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STUDY OF THE OPTICAL POWER OF NANOPHOTONIC SOFT CONTACT LENSES BASED ON POLY (2- HYDROXYETHYL METHACRYLATE) AND FULLERENE

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Abstract: In this paper results of comparative study of the optical power of soft contact lenses (SCL) made of standard material for SCL and nanophotonic materials with different measurement techniques used for the final contact lens controllers are presented. Three types of nanophotonic soft contact lenses were made of standard polymacon material (Soleko SP38™) incorporated with fullerene C_{60}, fullerol $C_{60}(OH)_{24}$ and fullerene metformin hydroxylate $C_{60}(OH)_{12}(OC_4N_5H_{10})_{12}$.

For the purposes of material characterization for potential application as soft contact lenses, the optical properties of the soft contact lenses were measured by Rotlex and Nidek device. With Rotlex device the following optical results were obtained: optical power and map of defects, while with the Nidek device: optical power, cylinder power and cylinder axis. The obtained values of optical power and map of defects showed that the optical power of synthesized nanophotonic soft contact lens is same to the nominal value, while this was not the case for the standard soft contact lens. Also, the quality of the nanophotonic soft contact lens is better than the standard one. Hence, it is possible to synthesize new nanophotonic soft contact lenses of desired optical characteristics, implying possibilities for their application in this field.

Keywords: soft contact lenses, nanophotonic materials, characterization, optical power.

1. INTRODUCTION

There has been a fairly continuous evolution in the field of contact lens materials since 1930s. The technology of vision correction using a lens in intimate contact with the cornea was first reduced to practice in the form of a glass lens in the 1800s. Wichterle forever changed the contact lens industry with his contributions of soft hydrogels including the process of lathing hydrogel materials as zerogels and also, the direct spin casting of soft hydrogels as a more viable, high volume production process. Soon after the commercial introduction as polymacon in 1970, Wichterle's poly-hydroxyethylmethacrylate (PHEMA) hydrogel was rapidly followed by a wide range of new hydrogel polymers [1] driven by the obvious pursuit for a competitive position in this new emerging soft contact lens market. The pursuit of new materials was also motivated by the understanding the cornea uses oxygen to maintain its clarity, structure and function and obtains its oxygen from the air.

The ocular environment places high demands on the performance of contact lenses as biomaterials. Ophthalmic compatibility of a contact lens on the eye requires the lens maintain a stable, continuous tear film for clear vision, is resistant to deposition of tear film components, sustains normal hydration, is permeable to oxygen to maintain normal corneal metabolism, is permeable to ions to maintain movement and to be nonirritating and comfortable. Therefore, the lens must have excellent surface characteristics being neither hydrophobic nor lipophilic and must possess the appropriate bulk polymer composition and morphology to be successful [2].

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The surface properties of the contact lens that include friction, adhesion, and structural arrangements of polymer chains are not well understood [3−4]. The lack of this information has hindered the establishment of fundamental relationships between the chemical and physical properties and the biological responses of the contact lens such as wear comfort, protein adhesion, bacterial infection, etc [5–14]. It is well known that protein and cell adhesion depend on the mechanical properties as well as the chemical properties of the surface [15–17]. Therefore, surface characterization of the contact lens surface in a condition similar to the ocular environment is of paramount importance in fundamental as well as clinical studies.

Optical properties of the soft contact lenses were measured by Rotlex and Nidek devices. Measuring optical properties with Rotlex and Nidek device appear to be a proper techniques to study this problem for two reasons: (1) With Rotlex device the following results can be obtained: optical power and a map of defects; (2) With the Nidek device: optical power, cylinder power and cylinder angle.

The aim of this research is better understanding of optical properties of soft contact lens materials and their adaptability to the human eye.

2. MATERIAL

Hydrogels are described as hydrophilic polymers that are swollen by water, but do not dissolve in water. They are three-dimensional cross-linked polymeric structures that are able to swell in an aqueous environment. In recent years, hydrogels have been widely used in numerous medical applications due to their characteristic properties such as swelling in water, biocompatibility, and lack of toxicity. Poly(2-hydroxyethyl methacrylate) (PHEMA) hydrogel is a synthetic hydrogel, and it possesses a high mechanical strength, resistance to many chemicals and relatively high water content in swollen state. PHEMA hydrogel has high water content similar to body tissues and is currently used in medical applications [18].

HEMA homopolymers or copolymers are also used (or are under investigation) in a number of applications, especially in biomaterials and in novel nanotechnology applications for surface modification. For instance, interest in the late 1970s in hydrogels for biomedical applications, especially for contact lenses and blood-compatible surfaces, stimulated detailed investigation of the bulk and surface properties of PHEMA gels. Since that time, investigation of PHEMA for application in different biomedical devices has continued [19−21].

The field of nanoscience and nanotechnology is extending the applications of physics, chemistry, biology, engineering and technology into previously unapproached infinitesimallength scales. The polymer–nanoparticles/nanocomposites have been the exponentially growing field of research for developing the materials in last few decades and have been mainly focusing on the structure–property relationships and their development. Since the polymer–nanocomposites have been the staple of modern polymer industry, their durability under various environmental conditions and degradability after their service life are also essential fields of research [22].

A large number of papers presents the results of research and experiments in the field of fullerene incorporation in the polymer structure [23−26].

Incorporation of fullerenes can affect on optical properties of the material, which makes them very interesting for researching. Fullerenes have less transmission in the field of the ultraviolet, blue, and infrared spectrum, which negative affects the eye tissue. In the green and yellow area of the spectrum are higher values of transmission, which corresponds to the human eye [27].

Standard material for soft contact lenses (SL 38) that has been used in this research is polyhydroxyethyl methacrylate (PHEMA). New nanophotonic materials for soft contact lenses were standard material incorporated with molecules fullerene C_{60} (SL 38-A), fullerol $C_{60}(OH)_{24}$ (SL 38-B) and fullerene metformin hydroxylate $C_{60}(OH)_{12}(OC_4N_5H_{10})_{12}$ (SL 38-C).

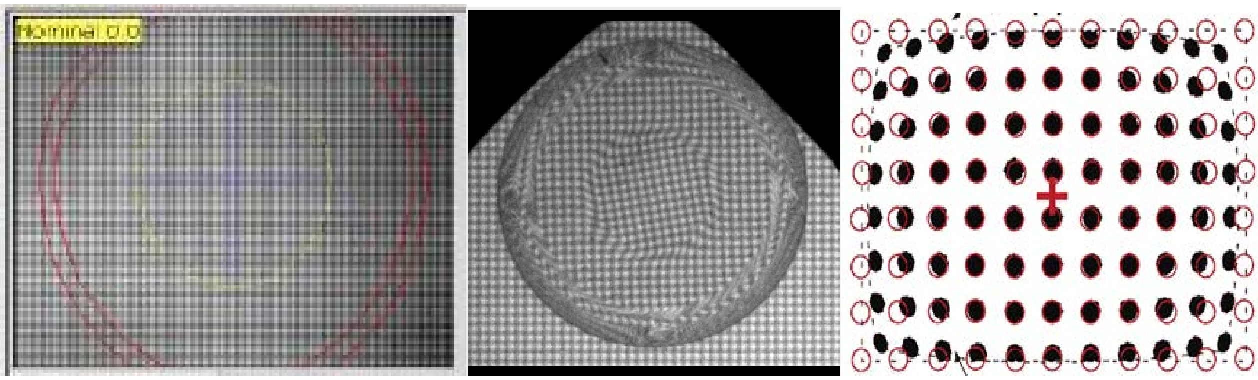
3. METHOD

3.1. Rotlex® CONTEST Plus

The CONTEST Plus system (Figure 1 (a)) employs a technology patented by Rotlex known as Moiré Deflectometry. A pair of gratings are separated a fixed distance apart. When a beam of ligh passes through the gratings, a fringe pattern is seen. When no lens is present, the fringes are straight and have uniform frequency (Figure 2 (a)). When a sample is placed in the system, the fringe pattern is rotated and the frequency is changed (Figure 2 (b) and 2 (c)). The amount of change is dependent on the local power and cylinder. The rotation is due to the different magnification each grating experiences. The software measures the local fringe frequency throughout the entire lens and is thus capable of producing a power map. The average power within the measurement window may then be calculated, as well as a histogram of the powers and a radial profile. The quality is calculated in terms of the uniformity of the power within the window and is relevant only for single vision lenses. The scribe marks of a toric lens are clearly legible and can be marked by the user for measurement of the axis of cylinder. The perimeter of the lens is clearly legible and can be traced by the user. The trace is calculated into the diameter of the lens [28].

(a) (b)

Figure 1. Devices for measuring optical power: a) Rotlex ® Plus CONTEST; b) Nidek LM – 990 (Optix, Zemun)



(a) (b) (c)

Figure 2. Grid layout: (a) contact lens is not set in the cuvette, (b) after placing the contact lens in the cuvette (c) image distortion of contact lens placed in the cuvette [27]

Measurements of optical power were carried out on Rotlex CONTEST ® Plus device (Intraocular Lens Analyzer , Israel). Specification of Rotlex device: range −30 D to +30 D, resolution 0.01 D, accuracy: 0.5%, cylinder: up to 6 D, measurement time: 4 s.

Experiments were carried out under strictly controlled condition, under constant control of temperature (25 °C), control of humidity (to 38%) and the quality of the air .

For all tested soft contact lenses, SL 38, SL 38–A, SL 38-B and SL 38-C, required nominal optical power is +3.00 D. The refractive index for all contact lenses is n = 1.4950. This value is the theoretical value of the refractive index calculated by the Company Soleko, Italy. The refractive index of the buffer solution (pH = 7.3) in cuvette is n = 1.3350. The lens is made with a base curve r = 8.6 mm. The thickness of the lens in the center is 0.21 mm. The tested contact lenses are spherical and convex. The measured optical power was calculated for a diameter d = 7.40 mm .

3.2. Nidek device

Nidek device (Figure 1 (b)), lensmeter, is used for measuring single vision lenses, bifocal (trifocal) lenses, Progressive Power Lenses (PPL) and Contact Lenses (CL). It has a measuring unit and a display unit in front, and printer unit on the right side. The display unit utilizes a full-graphic LCD, displaying measured values of right-eye and left-eye lenses at one time, and graphically showing the alignment condition in the shape of a Target. This graphic Target is especially useful when measuring PPL, since the Target moves on the illustration of PPL on the display to show the relation between the measuring point and the progressive channel of the lens. The ADD power value is also graphically indicated. Icons are conveniently located on the screen, next to the corresponding operational buttons [29].

4. RESULTS AND DISCUSSION

4.1. Rotlex device

Based on vertical and horizontal fringe it can be seen that there is no deformations between quadrates ie. that there is no major distortion of the image. The measured power was calculated for a diameter of 7.40 mm. In this range the measured power is +2.65 D. Figure 3 indicates colour change from yellow to blue light, which corresponds to the variations in optical power from +2.75 to +2.15 D. Domination of light green colour that corresponds to the optical power of +2.65 D is observed. This shows that the lens has a nearly uniform distribution of optical power. The tolerance limit of the human eye is ±0.25 D comparing to the nominal optical power, which indicates that the lens could not get out from production.

The quality of the contact lens presents a measure of optical homogeneity in the range of the measurements. If the optical homogeneity is larger, the result will be closer to the value of 10. Number that determines the quality is calculated as a number of all points that carry the values of the optical power that are in a particular environment of the average power divided by the total number of pixels in the area of measurement and multiplied by 10.

Based on the measured parameters, the quality of the contact lens, SL 38, is 9.9/10 was obtained. At the ends of the lens there is a little distortion, which can be the cause of the transition from an optical zone to peripheral zone. Yellow power ring on the map gives a higher value of optical power, which may be due to different radius or refractive index.

Based on the map of defects irregularities in the lens can be observed, ie. which fragments of the lenses refract light more and which one less. Map of defects of lens SL 38 (Figure 4) shows no significant irregularities.

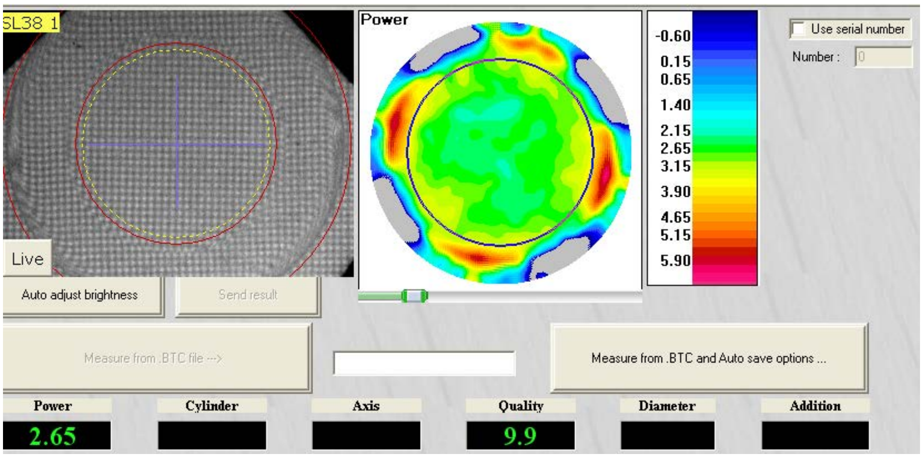


Figure 3. Distribution of optical power of the soft contact lens SL 38 [27]

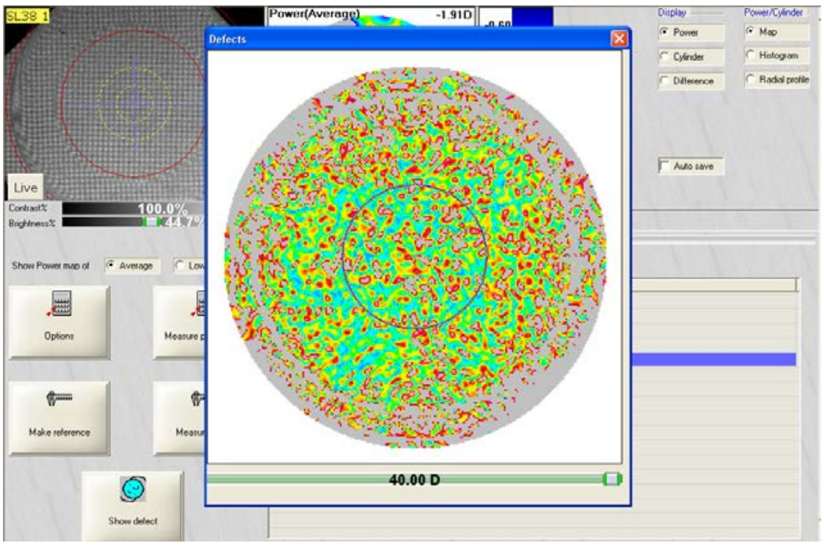


Figure 4. Map of defects for soft contact lens SL 38 [27]

Measured power of the lens SL 38-A is +3.00 D, which is the same value as the nominal optical power. This lens could come out of production, unlike lens SL 38. The obtained quality of the lens is 10/10. Figure 5 shows that green and light blue colour are dominant, indicating that the lens has a uniform distribution of the power, and optical power varies from +3.00 D to +2.60 D.

Looking at the map of defects, figure 6, it can be concluded that there are no major changes in the homogeneity of the material for nanophotonic soft contact lens, SL38-A [27].

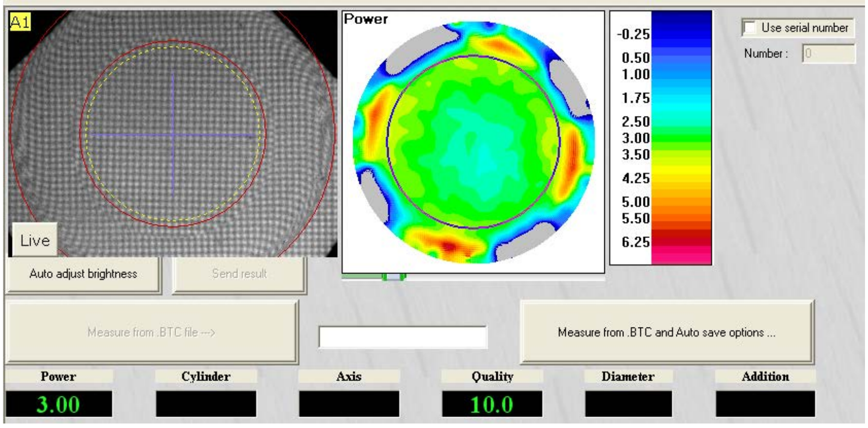


Figure 5. Distribution of optical power of the soft contact lens SL 38-A [27]

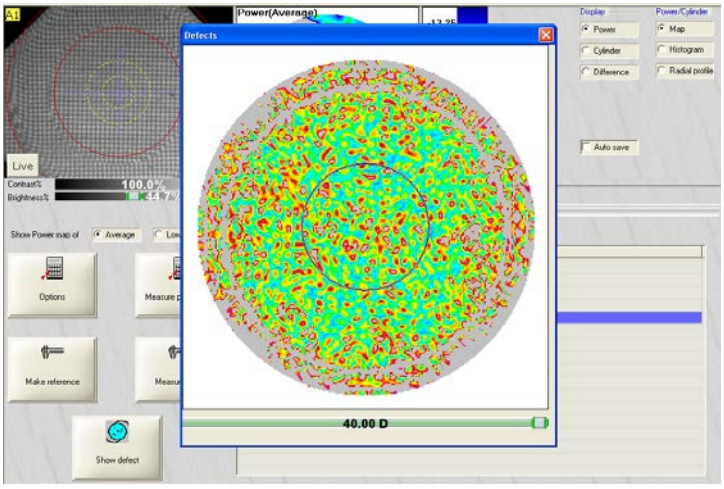


Figure 6. Map of defects for soft contact lens SL38-A [27]

Measured power of the lens SL 38-B is +2.76 D. Since the tolerance limit of the human eye is ± 0.25 D comparing to the nominal optical power, SL38-B could come out of production. The obtained quality of the lens is 10/10. Figure 7 shows that yellow and green colour are dominant, which indicates that the lens has a uniform distribution of the power. Optical power varies from +3.26 D to +2.70 D.

Map of the defects (figure 8) shows that there are no major changes in the material. There is one change that is marked with the white arrow. The cause may be due to the dust that fell on the frontal surface of the lens, or a small defect in material caused by doping of the fullerene derivate. This is the lens periphery, so this small defect can be ignored.

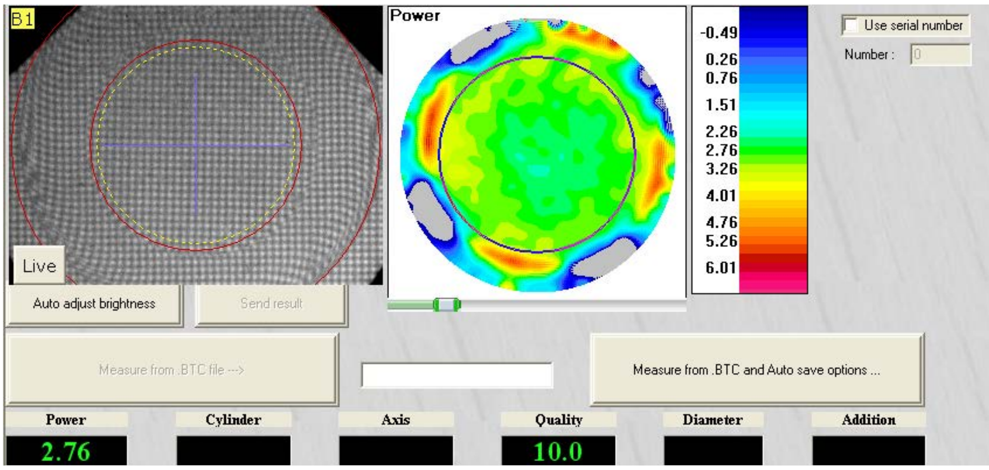


Figure 7. Distribution of optical power of the soft contact lens SL 38-B

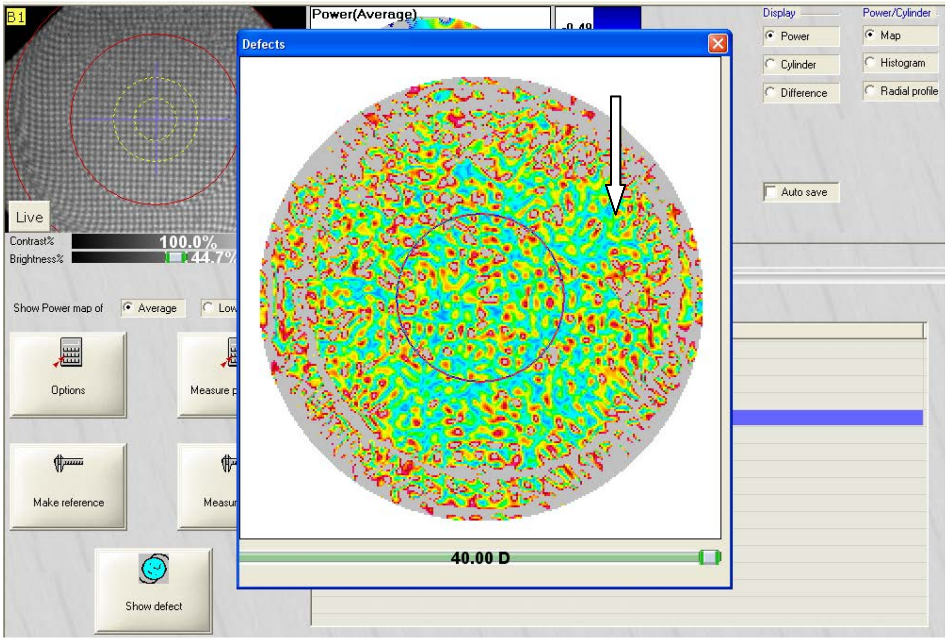


Figure 8. Map of defects for soft contact lens SL38-B

Measured power of the lens SL 38-C is +3.02 D, which is roughly the same value as the nominal optical power. This nanophotonic lens could also come out of production. The obtained quality of the lens is 10/10. Figure 9 shows that green and light blue colour are mainly represented. This fact indicates that the lens has a uniform distribution of the power and that optical power varies from +3.10 D to +2.70 D.

Map of defects (figure 10) shows no major changes, indicating the homogeneity of the structure of the lens SL38-C.

4.2 Nidek device

The lowest value of the optical power has lens SL 38-A (table 1), while the SL 38 lens shows the highest value of optical power comparing to the nominal value of the optical power. Nidek device measures the optical power of the small diameter of 3.00 mm but with Rotlex device the results for the diameter 7.40 mm could be obtained.

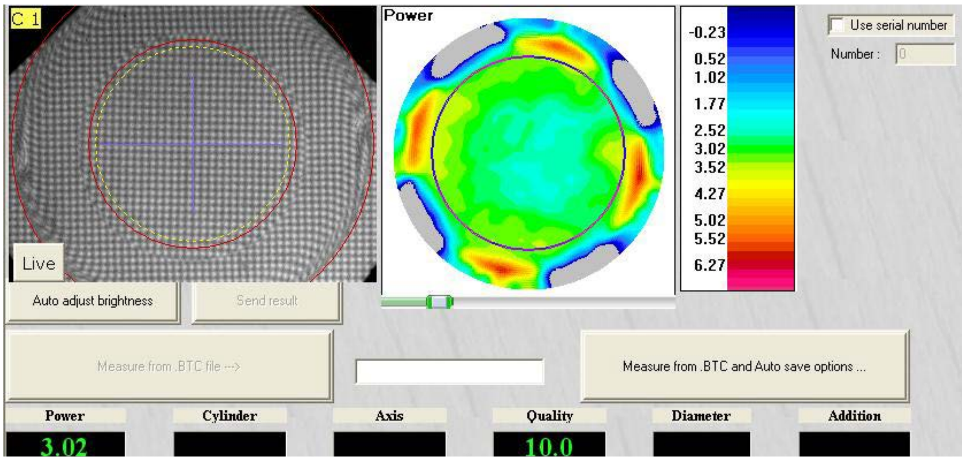


Figure 9. Distribution of optical power of the soft contact lens SL 38-C

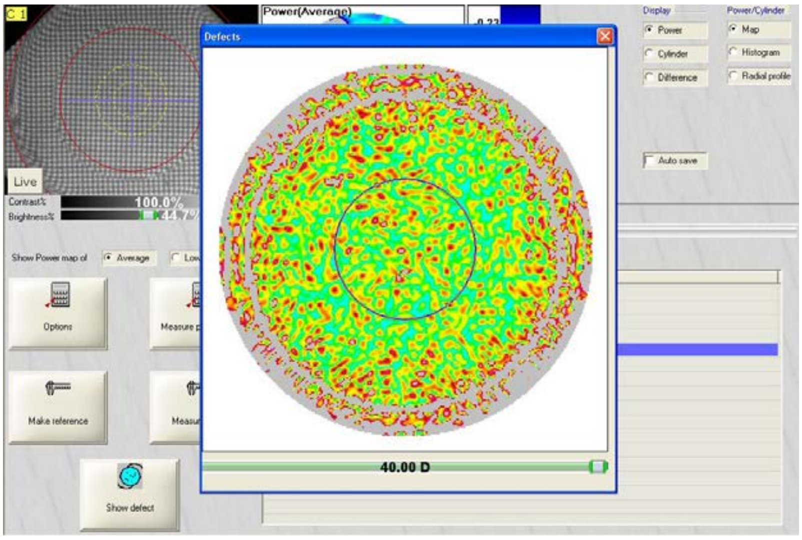


Figure 10. Map of defects for soft contact lens SL 38-C

Table 1. Summary of the results obtained by Nidek device

Soft contact lens	Nominal power [D]	Device Nidek LM-990					
		SE	SPH	CYL	AXS	PSM	BAS
SL 38	+3,00	+3,62	−3,84	−0,44	95	0,11	41
SL 38-A	+3,00	+3,36	+3,47	−0,22	85	0,26	99
SL 38-B	+3,00	+3,51	+3,59	−0,17	87	0,24	275
SL 38-C	+3,00	+3,44	+3,66	−0,34	174	0,22	236

Another disadvantage of Nidek device is the measurement of the optical power for soft contact lenses. To measure an optical properties of soft contact lenses, the lens must be removed from the cuvettes in which is the liquid (buffer solution). If the measuring is longer, damage to the lenses may be caused. However, all tested soft contact lenses have value of optical power which is within the tolerance limits (± 0.25 D). The reasons for deviation could be:

1. With the Nidek device optical power is not measured in a cuvette with liquid (which has a refractive index n = 1.3350, and the tear film is n = 1.33815) as with Rotlex device. The optical power is measured directly on Nidek device in the air, which has an index of refraction n = 1.00. Higher refractive index difference such as in this case, may affect the accuracy of the results.

2. Nidek device is not precise as modern Rotlex device, so usually in practice the following rule is applied: if the specified nominal optical power is

for example +3.00 D, in the process of lathing the set nominal optical power is +2.75 D. Than, after the measurement with Nidek device for tested contact lens, value of optical power is up to +3.25 D, which is within the tolerance limits.

5. CONCLUSION

Nidek device provides some basic information such as the total optical power, spherical power, cylinder, cylinder axis. Digital Nidek device gives the data of optical characteristics in a narrow diameter in the center of the lens and this could be the lack of this device. Observing and comparing the results obtained with Nidek and Rotlex device, it can be seen that the Nidek device measures the optical power of the small diameter (3.00 mm) and Rotlex device diameter of 7.40 mm. Another disadvantage of Nidek device is during the measurements of optical power because the soft contact lens must be removed from the cuvette in which is the liquid . If the measurement lasts longer, it may cause damage to the contact lenses. That is not the case with Rotleks device because it allows measurement in a separate cuvettes in which is poured a suitable solution, so that the measurements are performed while the tested contact lens is in a solution. Nidek gives less information than Rotlex, but the measurements are much faster with Nidek device. Nidek is suitable for controlling the lens because the operator can quickly be trained to work on this device.

With Rotlex device, values of optical power and map of defects were showed. The obtained values of optical power and map of defects showed that the values of the optical power of synthesized nanophotonic soft contact lenses are close to the nominal value while this was not the case for the standard contact lens, SL 38. Also, the quality of the nanophotonic soft contact lenses are better than the quality of SL 38. Hence, it is possible to synthesize new nanophotonic soft contact lenses of desired optical characteristics, implying possibilities for their application in this field.

Measurements with Nidek device for all soft contact lenses have given the values of the optical power that are within the tolerance (± 0.25 D). The reasons for the deviation could be:

1. With the Nidek device, the optical power of the lens is measured directly on the device, on the air which has an index of refraction n = 1.00;
2. Nidek device is not precise as modern Rotlex device.

Lower value of optical power than the nominal optical power can cause poorer vision to shortsighted person. It is common that in the manufacture process for shortsighted people contact lenses that have higher value of optical power than nominal for 0.25 D are made. Higher optical power will not affect on poorer vision, while the lower optical power can be a problem with slightly poorer eyesight.

6. ACKNOWLEDGMENTS

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[29] Nidek LM990 manual.

ИСПИТИВАЊЕ ОПТИЧКЕ СНАГЕ НАНОФОТОНИЧНИХ МЕКИХ КОНТАКТНИХ СОЧИВА НА БАЗИ ПОЛИ(2-ХИДРОКСИЕТИЛ МЕТАРИЛАТА) И ФУЛЕРЕНА

Сажетак: У раду су представљени резултати компаративних истраживања оптичке снаге меких контактних сочива (МКС) са различитим техникама мјерења које се користе при финалној обради контактних сочива.

Три врсте нанофотоничних меких контактних сочива су направљене од стандардног polimacon материјала (Солеко SP38™) са инкорпорираним фулереном C_{60}, фулеролом $C_{60}(OH)_{24}$ и фулерен-метформин-хидроксилатом $C_{60}(OH)_{12}(OC_4N_5H_{10})_{12}$.

За потребе карактеризације материјала за потенцијалну примјену код меких контактних сочива, мјерена су оптичка својства меких контактних сочива Ротлекс и Нидек уређајем. Са Ротлекс уређајем добијени су следећи оптички резултати: оптичка снага и мапа дефеката, а са Нидек уређајем: оптичка снага, снага цилиндра и угао цилиндра. Добијене вриједности оптичке снаге и мапе дефеката показали су да оптичка снага синтетисаних нанофотоничних меких контактних сочива је идентична номиналној вриједности, док то није био случај за стандардна мека контактна сочива. Такође, квалитет нанофотоничних меких контактних сочива је бољи него код стандардних меких контактних сочива. Из приказаног се може закључити да је могуће синтетисати нова нанофотонична мека контактна сочива жељених оптичких карактеристика, што отвара могућности за њихову примјену у овој области .

Кључне ријечи: мека контактна сочива, нанофотонични материјали, карактеризација, оптичка снага.

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