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Permeability coefficients of minus contact lens studied by optical interference method

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ABSTRACT

Contact lenses frequently used for correction of short-sightedness make a barrier between the cornea and the external lacrimal film. The materials of which they are made must meet special demands not only as to mechanical properties (elasticity, mechanical strength) but mainly as to the compatibility with the eyeball tissue, among others they must permeate oxygen and lacrimal fluid. The problem of permeability of these substances is similar to their permeability through a membrane and is based on mass transportation via diffusion. As the lens power depends on the curvature radii of refracting surfaces, which determines the mean thickness of the lens, in this study the method of optical interference was applied to evaluate the permeability of negative contact lenses towards the main components of lacrimal fluid Na^+ and Cl^- ions. Permeability parameters of the commercial soft contact lenses SoftLens® made by Bausch & Lomb and made of hilafilcon B, of optical powers from −0.5 D to −3.75 D were measured. On the basis of a nonparametric test a correlation between the lens power and permeability was evaluated.

1. Introduction

Short-sightedness (myopia) is a refractive error, which means that the eye does not bend or refract light properly to a single focus to see images clearly. At the relaxed accommodation a beam of parallel rays entering the eye do not focus at the retina as it happens in the normal eye (emmetropic) but in front of the retina which leads to blurred images of distant objects. This error is a consequence of mismatch between the size of the eyeball to the power of the optical system of the eye. When the axial length of the eyeball is standard and the optical system power is too high we deal with the refractive error, while otherwise — with the axial error. According to the epidemiological data from different regions of the world [1], short-sightedness is the most often met refractive myopia in children and young people. In the USA short-sightedness in people aged 12 to 54 is met in 25–26% of white population and 12–13% of black population [2]. In India, according to different authors, it occurs in 11–32% of the population [3], in Finland it is met in 23–25% of children aged 14–15, while in Denmark in the same age group it estimated to occur in 36.2% [4,5]. In Poland every third or every fourth high school graduate shows short-sightedness [6]. The highest intensity of short-sightedness is noted in Asia; in Taiwan this error occurs in 5–10% of 7 year old children, 35% of 13 year old children and in 75% of 18 year old people [7]. In Japan this error is diagnosed in 50% of high school students [8].

Although experimental and clinical studies have been continued for a long time, the problem of its aetiology has not been finally resolved yet. Advocates of the environmental aetiology claim that the cause of this condition is excessive accommodation. However, according the predominant opinion, this error develops in response to a combined influence of the genetic factor and environmental factors related to the lifestyle, diet, too much work on close distance objects or under insufficient lighting or in lying position and air pollution.

In Poland short-sightedness occurs only in 2% of 6 year old children, its frequency increases substantially in the period of school learning [9,10]. It has been estimated that short-sightedness of at least −0.5 D increases in an approximately linear way from about 2% in 6 year old children to about 20% at the age of 20 [11,12]. A method of myopia correction by the use of lenses of negative focusing ability has been known for a long time. Such lenses of adjusted focusing ability have been set in a rim of spectacles in front of the eyes. However, wearing glasses may be problematic or even impossible in certain forms of physical activity, e.g. dancing, jogging, sports of different kinds. Another problem appears when the refractive error is different in each eye and the difference between these errors is significant, then correction by spectacles may lead to generation of different size images on retina and bring the loss of fusion in binocular vision. Finally there are people who do not accept their look in spectacles. To solve these problems a new mode of wearing correction lenses directly on the eyeball was proposed. The lens materials satisfying high demands including excellent transparency to visible light, elasticity, mechanical strength, excellent wettability, permeability to gases and components of lacrimal fluid, nontoxicity and resistance to deposit formation, have been provided by polymer chemistry. The comfort of wearing contact lenses depends significantly on the lens permeability of gases and fluids as cornea for correct functioning needs continuous influx of oxygen and

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contact with lacrimal fluid. The anterior lacrimal layer forming upon wearing contact lens plays a protecting, cleaning and optical role, while the posterior lacrimal layer plays the optical role and via influx of fresh and oxygen rich tears it supplies oxygen to cornea and removes the products of metabolism from under the lens. The contact lens covers the cornea so its permeability to oxygen and lacrimal fluid is of crucial importance.

In this study an attempt was made at evaluation of permeability of contact lenses used for correction of myopia to Na^+ and Cl^- ions being components of lacrimal fluid, by employing a highly sensitive method of optical interference. This method has been earlier successfully applied in investigation of the dynamics of transport of substances through semipermeable membranes [13].

2. The theory of lacrimal fluid flow through a contact lens

If a porous contact lens of active area A at time t separates two compartments R and W of the same volume V, numbers of molecules of a given substance $N_1(t)$ and $N_2(t)$, and molar concentrations $C_1(t) > C_2(t)$ in the two compartments, then the transport of the substance driven by the thermodynamical force following from the difference in concentrations is:

$$\Delta C(t) = C_1(t) - C_2(t), \tag{1}$$

and takes place from compartment R to W.

The flux of the substance $J(t)$ flowing through a single pore in the lens material is described by the Fick equation:

$$J(t) = -\pi \cdot a^2 \cdot D \cdot \frac{C_1(t) - C_2(t)}{\delta \bar{x}}, \tag{2}$$

where: a — pore radius, D — diffusion constant, $\delta \bar{x}$ — mean length of pores in the lens active area. Because of the spherical shape and different curvature radii of the first and second refractive surface of the lens, the pore lengths are different and depend on the distance from the symmetry axis of the lens.

The total flux of a given substance $J_S(t)$ flowing through the lens depends on the number of pores per area involved in the flow:

$$J_S(t) = m \cdot J = m \cdot \pi \cdot a^2 \cdot D \cdot \frac{C_2(t) - C_1(t)}{\delta \bar{x}}. \tag{3}$$

According to the Osanger theory [14] the flux can be described as a product of the thermodynamic force driving the flow and a proportionality constant characterising the type of transport:

$$J_S(t) = P \cdot \Delta C(t). \tag{4}$$

The coefficient P describes the lens permeability and can be expressed as:

$$P = \frac{m \cdot \pi \cdot a^2 \cdot D}{\delta \bar{x}}. \tag{5}$$

Temporal changes in the number of molecules on both sides of the lens taking place as a result of transportation can be expressed as:

$$\begin{aligned} \frac{dN_1(t)}{dt} &= V\frac{dC_1(t)}{dt} = -J_S(t)A = -A \cdot P \cdot [C_1(t) - C_2(t)], \\ \frac{dN_2(t)}{dt} &= V\frac{dC_2(t)}{dt} = +J_S(t)A = +A \cdot P \cdot [C_1(t) - C_2(t)]. \end{aligned} \tag{6}$$

For a closed system, the total number of molecules $N(t) = N_1(t) + N_2(t)$ remains constant, so:

$$\frac{dN(t)}{dt} = \frac{dN_1(t)}{dt} + \frac{dN_2(t)}{dt} = 0. \tag{7}$$

which leads to:

$$V\frac{dC_1(t)}{dt} + V\frac{dC_2(t)}{dt} = \frac{d}{dt}[VC_1(t) + VC_2(t)]. \tag{8}$$

In the process of transportation, at each time t, the expression $VC_1(t) + VC_2(t)$ is constant, so:

$$VC_1(0) + VC_2(0) = VC_1(t) + VC_2(t) = 2VC_\infty, \tag{10}$$

where: C_∞ is the concentration that will be reached on both sides of the lens after infinite time of transportation, depending on the initial values $C_1(0)$ and $C_2(0)$:

$$C_\infty = \frac{C_1(0)}{2} + \frac{C_2(0)}{2}. \tag{11}$$

Employing Eqs. (6) and (11) we can write:

$$\frac{dC_1(t)}{dt} - \frac{dC_2(t)}{dt} = -2A \cdot P \cdot \frac{C_1(t) - C_2(t)}{V}. \tag{12}$$

Denoting:

$$\frac{1}{\tau_0} = \frac{2A \cdot P}{V}, \tag{13}$$

we get a differential equation of first order:

$$\frac{d\Delta C(t)}{dt} = -\frac{1}{\tau_0} \cdot \Delta C(t), \tag{14}$$

whose solution is:

$$\Delta C(t) = \Delta C(0) \cdot \exp\left(-\frac{t}{\tau_0}\right). \tag{15}$$

Employing Eq. (10) we finally get the equation describing the concentration of molecules studied in compartment R at time t:

$$C_1(t) = C_\infty + [C_1(0) - C_\infty] \cdot \exp\left(-\frac{t}{\tau_0}\right). \tag{16}$$

In the analogous way it is possible to derive the equation describing concentration changes taking place as a result of transportation in compartment W:

$$C_2(t) = C_\infty + [C_2(0) - C_\infty] \cdot \exp\left(-\frac{t}{\tau_0}\right). \tag{17}$$

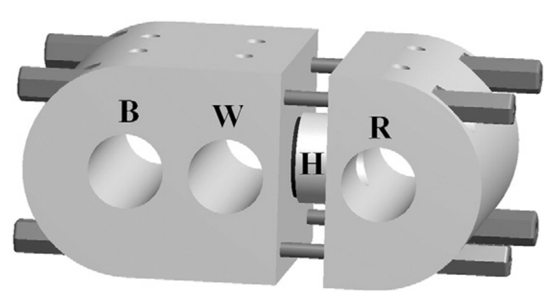

Fig. 1. A schematic presentation of the chamber for investigation of dynamics of transportation through the contact lens. R — compartment with physiological salt, W — compartment with water into which the transportation took place, B — compartment with reference water, H — lens holder.