A Comparative Study of the Oxygen Permeability of High Water Content Silicone and Conventional Hydrogels

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INTRODUCTION

Whilst a relationship between water content and oxygen permeability can be readily derived for conventional hydrogels[1] it is not possible to derive such an accurate relationship for silicone hydrogels. Conventional hydrogels use water as the sole medium by which to transport oxygen, whereas silicone hydrogels create additional or alternative pathways, and although they demonstrate a general inverse relationship between oxygen permeability and water content it cannot be accurately defined. The additional factor affecting the relationship is that the different materials available belong to different families, and achieve the increased oxygen transport with greater or lesser efficiency[2].

It has been suggested that for some families of materials at high water contents the increase in oxygen permeability will be negligible[2]. However, if the oxy-permeable components posses the correct connectivity then it should be possible to enhance the materials oxygen permeability over that observed for conventional high water materials[3,4]. Such materials would be advantageous for daily wear modalities, particularly for custom designed lenses.

A silicone hydrogel with the relatively high water content of 74% is marketed under the trade name Definitive™ (Contamac Ltd, Saffron Walden, UK). The oxygen permeability of the material was evaluated and compared to three conventional hydrogels .

% Water Content	Material	Trade-name
38	Polymacon	Contaflex 38
58	VP/MMA	Contaflex 58
75	VP/MMA	Contaflex 75
74	Silicone Hydrogel	Definitive™

Table 1. Test lens materials.

METHOD

The methodology followed in this study to establish the oxygen permeability is outlined by ISO 18369-4:2006 including correction for edge and boundary effects, and calibration by three reference materials[5] (Table 2) obtained from the Oxygen Permeability Reference Material Repository held at the University of Alabama. Measurements were taken at 35±0.5°C in a water-saturated atmosphere on a Model 201T Oxygen Permeometer with a 4mm diameter curved cathode of 7.8mm radius. Sample harmonic thickness was measured using a Mitutoya centre gauge with an operating tolerance of 0.01mm.

For each reference material, three amperage measurements were taken from each lens of a series of four thicknesses. For each unknown test sample, three amperage measurements were taken from each lens in three series of four thicknesses.

Units of oxygen permeability are stated in Barrers ($\times 10^{-11}$cm^2/sec][mLO$_2$]/[mLxmmHg]).

Material	Trade-Name	Dk
Paflufocon C	Fluoroperm 30	26
Tolofocon A	Menicon EX	62.4
Melafocon A	Melafocon SF-P	133.6

Table 2. Established oxygen permeability (Dk) of reference materials.

RESULTS & DISCUSSION

For each series the mean amperage measurements taken from each lens were used to calculate preliminary oxygen transmissibility values (Dk/t) that could be subsequently corrected for edge effects and used to create t/Dk against thickness (t) plots as shown in Figure 1. The resistance plots are linear and have high coefficients of determination (R^2) in excess of 0.997 (Table 3).

A calibration curve was constructed from the reference materials and a regression derived. The calibrated Dk of each series (given in Table 3) was then determined by application of the regression given in Figure 2. Standard deviations for each series were estimated from the multiple amperage measurements.

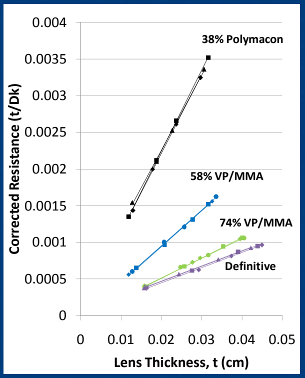

Figure 1. Corrected resistance versus thickness plots for each series of lenses.

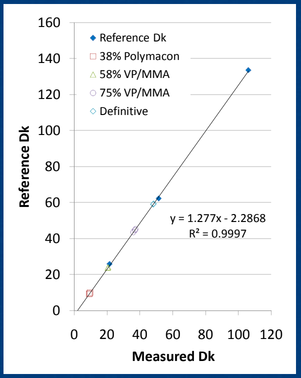

Figure 2. Plot of established Dk of the reference materials versus measured, corrected oxygen permeability. The test materials have been plotted to demonstrate how calibration was achieved. Dk in units of ($\times 10^{-11}$cm^2/sec][mLO$_2$]/[mLxmmHg]

Material	Lens Series	Dk (Barrers)	SD	r^2
38% Polymacon	1	9.6	0.2	0.9996
	2	9.3	0.2	1.0000
	3	10.1	0.1	0.9990
58% VP/MMA	1	23.8	0.5	0.9985
	2	24.1	0.8	0.9999
	3	23.9	1.0	0.9983
75% VP/MMA	1	43.6	1.8	0.9994
	2	44.7	0.6	0.9997
	3	45.1	0.2	0.9977
Definitive	1	59.1	0.4	0.9986
	2	59.5	0.7	0.9984
	3	59.2	0.1	0.9993

Table 3. Corrected Dk of each lens series with standard deviations (SD) and coefficeints of determination

Material	Average Dk (Barrers)	SD	Benjamin[1] Dk (Barrers)
38% Polymacon	9.7	0.43	11.4
58% VP/MMA	23.9	0.15	25.5
75% VP/MMA	44.5	0.80	50.7
Definitive	59.3	0.20	/

Table 4. Average corrected and calibrated Dk of each material and compared to literature data where applicable.

CONCLUSIONS

- The Dk of the 74% Silicone Hydrogel was determined to be 60 Barrers.
- The Dk was 33% higher than that determined for an equivalent water content conventional hydrogel and the difference is significant with respect to the estimated error.

The enhancement of oxygen permeability might be accounted for by one or more mechanisms operating singularly or in combination:

- The aqueous phase is structured more effectively providing a more efficient pathway to transport oxygen.
- The fluoro-silicone content provides an oxygen permeable pathway through the polymer that is not present in conventional hydrogels.

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