Measurement of oxygen permeability of contact lenses based on analysis of porosity

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Abstract: *Oxygen permeability seems to be the most important parameter characterize the contact lens. Lenses, which permeable more oxygen to the cornea are safer, reduce the risk of infection and provide greater comfort of wearing. Oxygen permeability of contact lenses might be calculated by analysis of porosity of its surface. With using special program the size and number of pores on definite area was calculated and dependence of permeability and hydration on porosity were established.*

Keywords: *Oxygen permeability, contact lens, porosity*

1. Introduction

Contact lenses are modern and more widely used method of vision correction. Obviously, there is a need to use contact lenses, which are the most comfortable and safe. A contact lens is a barrier to the oxygen, which is necessary for the normal metabolism of the cornea. Oxygen is responsible for maintaining the proper structure and function. The cornea does not have blood vessels and it must collect oxygen from the tear film. The most exposed to hypoxia is its central part. Thus, the modern contact lenses should provide adequate oxygen permeability [1, 2].

In order to describe the amount of oxygen passing through the lens a number of different terms, methods of measurement and calculation were introduced. One of the most characteristic features of a contact lens materials is their porosity, which is characterized by the relative area occupied by the pores with respect to the total area. Control of density and number of pores of porous materials is very important, because the number and size of pores in the material greatly affects its mechanical properties and oxygen permeability.

The aim of the study was to analyze the porosity (size and number of pores, pore distribution, the percentage of porous surface) of different types of contact lenses. Parameters such as oxygen permeability and water content have a significant impact on the comfort of wearing contact lenses. Therefore, the present study shows the results of the porosity and the oxygen permeability and water content values given by the producer.

2. Materials and methods

For the evaluation of the surface of the porous optical microscopy was used, by which one can determine the size and number of holes in the porous contact lens. Therefore, it can be calculated what will be the oxygen permeability of the lens [3].

The subjects of the study were new hydrogel and silicone hydrogel contact lenses [Table A]. The power of the lenses was -3.00 D, because the producer gives the oxygen permeability and water content values for such power [4].

In order to improve the image quality, which for moist lens is unsatisfactory, research was carried out on the lens slightly dried.

Device set of image analysis consisted of a biomicroscope type optical Olympus BH-2, computer and a digital photographic camera, which was controlled by a computer program VideoImgProc. Nominal magnification microscope lens was 10x. The photos were made for the central part of the lens. The analyzed area was 0.42 mm x 0.34 mm, which corresponds to a resolution of 720x576 pixels. Image analysis program ImageJ was used, so that it was possible to determine the number of pores, their location and the average area of the surface. Pores with dimensions of 0-1 mm^2 were analyzed. Pores with very irregular shapes, including objects located close to each other and treated as one were rejected. Statistical analysis was performed using Excel spreadsheet .

3. Theory or Calculations

A parameter characterizing the permeability of the material itself is *Dk*, expressed in Barrer ($[cm^2 \cdot mlO_2]/[s \cdot ml \cdot mmHg]$), while the parameter of contact lens is the oxygen transmissibility *Dk/t* ([Barrer/cm]), taking into account the central or average thickness *t* of the lens. On the basis of permeability *Dk* the range of oxygen permeability is determined [4, 5]. Very low permeability to oxygen and carbon dioxide and a moderate moisture of the lens surface by the tear film are made of PMMA. Delivery of oxygen to the cornea for such lenses based on the exchange of tears under the lens. Strongly improved properties have soft lenses, especially hydrogel and silicone hydrogel lenses, which are the latest generation of soft contact lenses [6, 7, 8]. The network hydrogel has a unique ability to store water. Oxygen is dissolved in the water and with it passes through the lens structure to the surface of the eye and because of that the level of water content of the polymer determines the oxygen permeability. In turn, if the water content is higher, the lens is more supple and the evaporation of water is greater, which results in a higher consumption of tears, that must be replaced by water. Addition of silicon results in improved mechanical and optical properties of lenses and first of all it increases their gas permeability [9, 10]. These lenses have siloxane groups that are better oxygen permeable compared with the water.

Oxygen permeability increases with the increase in the quantity of siloxanes and decrease in water content of the lens [11]. This material has excellent biocompatibility with the tissues of the eyeball and ensures the correct transport of fluids and ions through the lens. Besides it is resistant to drying and has the ability to moisturize the lens surface. Proper oxygen permeability is also dependent on the thickness of the lens. Hence, the thicker the lens and highly hydrated or the thinner the lens and medium hydrated, the easier diffusion of oxygen and the less the corneal metabolism is disturbed. In the prolonged wear lenses, it is observed that with time of usage there is a reduction in gas permeability, which may result from the accumulation of protein deposits.

4. Results and Discussion

Recorded images of the central part of lenses are shown in Fig. A. On the basis of the analysis for each type of lenses obtained data of the number of pores per volume of the recorded area (Fig. B).

Lenses such as: Pure Vision™, Dailies®, Acuvue® Moist™, characterizes increase in pore size with the decrease in its number (Fig. B) at the same time. In the case of other types of analyzed contact lenses, the distribution of the number of pore size does not show any unequivocal tends (Fig. B).

Number of pores per 0,15 mm^2 of the central part of the lens surface is characteristic parameter describing each type of the lenses. Calculated values of different types of contact lenses are shown in table 1. It is worth to notice, that Focus® Night&Day™ (Ciba Vision), has the lowest number of pores, what devates significantly from the values for other lenses, while the largest number of pores characterizes Air Optix™ i Acuvue® Oasys™.

In order to obtain full information about porosity of the lenses, it is necessary to find the average size of pores (Table 1). Among the tested lenses the largest average pore size in the lens material is for Focus® Night&Day™. Greater number of pores on lens surface is connected with its smaller size.

On the basis of these parameters (number of pores in the central part of contact lens and its average size) the total area of pores was calculated (Table 1).

Table 1. Analysis of porosity of different types of contact lenses

Lens type	Number of pores	Average size of pores [μm²]	Porous area [μm²]
Air Optix™	500	36,2	18100
Acuvue® Oasys™	504	18,3	9223
PureVision™	334	24,9	8317
Dailies®	335	18,1	6064
Acuvue® Moist™	265	14,3	3790
Focus® Night & Day™	32	92,3	2954

Above analysis allowed to determine porosity, which by definition is equal to the relative area of pores with respect to the total area, e.g. for Air Optix™:

$$p = \frac{18100\ \mu m^2}{150000\ \mu m^2} \cdot 100\% = 12\%$$

Porosity of different types of contact lenses is shown on the Fig. 1.

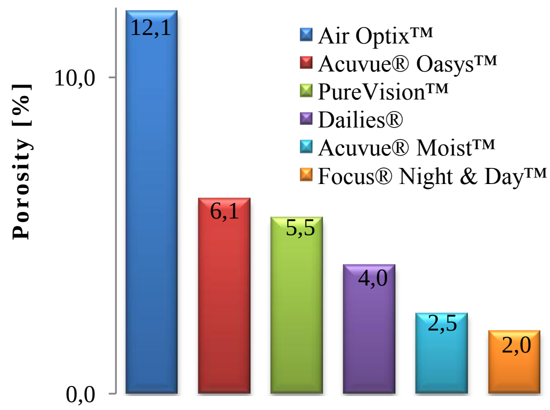


Fig. 1. Porosity of different types of contact lenses

It should be seen that despite the fact, that the pore size of Focus® Night&Day™ is significantly higher than in other cases, it is characterized by the smallest porosity. The largest porosity occurs in Air Optix™, where number and size of pores is relatively large (Table 1).

4.1. Summary of the results with data on oxygen permeability for given materials

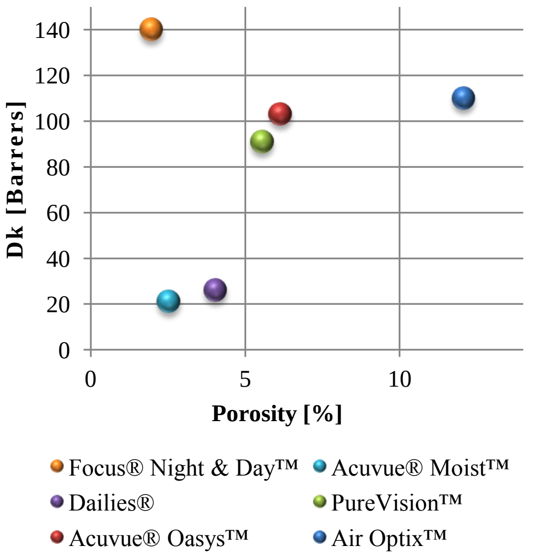


Fig. 2. Dependence of oxygen permeability (manufacturer data) on measured porosity of contact lenses

It is worth to notice, that Focus®Night&Day™ characterized by the highest permeability, has the smallest number and the biggest size of pores among of the lens made of the same material.

One-day hydrogel lenses (Air Optix™, Dailies®) shows the lowest oxygen permeability and very low porosity at the same time.

Other lenses are made of silicon-hydrogel material have much larger oxygen permeability.

These results do not show any dependence between oxygen permeability and porosity of contact lenses.

4.2. Summary of the results with hydratation

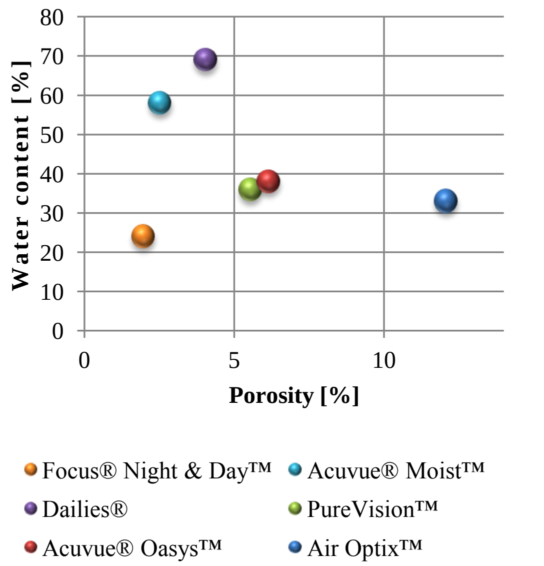


Fig. 3. Dependence of hydratation on porosity of contact lenses

Fig. 3 shows that lens hydratation it is not dependent on porosity. The biggest hydratation characterizes hydrogel lenses. Dailies®, that is lens with larger porosity, is more hydrated in comparison with Air Optix™.

Other lenses made of silicon-hydrogel material are characterized by smaller hydratation. The smallest hydratation is for Focus®Night&Day™, which is characterized by the largest oxygen permeability and the smallest porosity.

5. Conclusions

It seems to be important that a lens which has the highest oxygen permeability obtained in these studies and the fewest number of the largest size of the pores in the mold material.

Hydrogel lenses have high softness and flexibility, which makes it a good fit for the corneal surface, and are well tolerated by the eye tissue. They show where a high degree of permeability to liquids and gases, which is important in normal tissue respiration and metabolism of the cornea.

From the point of view of the physiology of the eye oxygen permeability is one of the most important parameters characterizing the contact lens. The more oxygen reach the eye, that is, the less will be retained by the lens, the eye will be healthier. Most of the oxygen-permeable lenses to the cornea substantially reduce the risk of infection, provide safer and more comfortable to use.

Appendices

Table A. List of parameters of soft lenses – the producer's data

L.p.	Trade-name (producer)	Material	Dk [Barrers]	Dk/t* [Barrers/cm]	Water content [%]
	Hydrogel contact lenses				
1.	Acuvue® Moist™ (Johnson&Johnson)	etafilcon A	21	26	58
2.	Dailies® (Ciba Vision)	nelfilcon A	26	27	69
	Silicone hydrogel contact lenses				
3.	Air Optix™ (Ciba Vision)	lotrafilcon B	110	138	33
4.	Acuvue® Oasys™ (Johnson&Johnson)	senofilcon A	103	147	38
5.	PureVision™ (Bausch&Lomb)	balafilcon A	91	101	36
6.	Focus® Night & Day™ (Ciba Vision)	lotrafilcon A	140	175	24

* Dk/t for thickness of central part of the lens (Power -3.00 D) measured with using polarographic method

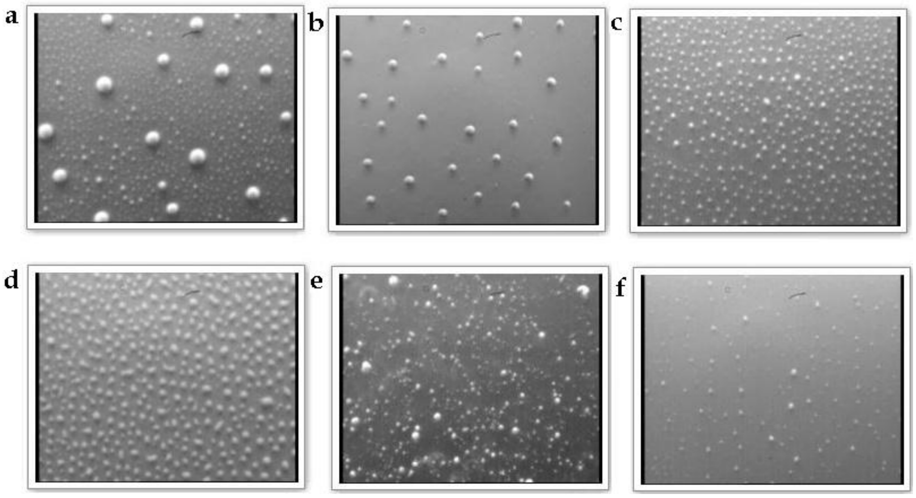
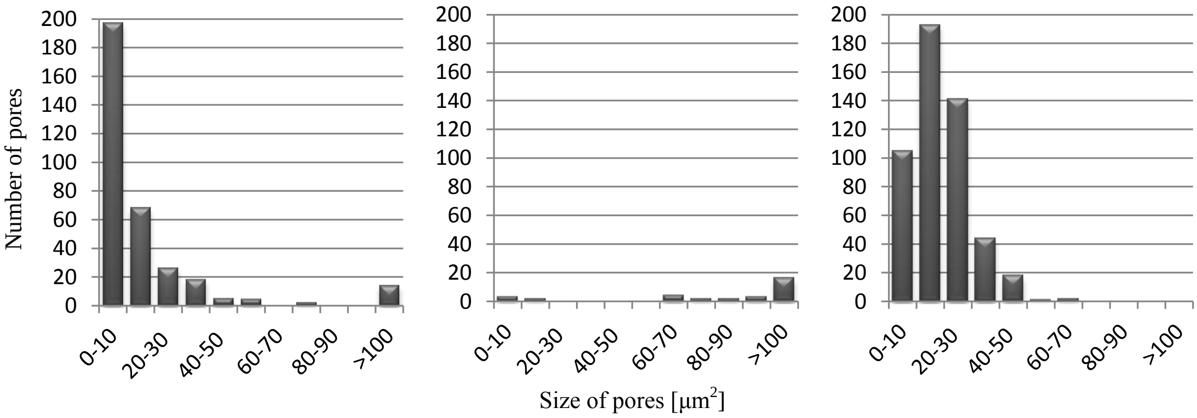


Fig. A. Recorded images of the central part of lenses: a) PureVision™, b) Focus® Night & Day™, c) Acuvue® Oasys™, d) Air Optix™, e) Dailies®, f) Acuvue® Moist™



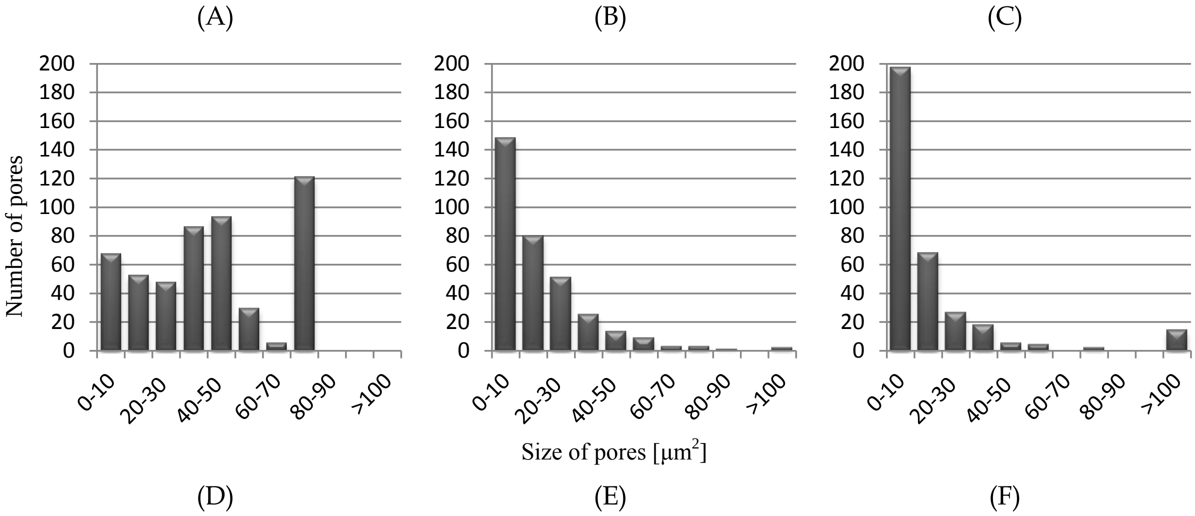


Fig. B. Dependence of number of pores for 0,15 mm^2 central part of the lens on size of pores for different types of lenses: PureVision™ (A), Focus® Night & Day™ (B), Acuvue® Oasys™ (C), Air Optix™ (D), Dailies® (E), Acuvue® Moist™ (F)

References

[1] Harvitt D.M., Bonanno J.A.: "Re-evaluation of the oxygen diffusion model for predicting minimum contact lens Dk/t values needed to avoid corneal anoxia", Optometry and Vision Science, 1999; 76: s. 712-719.

[2] Garr-Peters JM, Oxygen transfer in the corneal-contact lens system., Crit Rev Biomed Eng. 1987;14(4):289-372.

[3] Gatin E., Alexandreanu D., Popescu A., Berlic C., Alexandreanu I.:"Correlations between Permeability properties and the pore-size distribution of the porous media", "Hydron" useful as contact lenses, 1999;

[4] Norma: PN-EN ISO 18369-1:2008: Optyka oftalmiczna. Soczewki kontaktowe. Część 1: Terminologia, system klasyfikacyjny i zalecenia dotyczące etykietowania specyfikacji, s.25-26.

[5] Joon Bu Park, Roderic S. Lakes, Biometarials: An Introduction, Springer, 2007;

[6] Norma: PN-EN ISO 18369-4:2010: Optyka oftalmiczna. Soczewki kontaktowe. Część 4: Fizykochemiczne właściwości materiałów soczewek kontaktowych, s.12-26.

[7] Fatt I., Rubin C., Oxygen permeability of rigid contact lenses., Cont Lens Ant Eye., 1994, 18(2):49-53;

[8] Mandel R.B., Liberman G.L., Fatt I., Corneal oxygen supply: RGP versus soft lenses, CL Spectrum, 1987, 2(10):37-39;

[9] Schnider C.: "Acuvue Advance with Hydraclear : A new and different silicone hydrogel lens", Refractive Eyecare for Ophthalmologists, 2004 r., 11-13;

[10] Efron N., Morgan P.B., Cameron I.D. Brennan N. A., Oxygen Permeability and Water Content of Silicone Hydrogel Contact Lens Materials, Optometry and Vision Science, Vol. 84, No. 4, April 2007;

[11] Schofield J.: "A new silicone hydrogel lens", Optician, 2005, 229 (5995), s.16-18.