficient of friction μ. A modified nano-scratch tester was used to measure the coefficient of friction μ as a contact lens is dragged over a substrate (μ = F/W, where the force F is required to produce sliding when a load W is pressing two solid bodies together). An important aspect of this is the difference between the situation where the surface first start to move (so-called start-up or static friction) and when they are in motion (known as steady state or dynamic friction).

CONCLUSIONS

• The newly extended range of silicone hydrogels is moving closer to the cornea in physical properties although not in dehydration resistance.

• The trend to higher water contents has produced a dramatic reduction in stiffness both in simple tension tests and in dynamic studies.

• All lenses have relatively low coefficients of hydrated friction although differences in material surfaces produce different values.

• The inclusion of PVP in ACOVUE ADVANCE and ACOVUE OASYS lenses produces particularly low friction values closely approaching that of human corneas.

• The PVP effect also produces low values of advancing contact angles while the PVP-modified lenses but show less loss of wettability on dehydration.

• The extended range of water contents, wettability and stiffness values offered by the commercially available silicone hydrogels provides practitioners with a wide selection of significantly different clinical materials.

• The wettability and dehydration data presented here indicate that although the newer silicone hydrogels are in many ways similar to conventional hydrogels, lipid-related equilibration will pose greater problems for some patients than is the case with conventional hydrogels.

• The fact that current silicone hydrogels are significantly different from conventional hydrogels and also from each other highlights the need for standardised relevant in-vivo methods of assessment for these materials.