High technology contact lens materials and their biomimetic properties

Part 2

In the second and final part of this series on materials and biomimesis, Professor Carol Morris looks at material interaction with tissues and suggests what may lie ahead in material development. Module C8861, one contact lens point for optometrists and CLOs, one general point for DOs.

To make a lens surface which mimics the natural biology of the eye, it is important to look at the microscopic surface of the cornea, and understand how it functions. The first frame in Figure 1 shows an electron micrograph of a slam frozen rat cornea. In the outermost epithelial layer we see the hills and valleys contour of the microplicae surface, with ‘bottle brush’ like structures protruding from the top.

Large molecules called mucins, play a critical role in the healthy function of the eye and exist in two forms. The first is the membrane-bound form which is embedded in the surface of the corneal and conjunctival epithelium, coating the surface of the cornea with a sticky layer called a glycocalyx. This layer makes the surface more ‘wettable’, and allows the tears to spread smoothly across the surface of the eye. The second and larger form of mucin, the soluble form, is secreted into the tear film from the conjunctival goblet cells and interacts with the membrane-bound mucin at its surface, as shown in the second panel of Figure 1. When dust or other debris fall into the eye, the sticky mucus collects it together and wraps it up, after which both debris and mucus are swept from the surface by the eyelids during blinking. More secreted soluble mucin and a new surface layer of cells replace the depleted mucus layer, restoring the ocular balance. The cornea therefore has a renewable surface, in which blinking provides an essential function.

Recent research supports the concept that lubrication during the blink provides the key to a biomimetic lens. Manufacturers have therefore considered that to imitate the biological effect of the eye, the contact lens must consist of materials that behave in a similar way to the corneal surface, stabilising the tear film through moisture retention and with moisturisers that constantly renew themselves during blinking. The potential advantages of this type of lens are superior comfort for the wearer, as occurs with the natural defence mechanisms. As expected, there are varied approaches taken by the manufacturers to achieve this end, as indicated in Table 1.

Current daily disposable products fall into three classes:
- PolyHEMA materials which contain copolymers specifically designed to hold more water (colour-coded yellow)
- PolyHEMA materials which take up additives from the solutions in which they are packaged (colour-coded blue)
- Materials made of polyvinyl alcohol

### Table 1
**Current products**

<table>
<thead>
<tr>
<th>Lens</th>
<th>Polymer</th>
<th>Water content</th>
<th>Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus Dailies</td>
<td>Nefficon A (cross-linked PVA)</td>
<td>69%</td>
<td>none</td>
</tr>
<tr>
<td>Focus Dailies All Day Comfort</td>
<td>Nefficon A (cross-linked PVA)</td>
<td>69%</td>
<td>PVA</td>
</tr>
<tr>
<td>Focus Dailies AquaComfort Plus</td>
<td>Nefficon A (cross-linked PVA)</td>
<td>69%</td>
<td>HPMC, PEG, PVA</td>
</tr>
<tr>
<td>Acuvue 1-Day</td>
<td>Etafilcon A (copolymer of HEMA and methyl methacrylate)</td>
<td>55%</td>
<td>none</td>
</tr>
<tr>
<td>Acuvue 1-Day Moist</td>
<td>Etafilcon A (copolymer of HEMA and methyl methacrylate packaged in saline containing up to 500 ppm PVP)</td>
<td>55%</td>
<td>none</td>
</tr>
<tr>
<td>Clear 1-Day</td>
<td>Hioxifilcon A (copolymer of HEMA and glycerol methacrylate)</td>
<td>58%</td>
<td>none</td>
</tr>
<tr>
<td>SofLens</td>
<td>Balafilcon B (copolymer of HEMA and methyl methacrylate packaged in saline containing tetronic 1304)</td>
<td>59%</td>
<td>none</td>
</tr>
</tbody>
</table>

**Figure 1**

Biomimesis - corneal surface

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Biomimesis - corneal surface
PolyHEMA modification for improving water content

Although one of the original aims of improving the water content of polyHEMA lenses was to increase O₂ permeability, it is also possible to consider whether increasing the water content of a lens through the process of co-polymerisation with hydrophilic monomers will make the lens behave more like the natural tear film (colour-coded orange on Table 1). However, lenses with higher water content dehydrate more rapidly than those with lower water content. This is because the thermodynamic activity of water is approximately equivalent at all water contents. Whether free or bound, the water will eventually equilibrate with the tear film, and no improvement in the drying time of the lens will be observed.

Addition of compounds during or post manufacture to enable contact lenses to retain moisture and lubricity during wear

As discussed above, the biomimicry of the corneal surface requires a more proactive approach, and lens manufacturers have begun to engage in this process. If a chemical is added to the lens, there are three different outcomes, all of which can potentially affect the comfort of a lens during wear. If the additive is in the packaging solution and does not interact with the lens, it will wash away in the first few blinks after insertion. This might have the effect of improving comfort upon insertion, but no role during wear. If, on the other hand, such an additive in the packaging solution does interact with the lens material, there is the potential that the surface of the lens will be changed for the better, and will remain so during wear (colour-coded blue in Table 1). The third approach is to add the additive during manufacture so that there is the potential for the compound to leach out slowly during wear and give sustained comfort in that way (colour-coded blue Table 1).

Influence of method of manufacture

To come to grips with these concepts, it is necessary to have some understanding of the manufacturing processes involved in producing the different lens types. The most common method of manufacture of lenses based on pHHEMA is the double-sided cast moulding process. Cast moulding consists, basically, of polymerising a liquid mixture in a mould to produce the desired lens geometry. As shown in Figure 2, a pair of transparent moulds is utilised, with the cavity between the front curve mould and the base curve mould determining the desired contact lens geometry. A mixture of polymerisable monomers, cross-linker, photo-initiator and, in some cases, solvents, is dosed into the female mould. The moulds are then closed and exposed to UV light. The monomer mixture is radically polymerised to form a cross-linked polymer, after which the moulds are separated and the lens is removed. As the conversion of monomers to a polymer is never 100 per cent, hazardous or even toxic monomers remain in the lens. These compounds must be extracted with a suitable solvent.

The photopolymerisation reaction and the extraction of the lens are both time-consuming steps and far from ideal in a straight-forward process and many clever variations have ensued. However, whichever way the polyHEMA lens is made, the incomplete polymerisation and necessary extraction of potential toxic monomers makes it extremely difficult to add compounds conveying moisture retention and lubricity during manufacture. They will simply be removed during the extraction step.

Therefore, manufacturers basing their lenses on polyHEMA chemistry have so far opted to place such additives in the final packaging solution (colour-coded blue; Table 1).

Lenses which are made out of PVA, a relatively new material for soft contact lenses, do offer the possibility of adding compounds during manufacture. This is because PVA is a water soluble biocompatible polymer already approved for use in the eye. To use this chemical in contact lens manufacture, it was necessary to first produce a water soluble photopolymer based on PVA such that it will cross-link under the influence of UV light. Since the total reaction takes place in water and unpolymerised PVA is biocompatible, the extraction step can be avoided.

This chemistry has prompted the manufacturer using PVA for daily disposable lens production (CIBA Vision Corporation) to set up a fully automated unique system (Figure 3) using rigid moulds and online inspection, a patented process called Lightstream Technology. A fortuitous outcome of this process is the fact that residual amounts of unpolymerised PVA will now have the potential to leach out of the lens during wear. A careful
The leading lens products revealed that the coefficient of friction or least resistance over time and therefore possibly the most biomimetic situation.

The future of additives
No doubt we will see a great deal more activity in this area in the near future, we are only at the beginning of these developments. In this vein, CIBA Vision released a new lens late last year, Focus Dailies AquaComfort Plus, which contains more than one type of additive. The rationale for such developments is an attempt to maximise comfort throughout the wear time. Each compound has a different function, and may be released from the lens during blinking or added to the packaging solution. However, there are many more avenues to be explored and compounds to be tested. In all cases it will be important to develop a chemistry that acts in concert with the natural processes of the tear film, as does the corneal surface.

References

Biotribology
A further avenue of in-vitro measurement of the resulting lubricity of lenses containing additives has come through the study of biotribology. Ocular biotribology, as concerns contact lenses, focuses on the lubrication/friction created between the lens and the corneal surface during the blink. Although this is an important factor in achieving a biomimetic lens, measurement of the actual friction force created has been extremely difficult. Brian Tighe’s group at Aston University has spent some years adapting an instrument that measures friction, making it applicable to the contact lens situation. They adapted a high sensitivity tribometer, utilising a counterweight pulley system for this purpose. In this modified tribometer the lens is held steady and the eyelid-like substrate is dragged along the bottom. The force generated is measured and expressed as a coefficient of friction.

While the measurements achieved are not absolute in nature, they are excellent for comparing the coefficient of friction, and thus the lubricity, of various lenses in the situation of the eyelid blinking over the top of the lenses. Because such comparisons are now possible, new materials can be evaluated against existing materials and against each other. Taking these ongoing comparisons one step further, it became clear that these additives that stay bound to the material created a lower coefficient of friction during the course of wear. However, a study of the leading lens products revealed that those lenses releasing a lubricant during the blink showed the lowest coefficient of friction or least resistance over time and therefore possibly the most biomimetic situation.

MULTIPLE-CHOICE QUESTIONS - take part at opticIanonline.net

1 Which of the following has the highest water content?
A Focus Dailies
B Acuvue 1-Day Moist
C Soflens
D Clear 1-Day

2 Which of the following contains an additive?
A Focus Dailies All Day Comfort
B Acuvue 1-Day Moist
C Soflens
D Clear 1-Day

3 Which of the following statements about higher water content lenses is true?
A They will dehydrate more slowly than lower water content lenses
B The thermodynamic activity of water is increased
C They will show an improved drying time throughout wear
D They dehydrate more rapidly than lower water content lenses

4 What is the commonest method of manufacture of polyHEMA lenses?
A Spin casting
B Lathe cutting
C Double-sided cast moulding
D Single-sided cast moulding

5 What is the function of the glycoalyx?
A It acts as a physical barrier to pathogen penetration
B It exists within tears to envelope particular material
C It serves to improve wettability of the epithelial surface
D It increases the surface area of the epithelium

6 What does a tribometer measure?
A Mucus levels
B Friction between surfaces
C Bacterial load
D Transmissibility

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