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Optical Characterization of Hydrogel and Silicone Hydrogel Soft Contact Lenses

Reşit ÖZMENTEŞ[1*], Abdulkadir KORKUT
[1] Vocational School of Health Services, Bitlis Eren University, 13100 Bitlis, Türkiye
[2] Van Yüzüncü Yıl University, Faculty of Science, Department of Physics, Van, Türkiye
[*1] rozmentes@beu.edu.tr, [2] akkut@yyu.edu.tr

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Abstract: Contact lenses are biomaterials that have emerged as an alternative to glasses in correcting vision defects. In this study, Nesofilcon A (Hydrogel-Hy) and Delefilcon A (Silicone Hydrogel-SiHy) daily disposable soft contact lenses were optically examined using UV-visible light spectroscopy. Optical absorption and transmittance measurements of the lenses were taken with a UV-visible spectrophotometer, and their properties of blocking the harmful part of the radiation to the eye and transmitting the harmless part were investigated. From the absorption spectrum, it was seen that the Nesofilcon A lens absorbed ultraviolet light better. From the optical absorption coefficient spectra of Nesofilcon A and Delefilcon A lenses, the absorption edges were obtained as 386 and 325 nm, and the optical band gap values were 3.34 and 3.98 eV, respectively. Additionally, the refractive index profiles of the lenses were plotted. The refractive indices of the lenses at 550 nm wavelength were calculated as 1.55 and 1.77 for Nesofilcon A and Delefilcon A, respectively. While the Delefilcon A lens transmitted visible light well, the Nesofilcon A lens blocked UV light better and its refractive index was determined to be closer to the 1.40 the value specified by the manufacturer.

Key words: Soft contact lens, UV-Visible spectroscopy, Optical properties, Silicone-Hydrogel.

Hidrojel ve Silikon Hidrojel Yumuşak Kontakt Lenslerin Optiksel Karakterizasyonu

Öz: Kontakt lensler, görme kusurlarını düzeltmede gözlük alternatifi olarak ortaya çıkan biyomalzemelerdir. Bu çalışmada, Nesofilcon A (Hidrojel-Hy) ve Delefilcon A (Silikon Hidrojel-SiHy) günlük tek kullanımlık yumuşak kontakt lensler UV-görünür ışık spektroskopisi kullanılarak optiksel olarak incelenmiştir. Lenslerin optik soğurma ve geçirgenlik ölçümleri UV-görünür ışık spektrofotometresi ile alınarak, göze gelen radyasyonun zararlı kısmını bloke etme ve zararsız kısmını geçirme özellikleri incelenmiştir. Soğurma spektrumundan, Nesofilcon A lensinin ultraviyole ışığı daha iyi emdiği görülmüştür. Nesofilcon A ve Delefilcon A lenslerinin optik soğurma katsayısı spektrumlarından soğurma kenarları 386 ve 325 nm, optik bant aralığı değerleri ise sırasıyla 3,34 ve 3,98 eV olarak elde edilmiştir. Ayrıca lenslerin kırılma indisi profilleri çizilmiştir. 550 nm dalga boyunda lenslerin kırılma indeksleri Nesofilcon A ve Delefilcon A için sırasıyla 1,55 ve 1,77 olarak hesaplandı. Delefilcon A lensi görünür ışığı iyi iletirken, Nesofilcon A lensi UV ışığını daha iyi bloke ettiği ve kırılma indeksinin üretici tarafından belirtilen 1,40 değerine daha yakın olduğu belirlendi.

Anahtar kelimeler: Yumuşak kontakt lens, UV-Görünür spektroskopi, Optik özellikler, Silikon-Hidrojel

1. Introduction

Contact lenses (CLs) are optical devices made of monomer, polymer or macromer combinations. Their structure is thin, transparent, and curved. Soft CLs are made of flexible polymers. Today's commonly used daily disposable or longer-wear CLs are made of hydrogel or silicone hydrogel materials. The first soft hydrogel contact lens was introduced in 1938 and quickly gained popularity. Hydrogel is a water-absorbent material, while silicone has good gas permeability [1-5]. Hydrogel lenses are a type of hydrophilic, water-retaining monomers (HEMA, 2-hydroxy ethyl methacrylate, NVP, N-vnyl pyrrolidone, polyvinyl alcohol). The Hy lens contains a high percent of water. This keeps the eye moisturized. They have high oxygen permeability. In this way, the eyes breathe better and they are comfortable lenses to use. It is also known to protect the eyes from harmful UV rays. Silicone hydrogel (SiHy) CLs were produced in the 2000s. They are now the most popular type of lens. These lenses, which have high oxygen permeability, also reduce the risk of infection [6-9]. SiHy lenses are an advanced version of Hy lenses. They are produced by combining Si and Hy copolimer materials. The PMMA part of the material determines its optical transparency and hardness, and the silicon part determines its oxygen permeability. Since the silicone part is hydrophobic, its wettability is low. Thanks to the Si in their structure, they provide higher oxygen permeability than Hy lenses and allow lens use for longer periods of time. It is a type of hydrophobic (water repellent) copolymer lens [10-14]. The ability of contact lenses to absorb high energy UV light of the electromagnetic spectrum is a

[*] Corresponding author: rozmentes@beu.edu.tr. ORCID Number of authors: [1] 0000-0002-5893-0660, [2] 0000-0003-0100-4057

very important feature for eye health. The type of material from which CL is produced has a significant impact on this characteristic. There are further studies showing that even blue light affects the eyes [15,16]. Wavelength and energy values of UV and blue light are given in Table 1.

Table 1. Wavelength and energy range values of ultraviolet (UV) and visible blue light that have harmful effects on the ocular

Radiation band type	Wavelength (nm)	Energy (eV)
UV-C	200-280	6.20 - 4.43
UV-B	280-315	4.43 – 3.93
UV-A	315-400	3.93 – 3.10
Blue	400-515	3.10 – 2.40
Desirable light	515-780	2.40 – 1.59

Almost all UV-C and UV-B light is absorbed by the ozone layer. But almost all UV-A light passes through the ozone layer and reach the earth and therefore living tissues and especially the human eye. Therefore, unless UV radiation is filtered lenses or glasses, it can reach the inner layers of the eye and cause damage. In addition, as a result of our exposure to screens, LED lamps, TVs and other electronic devices, the blue light emitted from these devices negatively affects the secretion of the melatonin hormone at night, causing sleep disorders. Exposure to high levels of blue light throughout the day can cause permanent damage to the eyes. Plasmonic contact lenses have been proposed to alleviate these negative effects of blue light [1].

There are relatively few studies in the literature on the absorption and permeability properties of soft contact lenses. Ahmet Barlık and Gonca Ateş compared the UV light absorption and visible light transmittance properties of Senofilcon A and Lotrafilcon B soft contact lenses. They concluded that although the transmittances of the lenses in the visible region are close to each other, the Senefilcon A lens absorbs, that is cut, UV light better [17]. In another study, Gonca Ateş and Selma Bilici compared the properties of CR-39 and polycarbonate (PC) organic eyeglass lenses such as absorption, transmittance, optical band gap and UV protection using UV-visible absorption spectroscopy. The authors concluded that PC organic spectacle lenses protect the eyes better from UV radiation and they calculated direct band gap values of the lenses as in the range of 3.14-4.15 eV [18]. In a similar study, Gonca Ateş measured the absorption and transmittance of mineral and organic eyeglass photochromic lenses in vertical and horizontal directions and examined the effects of the color of the lenses and the polarization of the light on the optical properties of the lenses [19]. In a parallel study, K. Jez et al. They tested the transmittance and reflection spectroscopy of organic CR-39 eyeglass lenses in the UV-Vis-NIR wavelength range. The authors noted that the eyeglass lenses exhibited a transmittance of around 90%, not the 100% stated by the manufacturer, and that only two of the six UV-coated lenses they examined performed UV protection functions [20]. In a recent study, M. Alves et al. They investigated the effect of lens care solutions on the optical properties (transmittance, reflectance, absorbance and florescence) of SiHy and Hy lens materials. The authors reported that the optical properties of contact lenses mutually change with lens care solutions [15]. J. Rex et al. examined the surface elemental composition analyzes of different types of commercial SiHy lenses using the X-ray photoelectron spectroscopy (XPS) method. Detailed XPS analysis of the lenses revealed significant differences in the chemical composition of their surfaces in terms of the content of Si [13]. In a similar study using the soft daily disposable lenses used in this study, J. Schafer et al. compared the surface refractive index values of Delefilcon A, Nesofilcon A and Etafilcon A lenses before and after 15 minutes of wearing. The study showed that the surface refractive index value of the of the Delefilcon A lens increased from 1.34 to 1.43, while there wasn't a significant change in the refractive index value of the Nesofilcon A (1.38) and Etafilcon A (1.41) [21]. In a recent study, the dehydration and rehydration processes of daily disposable (Nesofilcon A and Delefilcon A) and two-month (Comfilcon A and Lotrafilcon B) lenses and the changes in their refractive index, water content, chemical structure and thermal properties were investigated by Lira M. et al. The study showed that there was no significant change in the chemical structures of the lenses with dehydration and rehydration processes, and in the refractive index and water content with rehydration [3].

In this study, the optical properties of Nesofilcon A and Delefilcon A daily disposable lenses were investigated by spectrophotometric method. Lenses were originally characterized by reflection and refractive index dispersion curves. The aim of this study is to examine the UV-visible absorption, transmittance and reflection spectra, UV light filtering properties of contact lenses and to calculate the optical band gap and refractive index values of these materials.

2. Material and Method

The Nesofilcon A (hydrogel-Hy) and Delefilcon A (silicone hydrogel-SiHy) polymeric material contact lenses examined in this study are commercially available daily disposable lenses. The most obvious differences between these lens materials are their water content and wetting properties. While Nesofilcon A is hydrophilic and contains 78% water, Delefilcon A contains 33% water and is hydrophobic [2].

Table 2: Some physical parameters of the contact lenses examined

Parameter	CL Material	
Technical Name	Nesofilcon A	Delefilcon A
Manufacturer-Brand	Bausch+Lomb	Ciba Vision
Water Content, WC (%)	78	33
Oxygen Permeability (Dk/t)	42	156
Base Curve:	8.6 mm	8.5
Diameter:	14.2 mm	14.1 mm
Center Thıckness	0.10 mm	0.09mm
Main Monomer	Hy	SiHy
Powers	-3.00 D	+0.50 D

Daily disposable Nesofilcon A and Delefilcon A contact lenses were optically characterized using the UV-Vis spectrophotometric method. The measurements were taken with a Shimadzu UV-Vis 2450 spectrophotometer (Fig. 1a). The device measures the percentage of light that is transmitted and absorbed by the material by sending light to it at wavelengths between 200 and 900 nm. The contact lenses investigated are shown in Figure 1b.

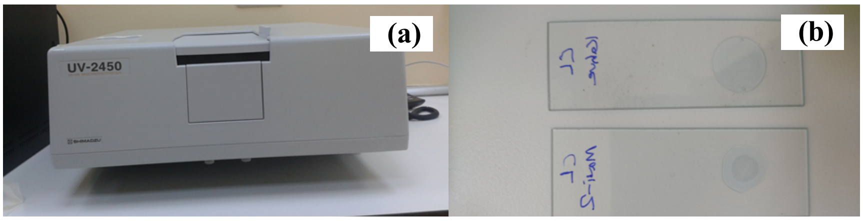

Figure 1: (a) UV-visible spectrometer used for optical absorption measurements of contact the lenses, (b) Examined lens samples

3. Results and Discussion

As can be seen from Figure 2a and b, the CLs exhibit a strong absorption in UV region (300-400 nm) and are transparent in visible region (400-700 nm). In order to determine the optical properties of the CLs; absorbance and transmission measurements were taken for determination of optical band-gap of CL materials. Optical bandgap of soft CL materials were analyzed by plotting $(\alpha h\upsilon)^2$ versus hν curve. The optical band gap of the lenses was calculated from the extrapolating of the linear portion of the curves to x-axis. Tauc plots of the CLs were obtained using Equation (1) [22,23]:

$$\alpha h\nu = A(h\nu - Eg)^n \quad (1)$$

where, α is absorption coefficient, hν is photon energy, Eg is the bandgap of the lens materials and n=1/2 for direct allowed optical band transition. After the lenses are removed from the blister package, a rapid change occurs in their physical properties depending on environmental conditions. The chemical composition, surface and mass properties of lens materials change during the dehydration process.

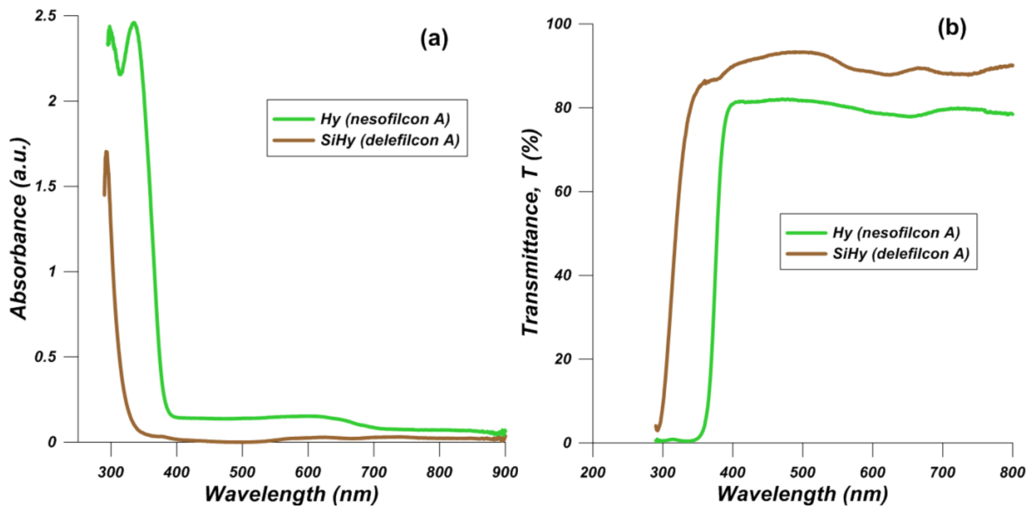

Figure 2. Absorption and transmittance variation of CLs versus wavelength (a) Absorbance - λ (nm) plots (b) Transmittance (%) - λ (nm) plots

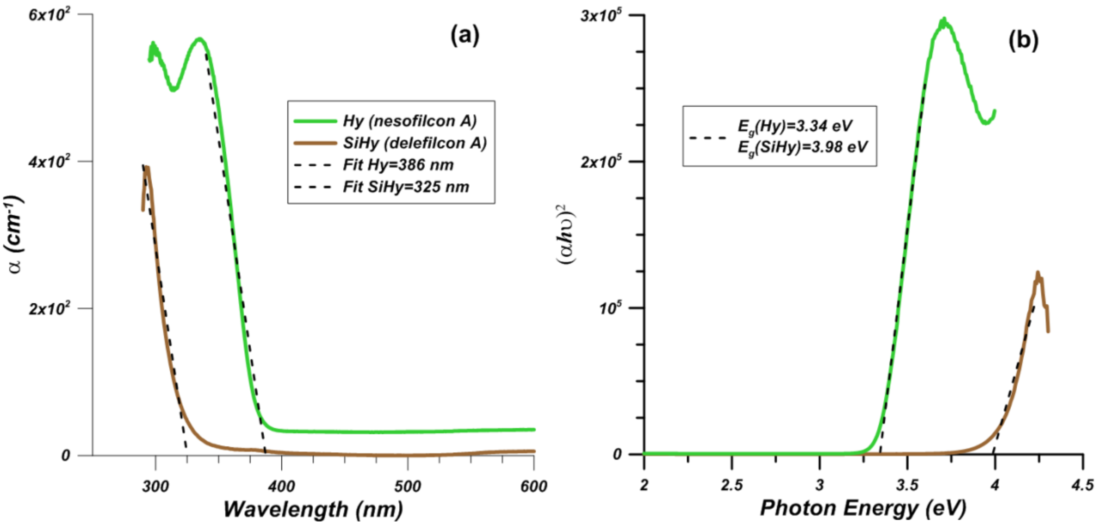

Figure 3. (a) Absorbance coefficient-wavelength plots of the CLs. (b) $\alpha(h\upsilon)^2$ versus hν curve plots of the CLs.

The two most important features of contact lenses are their water content and oxygen permeability. According to the Food and Drug Administration (FDA) classification, contact lenses typically containing less than 45% water are considered to have low water content, and lenses with a Dk value of less than 50 are considered to have low oxygen permeability. With reference to, it can be seen in Table 2 that the Nesofilcon A Hy lens (WC=78%, Dk=42) has higher water content and lower Dk oxygen permeability than the Delefilcon A (WC=33%, Dk=156) SiHy lens. CLs with Dk values below 50 were considered to have low oxygen permeability. These parameters have an impact on the optical characteristics of lenses. Since the examined lenses were produced under production conditions and methods and their chemical compositions were different, UV-Visible measurement parameters showed differences, that is, transmittance, absorption, reflection spectra, refractive index and optical band gap parameters. However, when compared with the literature, it appears that all these parameters are reasonably and compatible [1,15]. The Nesofilcon A Hy lens exhibited better UV absorption and lower transmittance and reflection characteristics in the visible region than the Delefilcon SiHy lens. Both lenses were permeable to blue light, so they could not prevent harmful UVA, UVB and blue rays from reaching the anterior and interior segments of the eye.

Table 3. Optical parameters of the examined Nesofilcon A and Delefilcon A contact lenses

CL Material	CL type	Band gap (eV)	Ref. İndex, n
Nesofilcon	Hy	3.34	1.55
Delefilcon	Si Hy	3.98	1.77

The absorption coefficient and optical band gap spectra of the lenses are given in figure 3a and b. The values of the cutting edge or absorption edge for the Nesofilcon A and Delefilcon A are 325 nm and 386 nm, respectively. These are the values at which the transmission of light begins and the optical absorption ends. Figure 2 shows that Nesofilcon A material absorbs, i.e. blocks, almost all UV light, while Delefilcon A is permeable to UV-A light. On the other hand, the band gap values were calculated by Equation (1) to be 3.34 eV for the Hy lens and 3.98 eV for the SiHy lens and are given in Table 3. If the absorption percentage of an optical material is high, the reflectance and transmittance will be low according to the A+T+R=1 rule [24]. From the reflectance spectra of the lenses in Figure 4a it can be seen that the SiHy lens has a higher reflectance characteristic. This resulted in a higher refractive index of the SiHy lens than that of the Hy lens (Fig. 4b). Equation (2) was used to calculate the refractive index of the lenses.

$$n = (1 + R^{1/2})/(1 - R^{1/2}) \tag{2}$$

Where, n is the index of refraction and R is the optical reflectance of the material. Hy and SiHy lenses reflected 4.7 % and 7.7 % of 550 nm light, respectively. The refractive index values of the lenses were calculated using formula (2) and were 1.55 and 1.77 respectively. These values are higher than the value of between 1.40 and 1.45 given by the manufacturers and in the literature [25]. A higher refractive index in contact lenses indicates that the lens is thinner and therefore may be more comfortable to wear.

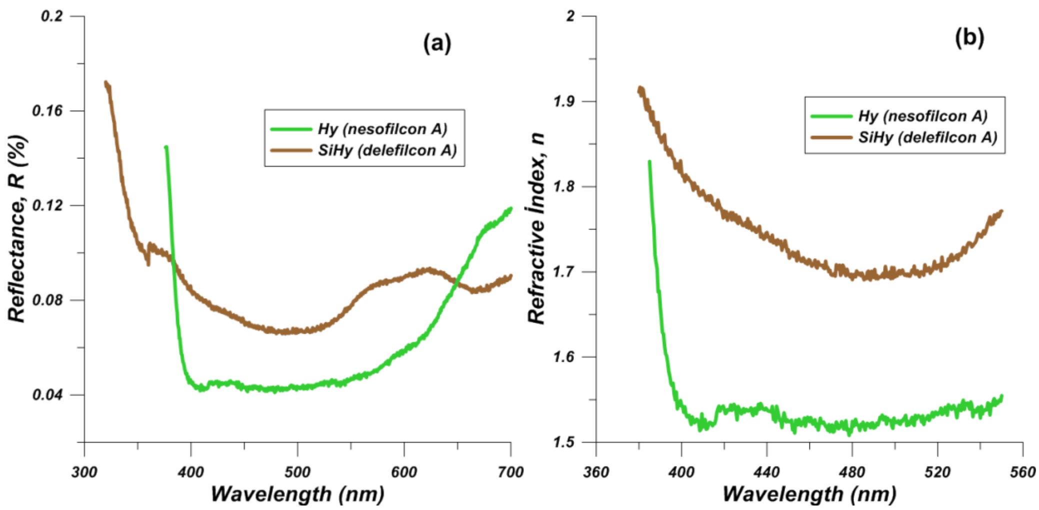

Figure 4. (a) Reflectance spectra of the contact lenses, (b) Refractive index dispersion of the contact lenses

4. Conclusion

Daily disposable soft nesofilcon A (hydrogel-Hy) and delefilcon A (silicone hydrogel-SiHy) contact lenses were optically analyzed by UV-Vis spectroscopy. The Hy and SiHy lenses showed a maximum transparency of %80 and %90 respectively in the visible region. From the optical absorption coefficient spectra of the Hy and SiHy lenses, the absorption edges were found to be 386 and 325 nm, and the optical band gap values were 3.34 and 3.98 eV, respectively. The refractive index profiles of the contact lenses were also plotted and calculated at 550 nm as 1.55 and 1.77 for Hy and SiHy, respectively. While the SiHy-Delefilcon A lens transmitted visible light well, the Hy-Nesofilcon A lens blocked UV light better and the refractive index was found to be closer to the literature values of 1.42-1.45. The nesofilcon A hydrogel contact lens was found to be relatively better at blocking UV light and its refractive index value was close to that reported in the literature.

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