COMPETENCIES COVERED
Dispensing opticians: Contact Lenses, Ocular Abnormalities
Contact lens opticians: Contact Lenses
Optometrists: Contact Lenses

Silicone hydrogel: the best all-rounder?

The first soft contact lenses (made from a hydrogel material) became available in 1957. At the time, less was known about the eye’s oxygen requirements but as early as 1967, researchers began to recognise that hydrogel contact lenses could cause contact lens induced hypoxia (which had already been recognised in PMMA wearers)1. Overnight wear of contact lenses became popular in the 1970s and by 1981, the US Food and Drug Administration (FDA) approved the first non-therapeutic, soft contact lens for wear across 30 consecutive days and nights. In the years that followed, researchers learned more about the cornea’s oxygen requirements and the increased infection risk that came with the overnight wear of lenses. Manufacturers thought that by increasing oxygen transmission through a soft contact lens, they could improve corneal health and reduce the infection risk.

The ability of silicone to transmit oxygen was already well known but silicone is intrinsically hydrophobic and, therefore, difficult to combine with hydrogel. It was not until 1999 that the first silicone hydrogel (SiHy) lenses became commercially available in the UK. Their popularity for fits and refits has steadily increased since that time and in the latest available Euromcontact market statistics report (2013)2, SiHy material now accounts for 86 per cent of fortnightly and monthly disposable lenses sold in Britain and 55 per cent of all soft lenses. SiHy lenses are now available in toric prescriptions, multifocal designs and planned replacement modalities.

FIRST GENERATION LENSES
The first generation lenses were PureVision by Bausch + Lomb and Focus Night & Day (now known as Air Optix Night & Day) by Ciba Vision (now Alcon). They were marketed as 30-day continuous wear lenses and were also indicated for therapeutic use, eg, as a bandage contact lens following corneal refractive surgery. These lenses had a special surface treatment to make them hydrophilic and to reduce the protein and lipid deposits commonly found with silicone.

The treatment used on PureVision transforms silicone to silicate using charged gas molecules to form islands of hydrophilic silicate between the hydrophobic silicone. The distance between the islands is small enough to make an overall hydrophilic surface3. It is also electrically neutral, which helps to prevent protein deposition4. The Night & Day lens undergoes a plasma treatment which makes it hydrophilic5. In both lenses, the treatment actually becomes part of the lens matrix and, therefore, cannot be rubbed off. First generation lenses have high Dks, low water contents and a high modulus.

SECOND GENERATION LENSES
In 2004, Johnson & Johnson Vision Care released its Acuvue Advance fortnightly SiHy lens for daily wear only, followed 15 months later by Acuvue Oasys, which could be worn up to seven days and six nights consecutively (extended wear) and which were also indicated for therapeutic use. These are known as second generation SiHy lenses. These lenses do not have a surface treatment to make them hydrophilic, instead the material itself has PVP (polyvinyl pyrrolidone) incorporated into it. The PVP binds moisture, making the material more flexible, and it provides a buffer between the hydrophobic silicone and the tears1. These lenses have lower Dks than the first generation, higher water contents and a lower modulus.

THIRD GENERATION LENSES
In 2007, a new generation of SiHy lenses was introduced to the market. These include Biofinity from CooperVision and PremiO from Menicon, both of which are indicated for extended wear. The silicone in the Biofinity lens is in the form of macromers and, therefore, this lens is hydrophilic without the need for surface treatments or wetting agents. PremiO combines siloxane and hydrophilic monomers using a patented polymerisation system, called MeniSilk, and it has a surface treatment.

This article has been approved for 1 CET point by the GOC. It is open to all FBDO members, including associate member optometrists. The multiple-choice questions (MCQs) for this month’s CET are available on page 22 and online. An answer sheet for posted or faxed entries is available for download on ABOO’s Dispensing Optics log-in page. Online entry: log in to www.abdo.org.uk, and follow the centre section link to ‘CET Online’. Please ensure that your email address and GOC number are up-to-date. The pass mark is 60 per cent. The answers will appear in the June 2015 issue of Dispensing Optics. The closing date is 15 May 2015.
This latest generation of lenses can provide high Dk values and higher water contents without necessarily having the high modulus values seen with the first generation lenses.

**OXYGEN TRANSMISSION**
SiHy lens materials were originally developed in order to supply the demand for overnight wear of contact lenses. The first generation lenses were approved for up to 30 days (and nights) consecutive wear, which is known as continuous wear. However, in spite of the fact that the subsequent second and third generation lenses also had excellent oxygen transmission, they were only marketed (and approved) for up to seven days (and nights) consecutive wear which is known as extended wear. This is because an increase in oxygen transmission did not solve all the problems inherent with overnight lens wear.

Several researchers have now concluded that a Dk/t of 125 is required to provide the cornea with a normal supply of oxygen even in the closed eye state6,7,8. Dk is a measure of the oxygen permeability of a material, whereas Dk/t measures the oxygen transmission through a particular lens with the “t” representing thickness. Table 1 shows the manufacturers’ stated Dk/t for various SiHy lenses. It can be seen from the table that most of the lenses meet the Dk/t requirement of 125. However, manufacturers normally state the Dk/t for a -3.00D lens and, as the lens thickness increases, the Dk/t drops and therefore most lens materials do not meet the 125 requirement in the higher prescriptions (particularly with plus prescriptions).

For daily wear, Harvitt and Bonano have proposed that a Dk/t of 35 would be sufficient to avoid hypoxia across the whole cornea8.

While the increase in oxygen transmission to the eye through SiHy materials solved some problems, eg. limbal neovascularisation, it did not reduce the risk of infection with overnight wear and this is probably why there has not been a significant increase in the rate of continuous wear prescribing in the last 10 years9.

**MODULUS AND WATER CONTENT**
Silicone is inherently stiff. It is the water content that gives a lens much of its flexibility. The modulus of a material gives an idea of the rigidity of the material (or how well that material resists deformation). However, modulus relates to the material and the actual stiffness of a lens will also depend on the lens thickness and shape. The first generation lenses had a low water content and a high modulus. The second generation lenses had internal wetting agents that increased water content and decreased modulus, but it is in the third generation of lenses that manufacturers have managed to combine higher water contents (thus reducing the modulus) without necessarily compromising on oxygen transmission. See Table 1 for the water content and modulus of SiHy lenses.

**FITTING TECHNIQUE**
The fitting technique for SiHy lenses is the same as for soft hydrogel lenses. If lenses are to be worn overnight then the movement of the lens post-blink should be optimal at 0.4-0.5 mm when the eye is in the primary position, and twice that again on upgaze. This is to ensure that overnight debris has the best possible chance of being washed from under the lens with tear exchange.

This aside, many contact lens experts feel that even with lenses designed specifically for overnight wear, patients should be encouraged to remove their lenses on waking and to carry out a rub and rinse step with a suitable cleaner before immediately reinserting the lenses.

**AFTERCARE**
If a patient is to wear lenses overnight they would normally be fitted with the lenses on a daily wear basis first, particularly if they are a new wearer. Once the patient commences overnight wear, it is usual to recommend that they have an aftercare appointment the morning after the first time they sleep in their lenses10. Overnight wearers are also normally checked more frequently than daily wearers.

At aftercare appointments, the practitioner needs to check carefully for specific signs that are more commonly encountered with SiHy lens wearers and overnight wear.

**SIGNS OF MECHANICAL PROBLEMS**
Because of the higher modulus of SiHy lenses (compared with hydrogel lenses) SiHy wearers have an increased risk of contact lens papillary conjunctivitis (CLPC) (Figure 1), superior epithelial arcuate lesions (SEALs), mucin balls and epithelial flaps. If a patient is exhibiting signs of any of the above, they should be changed to a lens with a lower modulus.

**DEPOSITS**
Silicone is notoriously lipophilic and SiHy lenses can deposit lipids very quickly.

<table>
<thead>
<tr>
<th>Lens</th>
<th>Generation</th>
<th>Dk/t</th>
<th>Water content</th>
<th>Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purevision</td>
<td>First</td>
<td>110</td>
<td>36%</td>
<td>1.1</td>
</tr>
<tr>
<td>Air Optix Night &amp; Day</td>
<td>First</td>
<td>175</td>
<td>24%</td>
<td>1.5</td>
</tr>
<tr>
<td>Advance</td>
<td>Second</td>
<td>86</td>
<td>47%</td>
<td>0.43</td>
</tr>
<tr>
<td>Oasys</td>
<td>Second</td>
<td>147</td>
<td>38%</td>
<td>0.72</td>
</tr>
<tr>
<td>Biofinity</td>
<td>Third</td>
<td>160</td>
<td>48%</td>
<td>0.8</td>
</tr>
<tr>
<td>Premio</td>
<td>Third</td>
<td>161</td>
<td>40%</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Table 1*
Continuing Education and Training

(Figure 2). Deposited lipids will soon smear a patient’s vision and lead to discomfort. Patients exhibiting signs of lipid deposition can have their lenses changed to a different replacement schedule, i.e. daily disposable lenses can be worn instead of fortnightly or monthly replacement. Protein deposits are generally less problematic. Natural protein from the tears is colourless, easily rinsed from lenses and may offer some protection from microbes.

When protein becomes denatured it can make a lens cloudy and may cause inflammatory reactions such as CLPC. Several studies from the University of Waterloo, Canada, have shown that SiHy lenses deposit far less protein than hydrogel lenses but that the protein deposited is more likely to become denatured11,12,13. This denaturing effect varies with different SiHy lenses as it is interaction with the specific material which causes the denaturation.

In general, protein deposition is not a significant problem with SiHy lenses but if a patient’s lenses appear cloudy they should be changed to a more frequent replacement lens, as denatured protein is very difficult to remove from a lens. Bausch + Lomb’s Biotrue multipurpose solution contains protein stabilisation agents which have been shown to minimise denaturation14.

MICROBIAL KERATITIS

Of all contact lens-related complications microbial keratitis (MK) is the most feared as, if left untreated, some cases of MK can result in corneal scarring and a subsequent permanent loss of one or more lines of best corrected visual acuity. Several studies have shown that the risk of MK is higher in patients who smoke15 and that overnight wear of contact lenses (regardless of type) increases the risk of MK by a factor of four16. This is why patients on continuous or extended wear need to be monitored more closely than daily lens wearers, and be specifically warned of the increased risk.

The symptoms of MK are pain, often photosensitivity and (if the central cornea is affected) possibly blurred vision. The signs are conjunctival hyperaemia, anterior chamber reaction, infiltrates, and significant corneal ulcer-like staining. Patients may not exhibit all of the signs and symptoms but if a patient complains of ocular pain and exhibits significant corneal staining, they should be asked to remove their lens immediately (if they have not already done so) and the patient should be referred to an eye hospital as an emergency. Patients should bring their lenses and case with them to the hospital as both can be swabbed to try to identify the pathogen.

INFLITRATIVE EVENTS

Infiltrates are focal aggregates of white blood cells, which appear in the corneal subepithelium as part of an immune-mediated response. Sterile infiltrates appear when there is no active infection but they are an indication that there is a build-up of bacterial exotoxins adhering to the cornea. They are usually small, round and white in appearance (Figure 3).

Sterile infiltrates are more likely to be peripheral and single and less likely to stain with fluorescein, when compared with those of an infectious nature. The patient should be instructed to cease contact lens wear until the infiltrates have resolved. Any blepharitis or meibomian gland dysfunction should be treated as both conditions result in an increase in exotoxins in the eye.

As infiltrates are more common with overnight wear, patients may have to be changed to daily wear. Sterile infiltrates do not progress to MK but patients should be warned to return to the practice immediately if their signs and symptoms worsen and they develop pain, as infective infiltrates can very easily be misdiagnosed as sterile in the early stages.

SOLUTION INDUCED CORNEAL STAINING

Solution induced corneal staining (SICS) was first reported in 2002. It is similar in appearance to a diffuse superficial punctate keratitis (Figure 4). It appears to occur in certain patients with specific lens-solution combinations. It has been seen with both hydrogel and SiHy lenses. Depending on how it is measured, it can appear to be more prevalent with biguanide preserved solutions or polyquad preserved solutions. Studies into SICS and its impact on ocular health have come up with conflicting conclusions. In 2012 Professor Nathan Efron...
produced a paper where he gave SICS a new definition and title\textsuperscript{17}. He called it ‘preservative-associated transient hyperfluorescence’ (PATH), which he described as a temporary hyperfluorescence of fluorescein which is bound to the corneal epithelium. Therefore, it is not a true pathological condition in which fluorescein stains the actual epithelial cells themselves or pools within disturbances in the epithelium.

There is evidence to support this theory in that the staining is asymptomatic\textsuperscript{18} and another paper from 2012 found that ocular surface shedding with contact lens wear was similar in all eyes regardless of levels of SICS observed\textsuperscript{19}.

On the opposing side of the argument yet another paper from 2012 found that eyes with SICS were more likely to show higher levels of upper and lower palpebral hyperaemia\textsuperscript{20} and tarsal roughness\textsuperscript{20}. Both of which would suggest that there is some pathological basis to SICS.

It seems that researchers have yet to reach a consensus regarding SICS and, therefore, for practitioners it is probably better to err on the side of caution and change patients with obvious signs of SICS into one of the hydrogen peroxide based solutions, which generally produce little or no SICS in combination with either SiHy or hydrogel materials\textsuperscript{21}.

CIRCUMLIMBAL STAINING

Circumlimbal staining is circular staining caused by the lens edge (Figure 5). It can be seen in hydrogel lens wearers but is more common in SiHy lens wearers. According to a 2012 study, circumlimbal staining is related to lens edge design and material rigidity\textsuperscript{22}. A rounded edge design (PureVision) was found least likely to stain but more likely to be associated with discomfort. A knife edge design (Acuvue) was found to be most likely to stain but least likely to be associated with discomfort. While circumlimbal staining does not appear to affect wearer comfort, its long-term impact is unknown and, therefore, patients with this sign should be monitored.

SUMMARY

SiHy lenses might be the first choice of lens to fit patients because of their exceptional oxygen transmission and because many of the high modulus-related problems seen with the first generation lenses appear to have been alleviated with the latest third generation lenses.

Practitioners should still be very cautious about fitting patients with lenses for overnight wear as the largest single stumbling block (increased risk of infection compared with daily wear) remains unsolved. Practitioners should check carefully at each aftercare for any contact lens-related adverse signs, but in particular those more commonly associated with SiHy wear.

REFERENCES


\textbf{Figure 5. Circumlimbal staining from a silicone hydrogel lens edge}


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### Multiple choice questions:

**Silicone hydrogel: the best all-rounder? By Claire Mc Donnell FAOI**

1. What is the usual cause of corneal neovascularisation in contact lens wear?
   a. Lack of oxygen transmission to the cornea
   b. Damage from the contact lens edge
   c. As a consequence of lipid build-up
   d. Wearing a contact lens with a low water content

2. Which statement is CORRECT?
   a. Lipid and protein deposits are rare with silicone-based material
   b. Second generation silicone hydrogel lenses have their surfaces treated so that they become hydrophilic
   c. Third generation lenses can provide high Dk values and high water content without having high modulus values
   d. Polyvinyl pyrrolidone dispels moisture and tends to stiffen the material

3. For a myope of 2.00D, which lens would NOT provide the cornea with a normal supply of oxygen in all circumstances?
   a. Advance
   b. Biofinity
   c. Premio
   d. Oasys

4. Complete the sentence correctly. A high modulus and increased oxygen transmission through silicone hydrogel materials have contributed to...
   a. a reduction in the occurrence of overnight infection
   b. the steady increase in continuous wear fittings
   c. a reduction in limbal neovascularisation
   d. less risk of contact lens papillary conjunctivitis

5. Complete the sentence correctly. If a patient wearing silicone hydrogel lenses presents with symptoms which may suggest microbial keratitis they should be told to...
   a. see an optometrist
   b. go to an eye hospital as an ocular emergency
   c. limit their wearing time to daily wear temporarily
   d. bring their next scheduled appointment for a check-up forward by 1 month

6. Complete the sentence correctly. The term modulus refers to...
   a. the accumulation of denatured protein
   b. the link between lens thickness and water content
   c. oxygen transmissibility
   d. the coefficient of elasticity of a material

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