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Importance of contact lens power and thickness in oxygen transmissibility

Madalena Lira*, Clara Pereira, M. Elisabete C.D. Real Oliveira, Elisabete M.S. Castanheira

Centre of Physics (CFUM), University of Minho, Campus de Gualtar, 4710-057 Braga, Portugal

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ABSTRACT

Purpose: The aim of this work was to study the central and peripheral thickness of several contact lenses (CL) with different powers and analyze how thickness variation affects CL oxygen transmissibility.
Methods: Four daily disposable and five monthly or biweekly CL were studied. The powers of each CL were: the maximum negative power of each brand; −6.00D; −3.00D; zero power (−0.25D or −0.50D), +3.00D and +6.00D. Central and peripheral thicknesses were measured with an electronic thickness gauge. Each lens was measured five times (central and 3 mm paracentral) and the mean value was considered. Using the values of oxygen permeability given by the manufacturers and the measured thicknesses, the variation of oxygen transmissibility with lens power was determined.
Results: For monthly or biweekly lenses, central thickness changed between 0.061 ± 0.002 mm and 0.243 ± 0.002 mm, and peripheral thickness varied between 0.084 ± 0.002 mm and 0.231 ± 0.015 mm. Daily disposable lenses showed central values ranging between 0.056 ± 0.0016 mm and 0.205 ± 0.002 mm and peripheral values between 0.108 ± 0.05 and 0.232 ± 0.011 mm. Oxygen transmissibility (in units) of monthly or biweekly CL ranged between 39.4 ± 0.3 and 246.0 ± 14.4 and for daily disposable lenses the values range between 9.5 ± 0.5 and 178.1 ± 5.1.
Conclusions: The central and peripheral thicknesses change significantly when considering the CL power and this has a significant impact on the oxygen transmissibility. Eyecare practitioners must have this fact in account when high power plus or minus lenses are fitted or when continuous wear is considered.

1. Introduction

Oxygen transmissibility has been previously defined in the contact lens (CL) literature as Dk/t, where D is the diffusion coefficient of oxygen in the CL material, k the solubility constant of oxygen in the lens material, and t the lens thickness [1,2]. Therefore, the thickness of a CL and the permeability (Dk) of the lens material determine the quantity of oxygen that diffuses through the lens at a given temperature and pressure.

Dk is usually measured in units $\times 10^{-11}$ (cm^2/s) mLO_2/(mL mmHg) and Dk/t in units $\times 10^{-9}$ (cm/s) mLO_2/(mL mmHg). For simplicity and comparison with published values in literature, in this paper Dk/t units refer to traditional units (1 unit = $\times 10^{-9}$ (cm/s) mLO_2/(mL mmHg)), as used by Holden et al. [3].

Hydrogel lenses with low oxygen transmissibility (Dk/t) may induce acute and chronic ocular changes particularly from extended wear (EW) [4]. CL that do not meet the cornea oxygen needs, compromise corneal metabolism and integrity and can induce corneal swelling, epithelial microcysts, limbal hyperemia, corneal vascularization and endothelial polymegethism [5–8]. Additionally, clinical studies show that hypoxia increases the risk of bacterial adhesion to epithelial cells [9,10] and others link the keratitis severity with Dk/t [11–14].

Holden and Mertz [15] established in 1984 that the critical Dk/t value of a lens should be of 87 units, to avoid overnight lens-induced corneal swelling and the transmissibility value for a lens worn under open-eye conditions should be of 24 units, to avoid corneal swelling. In 2005, Fonn and Bruce [4] reported that it seems the Holden and Mertz criteria of critical Dk/t for extended-wear should be revised upwards to at least 125 units.

Currently, new polymers containing highly permeable siloxane moieties are offered, which significantly improve oxygen permeation performance. Papas [16] has established an association between limbal hyperemia and oxygen deficiency under the lens periphery, indicating that a minimum Dk/t of 125 units is required to eliminate limbal redness with daily wear (open-eye). Maldonado-Codina [17] also compared limbal redness with hydrogel and silicone–hydrogel (Si–Hy) CL wear and identified

* Corresponding author. Tel.: +351 253604068; fax: +351 253604061.
E-mail addresses: mlira@fisica.uminho.pt, madalena.lira@gmail.com (M. Lira).

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Table 1
Specification of contact lenses used in this study (provided by manufacturers).

CL	Manufacturer	USAN name	Water content (%)	Central thickness (−3.00D) (mm)	*Dk* (−3.00D) 10^{-11} (cm^2/s) mL(O_2)/(mL mmHg)	*Dk*/*t* (−3.00D) 10^{-9} (cm/s) mL(O_2)/(mL mmHg)
Soflens® Daily	Bausch & Lomb	Hilafilcon B	59	0.09	22	18
Acuvue® One Day Moist™	Vistakon (Johnson & Johnson)	Etafilcon A	58	0.084	21	25
Acuvue® TruEye™	Vistakon (Johnson & Johnson)	Narafilcon A	48	0.07	100	118
Focus Dailies® Aqua Comfort	Alcon Vision Care	Nelficon A	69	0.1	26	27
Air Optix® Aqua™	Alcon Vision Care	Lotrafilcon B	33	0.08	110	138
Purevision 2™	Bausch & Lomb	Balafilcon A	36	0.07	91	130
Acuvue® Oasys™	Vistakon (Johnson & Johnson)	Senofilcon A	38	0.07	103	147
Biofinity™	CooperVision Hydron	Comfilcon A	48	0.08	128	160
Menicon PremiO	Menicon	Asmofilcon A	40	0.08	129	161

substantial differences between lenses with central oxygen transmissibilities of 26 and 86 units.

The information about oxygen transmissibility values provided by the manufacturers is usually for −3.00D lenses, but factors such as thickness differences across lenses of different power profiles can have influence on oxygen diffusion performance and a significant impact on oxygen supply to the cornea and the limbus. As *Dk*/*t* is often quoted for that power, a problem is created for the practitioner, who may not fully realize the impact of increased lens thickness on oxygen transmissibility, especially when the power required to compensate a refractive error is quite different from −3.00D. As suggested before by Holden and Mertz [15] and Tomlinson and Bibby [18], *t* is only averaged over the 6 mm central thickness. Fatt and Neumann [19] mentioned that the thickest part of the lens is the most important as it is that portion which will produce the greatest hypoxic effect to corneal tissue. A study where the lens thickness was measured, both centrally and at 3 mm peripheral location, showed that, apparently, it is not important to consider which lens thickness is used in calculating in-vivo oxygen transmission when CL material *Dk* attains the value of the current Si–Hy lenses in daily wear [20]. On the other hand, Bruce and Brennan reported that central corneal edema and limbal hyperemia during extended wear of hydrogel lenses should be related to local variations in corneal oxygenation [21].

The aim of this work was to determine experimentally the central and peripheral thickness of several CL (daily disposable and monthly or biweekly) with different powers, and analyze how thickness variation affects CL oxygen transmissibility.

2. Material and methods

2.1. Contact lenses

Four daily disposable CL were studied, Soflens® Daily, Acuvue® One Day Moist™, Focus Dailies® AquaComfort, Acuvue® TruEye™ and five monthly or biweekly Si–Hy CL: Acuvue® Oasys™, Menicon PremiO, Air Optix® Aqua™, Purevision 2™ and Biofinity™.

The powers of each CL were: the maximum negative power of each brand (between −9.00D and −12.00D); −6.00D; −3.00D; zero power (−0.25D or −0.50D); +3.00D and +6.00D. The characteristics of the lenses are detailed in Table 1.

2.2. Central and peripheral thickness

Central and peripheral thicknesses of the CL were measured with an Electronic Thickness Gauge (Model ET-3) at each of these identified positions (central and 3 mm paracentral) five times, and then the mean value was considered. After removing the lens from the blister, each lens was gently pressed by absorbent paper to eliminate excess solution, without leaving residues on the lens and without touching it. The comparison was made with the nominal value given by industry (−3.00D power reference). The instrument was always zeroed prior to each measurement, setting the value to 0 μm.

2.3. Oxygen transmissibility

The oxygen transmissibility was calculated through the expression *Dk*/*t*. Once the *Dk* of a lens material is known, then the *Dk*/*t* of all lenses made from the same material can be calculated. It was used the value of *Dk* provided by manufacturers and the central and peripheral thickness measured for the different CL and powers.

2.4. Statistical analyses

All data were analyzed using statistical package for social sciences (SPSS), Version 19. The mean and standard deviation for each variable were presented. The differences between the central thickness measured and the reference values provided by the manufacturers were compared using the *t*-test or the non-parametric Wilcoxon Sign Rank test. For all hypotheses testing, $p \leq 0.05$ was considered statistically significant.

3. Results

For monthly or biweekly lenses, central thickness changed with power between 0.061 ± 0.0024 mm and 0.243 ± 0.002 mm, and peripheral thickness varied between 0.084 ± 0.002 mm and 0.231 ± 0.015 mm (Tables 2 and 4).

Daily disposable lenses showed central values ranging between 0.056 ± 0.002 mm and 0.205 ± 0.002 mm and peripheral values between 0.108 ± 0.05 mm and 0.232 ± 0.011 mm (Tables 3 and 4).

For Air Optix® Aqua™ peripheral thickness, significant standard deviations were observed in the case of −9.00D, −6.00D and +3.00D lenses (Table 2). The same happens for Soflens® Daily CL with −9.00D (Table 3). This leads to an increased uncertainty in *Dk*/*t* peripheral values for these CL.

For all of the lenses studied, the differences in central thickness obtained in this study when compared to the reference values provided by the manufacturers are not statistically significant ($p > 0.05$).

As it could be expected, CL central thickness generally increases as its power becomes more positive and all CL have a similar behavior. The greater thickness is associated with the central power of +6.00 D for every CL studied. The point of maximum thickness was naturally in the periphery for minus lenses and in the center for plus lenses.

Oxygen transmissibility and its variation with central and peripheral thickness are presented on Tables 5 and 6. Oxygen transmissibility (in units) of monthly or biweekly CL ranged between 39.4 ± 0.3 and 246.0 ± 14.4 and for daily disposable lenses the values range between 9.5 ± 0.5 and 178.1 ± 5.1 (Table 7). The