Materials for contact lenses

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1 Introduction

A material placed in contact with a biological system which causes the minimum perturbation that can be tolerated by that biological system, can be considered to be biocompatible. In terms of biocompatibility contact lenses are a material that has to be studies intensively, because problems can become severe very fast. Oxygen deficit, which is caused by inability of the cornea to obtain oxygen, is the most common complication while wearing contact lenses. This implies that it is crucial to choose a correct material for the production of contact lenses to prevent – possibly long term – damage to the eye, especially the cornea.

Worldwide more than 125 million people do wear contact lenses, all of them for various reasons. Many prefer their appearance with contact lenses to that with glasses. Contact lenses are less affected by wet weather, do not steam up, and provide a wider field of vision. They are more suitable for a number of sporting activities and allow for a more accurate correction of certain opthalmological conditions – such as keratoconus[1] and aniseikonia[2] – than with glasses [2].

2 History

The general idea of vision correction has been around for approximately two thousand years; the roman emperor Nero was known to watch gladiator games using a crystal to correct his supposedly bad vision [3]. The precursors of contact lenses have been invented not until 1500 years later, by Rene Descartes, who proposed a glass tube filled with liquid which was placed in direct contact with the cornea to correct the vision. In 1888, the German physiologist Adolf Eugen Fick constructed and fitted the first successful contact lens. While working in Zürich, he described fabricating afocal scleral contact shells, which rested on the less sensitive rim of tissue around the cornea. These lenses were made from heavy brown glass and were around 20 mm in diameter [2].

Nowadays, contact lenses are all made of different polymers. The following section specifies the different materials in detail.

[1] Keratoconus is a degenerative non-inflammatory disorder of the eye in which structural changes within the cornea cause it to thin and change to a more conical shape than its normal gradual curve. [1]

[2] Aniseikonia is a binocular condition in which the two eyes perceive images of different size. [1]

3 Materials

3.1 General

Albeit that today there are abundant variants of polymers available on the market, only some of them are suited as material for contact lenses. These polymers have to offer certain features, which are shown in table 1. Some parameters are described in more detail below.

physiological	optical	mechanical	chemical	commercial
- high permeability for O_2 and CO_2 - good wettability - non toxic - allergen-free - good thermal conductivity	- transparent for visible light (400–800 nm) - homogeneous transmission	- machinable - high form stability - high surface quality	- hinders microbial growth - resistant against depositions of components from tear-film - easy to clean - no uptake of impurities from care products - inert (no migration of polymer components)	- affordable

Table 1: Requirements for polymers as contact lens materials. Adapted from [4]

3.1.1 Oxygen-permeability

A high oxygen permeability is one of the prerequisites for physiologically agreeable contact lenses. This factor leads to a preference for the selection of silicone materials for contact lenses, because they show a high permeability and a high equivalent oxygen percentage (EOP), a parameter that considers the oxygen demand of ocular tissue. A lens should have a minimum EOP of 5–7 % which is equivalent to the amount of oxygen available to the eye during sleep. It has been shown that an EOP of 10 % does not induce corneal edema [5, 6].

3.1.2 Wettability

The wettability of the contact lens surface is a second important factor for physiological tolerance. A good wettability helps with the integration of the contact lens into the tear-film and is a prerequisite for a good optical image.

A surface is called wettable, when a fluid can spread on the surface. This happens when the sum of the surface tension of the liquid (γ_{LG}) and the tension between the contact lens and the liquid (γ_{SL}) is lower than the surface tension of the contact lens material (γ_{SG}). To determine the wettability of a material one measures the contact angle θ between the fluid and the solid (see figure 1). The relation between the surface tensions and the contact angle are: $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} \cos\theta$.

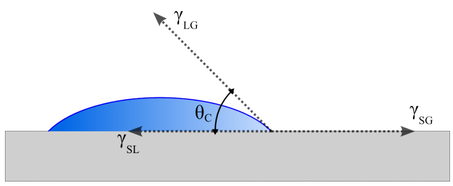

Figure 1: Contact angle (from [7])

In reality surfaces show a contact angle between 0° and 180°. A contact angle of 90° or greater generally characterizes a surface as non-wettable, and a contact angle of less than 90° means that the surface is wettable. 45° characterises a sufficient wettability [4].

3.1.3 Water Contents

The water content of contact lens material is one of the key factors of the differentiation in terms of comfort for the wearer. For rigid contact lenses water content is below 1 %. If the water content of a contact lens material is above 10 % the materials are called hydrogels [4]. For hydrogel contact lenses an increasing water content of the material increases the oxygen permeability [8].

The water holding capacity relates to the composition of the hydrogel material and varies between approximately 25 and 80 % [4, 9].

3.2 Materials for Rigid Contact Lenses

3.2.1 Polymethylmethacrylate

Polymethylmethacrylate (PMMA) – a $C_5O_2H_8$-polymer, commercially known as Plexiglas or Perspex – is the classical polymer for so called hard contact lenses. Its monomer, a methylester of methylmethacrylate is shown in figure 2. Through polymerisation of those monomers a single macro-molecule is generated, which has a thread-like structure where the side-chains of the molecule are not interconnected to each other [10].

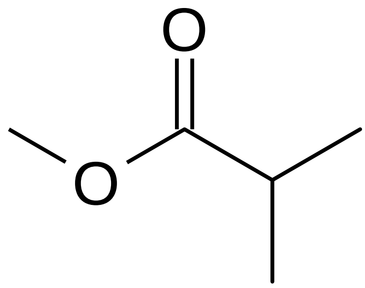

Figure 2: Methylmethacrylate, the PMMA-monomer

PMMA is an apolar, chemically only slightly reactive polymer. The apolar properties of PMMA make contact lenses out of this material resistant against depositions from the tear-film and resistant against microbial infection. This relates to uncomplicated handling of hard contact lenses made out of PMMA.

But today PMMA is replaced by other polymers, mostly because of two main problems. Firstly, the very low oxygen permeability of PMMA can lead to problems with the metabolism of the cornea (see section 3.1.1) and secondly, the very low wettability, which arises through the apolar character of PMMA. Today, PMMA is virtually obsolete and is only used in special cases. It has been replaced by polymers, which are gas permeable, leading to the term of rigid gas permeable (RGP) lenses. The term hard contact lens is now used to refer to PMMA lenses which are still occasionally fitted and worn, whereas rigid is a generic term which can be used for all form-stable lens types.

The five-page limit of this document could not be fulfilled with the description of more polymers, hence I described only one classical polymer for rigid contact lenses and will now describe polymers for flexible contact lenses in the next section.

3.3 Materials for flexible Contact Lenses

Today, all flexible contact lenses except the pure silicone contact lenses are composed of different variants of hydrogels, most of are made from Hydroxyethylmethacrylate (HEMA) compounds (see figure 3). Thin cross linked hydrogels have been patented in 1953 by Otto Wichterle and Drahoslav Lím and have been used in contact lenses since 1961 [11].

3.3.1 Hydroxyethylmethacrylate

Hydroxyethylmethacrylate polymer is hydrophilic; therefore, when the polymer is subjected to water it will swell. Depending on the physical and chemical structure of the polymer, it is capable of absorbing from 10 to 600 % water relative to its dry weight. Because of this property, it was one of the first materials to be successfully used in the manufacture of flexible contact lenses [12] and is still used today.

Hydroxyethylmethacrylate is an elastomeric compounds, but its glass transition temperature is around 58° C, thus it is hard and brittle when dry. HEMA is only useable as a contact lens material in hydrogel-form, when containing substantial amounts of water (approximately 40 to 80 %) [10].

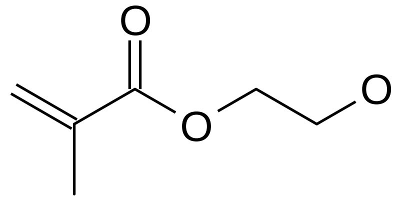

Figure 3: Hydroxyethylmethacrylate

3.3.2 Silicones

While it provides the desired high oxygen permeability, silicone also makes the lens surface highly hydrophobic and less wettable. This can result in discomfort and dryness during lens wear. In order to compensate for the hydrophobicity, hydrogels are often added to make the lenses more hydrophilic. However the lens surface still remains hydrophobic. Hence some of the lenses undergo surface modification processes which cover the hydrophobic sites of silicone. Some other lens types incorporate internal rewetting agents to make the lens surface hydrophilic [2]. Silicone contact lenses possessing a modified surface tend to accumulate lipid residues and even anorganic salts. This can lead to a very thin, but hard to remove hydrophobic layer on the contact lens surface [10]. Silicone contact lenses are thus not very comfortable in handling, because the need proper and sometimes complicated care, also because the material is prone to microbial infection.

One of the main advantages of silicone contact lenses is the very high oxygen permeability, thus having the distinction of a good physiological tolerance. These attributes make these lenses suited for continued wear - for up to 30 days – even during the night.

3.4 Other Contact Lens Materials

There are many other materials for contact lenses; thermoplasts (polyvinyl chloride, polyethene), modified polysiloxanes (silicone rubbers) and even collagen has been tested as a potential contact lens material [13] (and successfully used for the treatment of corneal epithelial defects [14]). The restriction of 5 total pages of this document does not allow to cover all of them, hence only the most important ones are covered above.

4 Conclusion

From the few sections above it seems evident, that rigid lenses are obsolete by now. Hydrogel contact lenses possess bigger oxygen permeability than lenses made out of PMMA and are more comfortable to wear, since they adapt better to the eye through their flexible material properties.

As mentioned above, PMMA is replaced by other polymers, often incorporating silicone, which makes them more flexible than PMMA, leading to a class of materials for so called RGP lenses. Those RGP lenses transmit more oxygen to the cornea than standard flexible contact lenses, and cover a smaller fraction of the eye, thus ironing out the big disadvantage of hard contact lenses (see section 3.2.1 for details).

Rigid contact lenses provide better vision, durability, and deposit resistance than flexible contact lenses. Better vision is provided because the contact lenses are rigid, hence retain their shape while blinking, durability is provided through the rigidity compared to flexible lenses, which can be torn apart. And since the materials (be it PMMA or modern polymers) contain very little water, the adhesion of proteins and lipids from tears of RGP materials is lower than for materials for flexible lenses.

One of the advantages of flexible lenses is, that they are instantly comfortable to wear, while rigid lenses need an adaptation period before they can be comfortably worn. Because of their material properties rigid contact lensed do not dry out and are thus more comfortable indoors, e. g. with an air conditioning system.

Because flexible contact lenses cover a bigger part of the eye than rigid lenses – around 16 mm diameter vs. around 9 mm diameter for rigid lenses – their edge sits under the eyelid, which provides for a firmer fit, which can be desired for e. g. water sports. Through the bigger contact area and the more firm fit the risk of trapping foreign particles under the contact lens is considerably smaller than with rigid contact lenses, flexible contact lenses are thus well suited for people with dust exposition, like construction workers.

The conclusion is that there is no material suitable for all cases, but that there is a suitable material for any case.

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