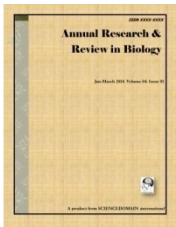

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Transmittance Properties of Contact Lens Multipurpose Solutions and Their Effects on a Hydrogel Lens

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Authors' contributions

This work was carried out in collaboration between all authors. Author ULO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FMJK and KCO managed the analyses of the study and contributed to the final draft. Authors TMA and SAA managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Purpose: The aim was to assess the compatibility of different multipurpose solutions (MPSs) with one type of silicone hydrogel (SiH) contact lens by, assessing the changes in both ultraviolet (UV) and visible light transmissibility of the hydrogel lens caused by the MPSs.
Methods: The light transmittance from 200-700 nm were measured for the lotrafilcon B blister pack solution (BPS), six MPSs namely, ReNuMultiPlus Multi-Purpose Solution (Bausch and Lomb Inc., Rochester NY, USA.); Complete RevitaLens Multi-Purpose (Abbott Medical Optics Inc., Quarryvale Co. Dublin, Ireland); All In One Light (Sauflon Pharmaceuticals Ltd., Twickenham, England); SOLO-care AQUA™ (Ciba Vision

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Corporation Duluth, Georgia, USA.); Biomedics All-in-one solution (CooperVision, Hamble, UK); and HippiaMultiPlus All-in-one solution (Interojo Inc., Kyeonggi-do, Korea), and a lotrafilcon B SiH lens (before and after storage), using a spectrophotometer.
Results: The UV transmitted through the BPS and the MPS were similar (p >.05, for all), except for the HippiaMultiPlus which was lower (p < 0.001) by 19.8%. Mean transparency values were statistically (p<.001) significantly different between the BPS and the MPSs. All MP solution/SiH lens combinations resulted in relatively high UV transmittance values especially in the UVC spectrum, and significantly increased (p <.001) the visible light transmittance values of the SiH lens. Greater changes in transparency were observed in the ReNu/SiH lens (28.5%) and the Complete RevitaLens/SiH lens (24.9%) combinations.
Conclusion: The six MPSs showed significant variations in the transmitted UV and visible light. Similar to the BPS, all MPSs were equally transparent, but showed very poor UVA & UVB attenuation, except for the Hippia MultiPlus. The MPS/SiH lens combinations did not significantly affect the lens transparency but it significant increased the lens transmittance of UV radiation, after storage. Further in-vivo studies are needed to validate if this effect is constant.

Keywords: Contact lens; Multipurpose Solution (MPS); Blister Pack Solution (BPS); ultraviolet; light transmission; electromagnetic spectrum.

1. INTRODUCTION

The last few years have seen significant improvements in contact lens (CL) solutions. From the older-generation multi-purpose solutions (MPS) which were developed for use with frequent replacement CLs, to the newer-generation MPSs, advancements have been directed at increasing the anti-microbial efficacy of the MPSs [1,2] with some having anti acanthamoeba activity [3]. MPS represent the majority of systems used for the care of soft CLs [4]. For convenience, they comprise a single solution for the rinsing, disinfection and storage of lenses. They are typically composed of surfactants and preservatives. Examples of surfactants include poloxamer and poloxamine to remove lipids, protein and debris. The solutions also contain sequestering agents such as citrate and hydranate to remove protein and calcium from the lens surface, and a buffering agent, edetate disodium (EDTA), which enhances anti-microbial activity [5]. Contrary to instructions and directions on the use of these products, compliance has remained an issue [6,7].

Many soft CL wearers experience a dry eye sensation while wearing their lenses and as was earlier noted [8] when this happens, some wearers instill the contact lens solutions into the eyes while the CL is in place. Although these solutions do not produce a lasting lubrication, it is common practice especially among patients visiting our practice.

Chronic solar UV exposure has been implicated in causing such ocular diseases as climatic droplet keratoparthy, pinguecular, cortical cataract and age related macular degeneration (ARMD) [9-11]. Ocular surface cells including corneal and conjunctival cells are frequently exposed to UV radiation, which may evoke epithelial damage, cell death, and inflammation [13,14]. Such disturbances to the patency of the corneal surface (inflammation in particular) usually affect tear film stability and lead to dry eyes, [12,13] and significant amount of high wavelength UVR has been detected in the sunlight in Saudi Arabia [14]. The different transmission and absorption properties of the ocular structures are significant in implicating which action spectra may be involved. The cornea transmits radiant energy only at 295nm and above, thus filtering the shorter wavelength UVB. The crystalline lens then absorbs almost all UVR transmitted by the cornea, with less than 1% of incident UVR transmitted to the retina. The International Commission on Non- Ionizing Radiation Protection (I.C.N.I.R.P), subdivided the UVR spectrum into three bands: UV-C (100–280 nm), UV-B (280–315 nm), and UV-A (315–400 nm) [15]. UV-B radiation has also been considered as the range 280 - 320 nm and UVA 320 – 400 nm (CIE bands) [16].

CL solutions differ in their disinfection efficacy [17,18] and were shown to alter the light transmittance of some CLs. A previous study [8] conducted decades ago using different hydrogel lenses and different solutions showed the effects of some solutions on the visible light transmission of different hydrogel lenses.

This study does set out to examine:

1. The compatibility of some of the current generation of MPSs with one type of soft contact lens in terms of light transmission
2. The effect of the MPSs on the UVR absorption characteristics of a soft CL
3. The transmittance of both the UVR and visible light of the MPSs.

2. MATERIALS AND METHODS

2.1 Test Solutions and Contact Lens

The study tested different CL MPS and a brand of contact lens before and after they were soaked in different solutions, for UV and visible light transmittance. Six multipurpose lens care solutions were randomly selected from the about 15 commercially available brands in the Saudi marketand the tested solutions were within their expiration dates, namely: ReNuMultiPlus Multi-Purpose Solution (Bausch and Lomb Inc., Rochester NY, USA.); Complete RevitaLens Multi-Purpose (Abbott Medical Optics Inc., Quarryvale Co. Dublin, Ireland); All In One Light (Sauflon Pharmaceuticals Ltd., Twickenham, England); SOLO-care AQUA™ (Ciba Vision Corporation Duluth, Georgia, USA.); Biomedics All-in-one solution (CooperVision, Hamble, UK); and Hippia Multi Plus All-in-one solution (Interojo Inc., Kyeonggi-do, Korea). The composition of the solutions tested as indicated by the manufacturers is shown in Table 1.

To assess the changes in lens transmittance induced by lens storage in different solutions over a period of seven days, CL with the following characteristics was used: lotrafilcon B, 33% water content, power ranged from -1.00 to -3.00 diopters, diameter 14.5 mm, base curve 8.6 mm, and center thickness 0.08mm. Whilst the choice of a non UV-blocking CL was based on the second aim of the study: we wanted to determine if the use of such MPSs in the relief of dry eye symptoms result in any unintended benefit in terms of the ability of this silicone-hydrogel lens to transmit UV and visible light; the choice of AIR OPTIX® Aqua CL was based on its popularity among CL wearers in the region [19] and its manufacturers extended wearing schedule meaning that wearers could store the lenses in solutions for a period of time when it's not being worn (daily wear and up to 6 nights extended wear). In this study, the CLs which were removed from the blister pack solution served as control.

Table 1. Composition of the contact lens Multipurpose (MPS) solutions

MPS solution	Manufacturer	Preservative(s)	Buffer System	Cleaning/lubricating agent	Chelating agent[a]
ReNu MultiPlus	Bausch and Lomb	0.0001% polyhexanide	Sodium borate,boricacid	Poloxamine 1%	Hydranate 0.03%(hydroxyalkyl phosphonate), EDTA 0.1%
Complete RevitaLens	Abbott Medical	0.0003%, Polyquad(polidr onium chloride), Alexidine 0.00016%	Sodium borate, boric acid	Tetronic 904	EDTA 0.1%, Citrate
All In One Light	Sauflon	0.0001%	Polyhexanide	Phosphate, Poloxamer	EDTA 0.1%
SOLO-care AQUA™	CibaVision	0.0001% Polyhexanide	Disodium hydrogenphosphate	Poloxamer 407	EDTA (0.025%)
Hippia MultiPlus	InterojoInc	0.0001% Polyhexanide	Sodium chloride,boric acid, Phosphate	Poloxamer 407Hydroxyethyl-cellulose	EDTA, Citrate
Biomedics All-in-one	CooperVision	0.0001% Polyhexanide Polyvinyl-	None	Poloxamer 0.25%, pyrrolidone PVP	EDTA 0.10%

[a]*EDTA (edetate disodium) and disodium edetate are the same chelating agent.*

2.2 Experimental Protocol

Approval was obtained from the Research Ethics Committee of College of Applied Medical Sciences, King Saud University prior to data collection. The Agilent 8453 UV-Vis spectrophotometer (Agilent Technologies, USA) was used to measure the transmittance for all CL solutions and lenses. The instrument uses a photodiode array (PDA) for simultaneous measurement of the complete ultra-violet to visible light spectrum (100 – 1100 nm) in less than one second. The PDA technique brings exceptional reliability and repeatability.[20] The instrument is equipped with a limiting aperture which restricts the light beam to the central 5 mm of the CL.

Before conducting each test, the instrument baseline was measured. For measurement of the CL solution transmissibility, three standard quartz glass cells (Human Corp., Seoul, Korea) of dimensions 12.5×12.5×45mm, were each filled with one CL solution and placed into the spectrophotometer cell holder. Triplicate measurements were obtained at 0.5 nm intervals, from 190 to 700 nm, as this waveband represents the UV-visible waveband within the electromagnetic spectrum. Therefore, for each test solution, nine transmissibility values were obtained and the averages calculated. At the end of each session, the quartz cell was emptied, washed, and air dried prior to their being filled up with a different brand of CL solution and measurements were again obtained. In all, seven measurement sessions were conducted corresponding to the six MPS CL solutions tested, and the CL blister pack solution (BPS) which served as control.

For measurement of the CL transmittance on day zero, five CLs were each removed from the blister pack using tweezers, and placed directly over the end of the aperture of the instrument with the concave surface. Triplicate measurements were again obtained from each CL, and the lenses discarded after measurement. The BPS served as blank for these measurements so that only the transmittance value of the CL was returned. The averages of the triplicate measurements were recorded for each lens, as control values for day one for that particular lens (for example, we had 5 averages, each from triplicate readings obtained by measuring transmittance of CL1, 2, 3, 4 & 5 soaked in solution 1). Subsequently, on the same day, thirty CLs were again removed from their blister packs, rinsed with the respective solutions (e.g. If it was to be soaked in ReNu, it was washed with Renu) so as to remove any remnant deposit of extra BPS and transferred into thirty CL storage cases (each five CL cases were filled with one of the six tested solutions). Twenty four hours later, thirty CLs were each removed from their respective storage solutions using tweezers, and placed directly over the end of the aperture of the instrument with the concave surface. Triplicate measurements of the lens transmittances were again obtained, the lenses were discarded, and the averages of these measurements recorded as day one values. On the second day, using the BPS as blank, measurements was again obtained from five CLs which were removed from the BPS, to serve as control for day two. Subsequently, another thirty CLs that had been stored in each of the six MPS for two days were also tested. The same procedure was repeated for days 3, 4, 5 and 6. In all, six control lenses were tested, one for each day. This condition was necessary to ensure that the lens that served as a control for each day was tested in the same conditions (in this case, the same day) as the lens that was stored in the MPSs. We discarded lenses after each measurement session rather than storing the same lens in the solutions for 6 days because of the fear of possibly altering the properties of the CLs through repeated measurements. By so doing, we ensured that when we measured a lens (for example after 2 days of storage), we were measuring the effect of only 2 days of storage, not 2 days of storage plus the effect of UV light from yesterday's measurement.

The same examiner (FK) carried out all transmittance measurements and was blinded to the brand of solution being tested and which storage solution the CL to be tested had been kept in. A second examiner (UO) who was responsible for extracting the data from the spectrophotometer also prepared the solutions and CL samples prior to measurement each day. Five CLs were used to assess the effects of solution on transmittance of the CL to ensure that values can be statistically analyzed and because CLs were samples often used by human subjects

Data was imported from the ChemStation software of the instrument into a personal computer. Using a Microsoft Excel spread sheet 2007 (Microsoft Corp. Redmond, WA, USA), the means of three measurements for each solution and the means of the five lenses stored in each solution, were calculated and used to derive the overall means and standard deviations of the measurements for all solutions within a brand and all CLs.

2.3 Data Analysis

Mean UV transmittances for the complete UV waveband, and for UVC, UVB, UVA and visible portions of the spectrum, were calculated and compared between solutions and between the stored CLs for each day and their respective controls for the same day (fresh blister pack CL). The FDA classifications define 380 nm as the upper limit of UVB, with the calculations in this study using the upper limit of 400 nm for UVB radiation as advised by the American National Standard Institute (A.N.S.I.) standard. [21]

Comparisons were made between solutions using a one-way analysis of variance (ANOVA) to establish whether a statistically significant difference existed between the UVC, UVB, UVA and visible transmittance means. A second comparison within the Lotrafilcon B tested lens was conducted by comparing the five means of the triplicate measurements obtained from each CL for each solution to ensure that there was no significant difference between them. Subsequently, the averages of the five triplicate measurements were then calculated and used for statistical analysis. A second comparison within the CL was then conducted by comparing the obtained mean transmittance of the control lens (i.e. the mean calculated from the five fresh blister pack CL) to every other mean, to establish whether the duration of lens storage in any of the tested solutions (corresponding to the recommended wearing regimen) significantly changed the transmittance values of the CL in the UVC, UVB, UVA and visible light spectrum. Further *post-hoc* test analyses were performed using *Bonferroni* and *Dunnett* multiple comparison tests, where applicable, to elicit the pairs of solutions and stored lenses where statistically significant differences existed for each of the wavebands tested. All statistical analysis was done using the Graphpad Instat software (version 3.00 – Graphpad Software Inc., San Diego, CA) and a P value < .05 (α) was considered statistically significant.

3. RESULTS

The mean UV-visible spectral curve for each brand of the CL solution tested is shown in Fig 1. The spectra for the solutions/SiH lens combination over a period of 6 days are presented in Fig. 2. The mean and standard deviations (SD) for each solution tested are shown in Table 2. The table also shows the overall means ± SD of the total UV, UVC, UVB, UVA and visible light transmittances for all seven solutions including the control solution.

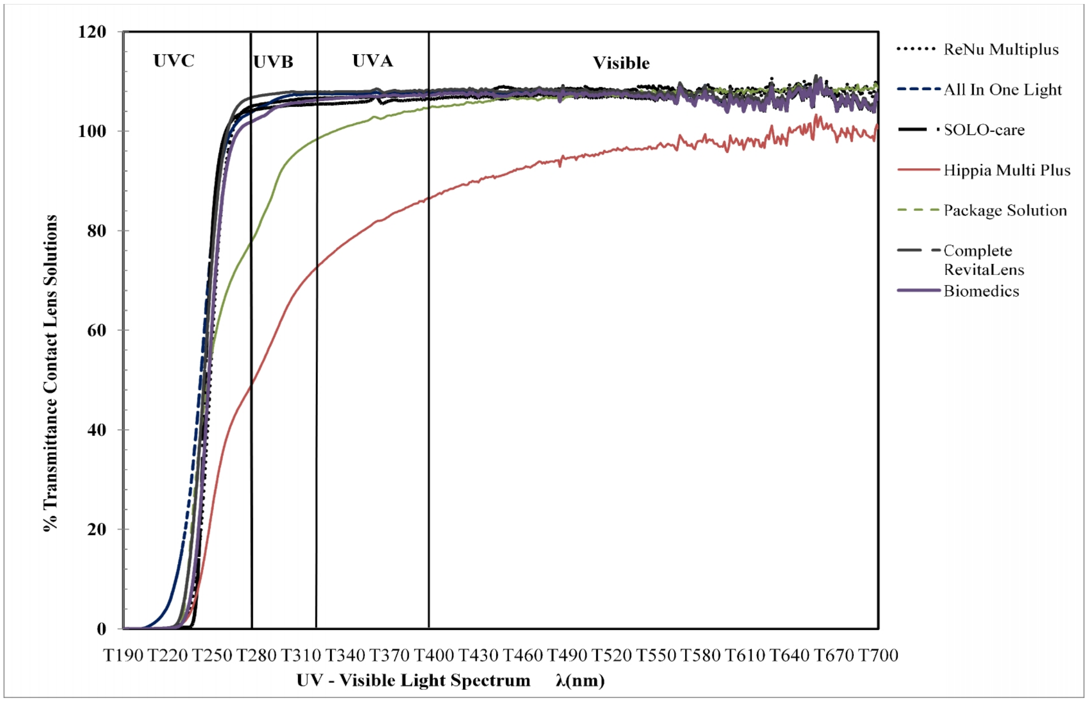

Fig. 1. Transmittance spectra (Ultraviolet (UV)-visible range) for the tested multipurpose solutions (MPSs)

Table 2 enables a comparison of the percentage transmittance of the tested solutions in each range of the radiation spectrum (UVC, UVB, UVA and visible). It can be seen that HippiaMultiPlus significantly reduced the transmission of UV across the spectrum. It transmitted only about 50% of the total UV, while the other solutions transmitted between 69% (package solution) and 80% (All in One Light) of the total UV.

3.1 Analysis of the UV-Visible Transmittances of Contact Lens Multipurpose Solutions (MPSs)

From the transmittance spectra shown in Fig 1, it can be deduced that except for the HippiaMultiPlus, all other tested MPS exhibited similar transmission spectra curves. These lenses show an overall reduction in the transmittance of UVC while transmitting almost all the incident UVB, UVA and Visible light. On the other hand, the control solution transmitted slightly less amount of UVB (90.6%). Also, the HippiaMultiPlus was able to attenuate about 84.1% of UVC, 38.0% of UVB, 19.7% of UVA and showed similar light transmission in comparison to the other MPSs in the wavelengths 400 – 700 nm. Between the tested solutions, the transmitted UVR ranged from: 15.9% to 44.1% for UVC, 62.0% to 107.6% for UVB, 80.3% to 108.0% for UVA, and 95.9% to 108.3% for visible light.

One way analysis of variance (ANOVA) showed that there were statistically significant differences in the total UV ($F_{(6,\ 1470)}$ = 13.4, *p*< .001), UVC ($F_{(6,\ 636)}$ = 4.9, *p*< .001), UVB ($F_{(6,\ 251)}$ = 947.6, *p*< .001), UVA ($F_{(6,\ 601)}$ = 2307.6, *p*< .001) and visible ($F_{(6,\ 2106)}$ = 2126.8, *P*< .001) light transmittances of the various CL solutions tested. Table 3 was drawn to show the results of *post-hoc* pairwise analysis between lens solutions where significant differences were observed. The results show that, there were statistically significant reductions in mean UV transmittance in all between-lens comparisons ($p < .001$) involving the Hippia MultiPlus solution, except between the Hippia and control solution in the UVC region where the 14% greater reduction observed did not reach a statistically significant level ($p > .05$). On the other hand, between the other tested CL solutions, mean transmittance was similar in the UVC region, but varied significantly in the UVB and UVA spectrum. In these spectra regions (UVB & UVA), the Complete RevitaLens, All in One Light, ReNu, SOLO-care Aqua and Biomedics transmitted significantly more light than the control solution ($p < .001$, for all).

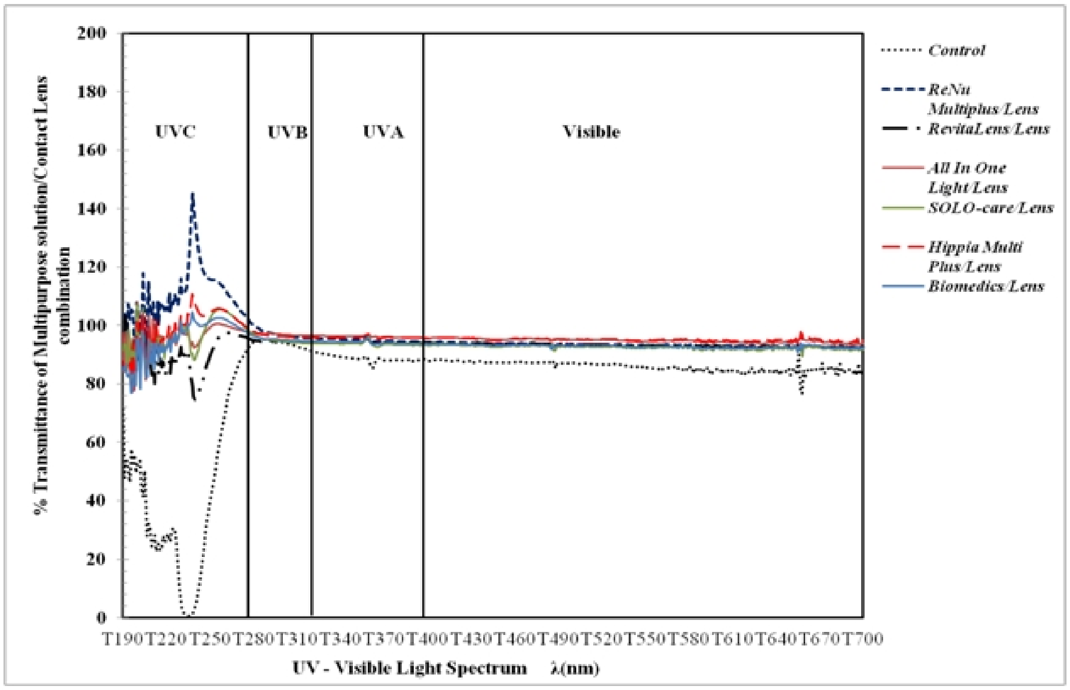

Fig. 2. Transmittance spectra (Ultraviolet (UV)-visible range) for the tested hydrogel lens after storage in, blister pack solution (control) and the six multipurpose solutions, for a period of six days

As can be observed in Fig. 1, almost all the solutions were completely transparent including the blister pack solution. There was a high but relatively uniform light transmittance of more than 96% for wavelengths longer than 400 nm among the tested solutions. Although there was a statistically significant difference in the mean transmittances between the tested solutions, *post-hoc* analysis using *Bonferonni* correction revealed that: ReNu, Complete RevitaLens, All in One Light, SOLO-care Aqua, Biomedics and control solutions transmitted statistically significantly more light than the Hippia. The corresponding mean differences (95% limits of confidence intervals) are: 12.5% (12.1 – 12.9%; $p < .001$); 11.8% (11.4 – 12.2%, $p < .001$); 11.4% (11.0 – 11.8%, $p < .001$); 10.7% (10.3 – 11.1%, $p < .001$); 11.0% (10.6 – 11.4%, $p < .001$); and 11.5% (11.1 – 11.9%, $p < .001$).

Table 2. Mean±Standard deviation transmittance values for the tested multi-purpose solutions (MPS)

CL Solutions (Multipurpose)	UVR (190 – 400nm)	UVC (190-280nm)	UVB (280 – 315nm)	UVA (315 – 400nm)	Visible (400 – 700nm)
ReNuMultiPlus	76.2±45.4	36.0±44.0	106.0±0.4	107.0±0.3	108.3±0.6
Complete RevitaLens	79.1±44.5	41.1±45.4	107.6±0.3	108.0±0.1	107.6±1.0
All In One Light	80.0±42.2	44.1±43.1	106.5±1.0	107.5±0.1	107.2±1.0
SOLO-care AQUA™	76.8±45.1	38.7±46.5	105.0±0.3	106.0±0.4	106.5±1.0
Hippia Multi Plus	49.6±32.8	15.9±19.1	62.0±6.3	80.3±4.6	95.9±3.7
Biomedics	76.1±44.7	36.3±43.0	104.8±1.2	106.9±0.3	106.9±1.1
Control	69.3±40.1	30.5±32.1	90.6±5.7	101.9±2.1	107.4±1.0

*control = blister pack solution in which the contact lenses are stored on supply.
Values are expressed in percentages (%)

Table 3. Mean difference (95% confidence interval) between contact lens solutions

Comparison	UVR (190 – 400nm)	UVC (190 - 280nm)	UVB (280 – 315nm)	UVA (315 – 400nm)
ReNu vs Hippia	20.1 (2.6 to 37.6)*	20.1 (2.6 to 37.6)*	44.0 (41.7 to 46.3)*	26.7(25.8 to 27.5)*
ReNu vs Blister	6.9 (-5.3 to 19.0)	5.5 (-12.1 to 23.0)	15.4 (13.0 to 17.7)*	5.0(4.2 to 5.9)*
RevitaLens vs Hippia	29.5 (17.4 to 41.7)*	25.2 (7.7 to 42.7)*	45.6 (43.3 to 47.9)*	27.7(26.8 to 28.6)*
RevitaLens vs Blister	9.8 (-2.4 to 21.9)	10.6 (-7.0 to 28.1)	17.0 (14.7 to 19.2)*	6.1(5.2 to 6.9)*
All in One Light vs Hippia	30.4 (18.3 to 42.6)*	28.2 (10.7 to 45.8)*	44.5 (42.2 to 46.8)*	27.2(26.4 to 28.1)*
All in One Light vs Blister	10.7 (-1.5 to 22.8)	13.6 (-3.9 to 31.1)	15.8 (13.5 to 18.1)*	5.6(4.7 to 6.5)*
SOLO-care vs Blister	7.5 (-4.7 to 19.6)	8.2 (-9.3 to 25.7)	14.3 (12.0 to 16.6)*	4.0 (3.1 to 4.9)*
Biomedics vs Hippia	26.5 (14.4 to 38.7)*	20.4 (2.9 to 37.9)*	42.8 (40.5 to 45.1)*	21.6 (25.7 to 27.5)*
Blister vs Hippia	19.8 (7.6 to 31.9)*	14.6 (2.9 to 32.2)	28.7 (26.4 to 31.0)*	21.6 (20.8 to 22.5)*
Biomedics vs Blister	6.8 (-5.4 to 18.9)	5.8 (-11.8 to 23.2)	14.1 (11.8 to 16.4)*	4.9 (4.1 to 5.8)*

**Difference significant for α = 0.05; Blister = Contact lens storage solution which is contained in the blister pack.*
Values are expressed in percentages (%)

3.2 Analysis of the Effect of Solution on UV-visible Light Transmittance of Lotrafilcon B Lens

The total UVR, UVC, UVB and UVA transmitted by the control lens (the CL that was removed from the blister pack and tested on day zero) of the lotrafilcon B CLs (a non UV-blocker) were; 71.5±29.2%, 46.3±29.0%, 95.1±1.2% and 88.8±1.7%, respectively. The lens also transmitted 84.2±2.0% of visible light incident on its surface.

Fig. 2 show the transmittance spectra curves of the tested CLs before (control) and after they have been stored for six days in: ReNuMultiPlus, Complete RevitaLens, All In One Light, SOLO-care AQUA™, Hippia Multi Plus and Biomedics All-in-one, MPS respectively. From the figure, it can be observed that the transmittance spectra curve of solution/SiH lens combination showed similarity across the UVB, UVA and visible light region, but differed in the UVC region. In that region, the spectra curves showed various undulating patterns, indicating a possible solution-high energy UV light interaction. The overall mean ± SD of transmitted UVC, UVB, UVA and visible light for the tested SiH lenses after 6 days of storage in the different solution shown in Table 4 revealed that, all the MPSs enhanced the transmission of visible light through the tested CLs.

Results of one way ANOVA showed that the SiH lens transmittance values in the UVC ($p < .001$), UVB ($p < .001$), UVA ($p < .001$) and visible light ($p < .001$) regions, were statistically significantly modified after they have been stored in ReNuMultiPlus, Complete RevitaLens, All In One Light, SOLO-care AQUA™, Hippia Multi Plus and Biomedics All-in-one, for six days (Table 4). Despite the statistical significant differences observed across the wavebands on analysis, these differences were greater only in the UVC (transmission in this region is clinically irrelevant) and visible light spectrum. *Post-hoc* (Dunnett multiple comparisons) analysis showing the day to day solution/ SiH lens transmission fluctuation is shown in Table 5. In relation to the control lens, greater changes in the UV-transmittance of the SiH lens was observed on the second and fifth days, with the ReNu/SiH lens and Complete RivitaLens/SiH lens combination resulting in the largest increases in UV-transmission.

Table 6 shows the results of similar *post-hoc* analysis conducted to assess the effects of the solutions on the CL translucency. It showed that, greater increases were observed on the second and fifth day, while the greatest reduction occurred on the fourth day. The ReNu/SiH lens and the Complete RevitaLens/SiH lens combinations resulted in an increase of about 28.5% and 24.9% in relation to the control lens.

Table 4. Mean transmittance values before (blister pack solution/lens = control) and after storage in the different MPSs, results of one way measures ANOVA

CL Solutions (Multipurpose)	UVR (190 – 400nm)	UVC (190 - 280nm)	UVB (280 – 315nm)	UVA (315 – 400nm)	Visible (400 – 700nm)
ReNuMultiPlus					
Control	71.5±29.2	46.3±29.0	95.1±1.2	88.8±1.7	84.2±2.0
After Storage	101.8±7.7	109.9±10.0	97.2±1.2	95.1±7.5	93.4±10.9
Complete RevitaLens					
Control	66.9±29.2	40.7±27.6	90.4±0.8	85.3±1.5	81.6±2.0
After Storage	92.6±7.3	90.4±10.3	94.6±5.4	94.2±7.3	93.3±10.0
All In One Light					
Control	72.2±30.6	44.7±28.9	96.5±0.8	91.6±1.3	89.5±1.3
After Storage	96.3±7.5	96.1±9.2	97.0±6.3	96.2±8.1	94.8±10.1
SOLO-care AQUA™					
Control	69.3±29.9	44.7±28.6	92.8±1.0	88.0±1.2	85.2±1.7
After Storage	95.2±6.8	96.8±8.1	94.9±5.9	93.7±8.0	92.5±10.6
Hippia Multi Plus					
Control	71.6±30.3	44.6±29.0	95.1±0.9	90.9±0.9	89.2±1.2
After Storage	97.2±6.6	98.7±10.2	96.6±4.7	96.0±6.5	95.2±9.2
Biomedics					
Control	89.6±30.0	43.4±28.6	94.4±0.9	88.9±1.5	85.6±1.6
After Storage	94.9±5.5	95.5±7.8	95.3±4.6	94.2±7.2	92.9±10.0

P<0.0001 for all comparisons and are results of one way Analysis of variance (ANOVA) comparing transmittance values of control Contact lens (day zero) versus contact lens stored in each solution for day one, day 2, day 3, day 4, day 5 and day 6, in each spectra waveband. Values are expressed in percentages (%)

Table 5. Limits of confidence intervals of the mean difference between total UV-transmitted through the control/lens and multipurpose solutions/lens combinations, for days one – six

95% Limits of confidence interval in total UVR transmittance of CL (control minus solutions) in percentages (%)						
Solution Brands	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
ReNuMultiPlus	-0.7 to 0.9	-10.0 to -8.4*	-1.8 to -0.2*	-0.2 to 1.4	-17.5 to -15.9*	-4.9 to -3.3*
Complete RevitaLens	-4.1 to -3.0*	-17.2 to -16.1*	-4.8 to -3.7*	-0.4 to 0.7	-15.5 to -14.4*	-6.5 to -5.4*
All In One Light	2.5 to 3.6*	-14.9 to -13.8*	-0.7 to 0.4	2.7 to 3.8*	-11.9 to -10.9*	-1.6 to -0.5*
SOLO-care AQUA™	-1.7 to -0.5*	-15.6 to -14.4*	-0.3 to 1.5*	2.1 to 3.3	-13.1 to -11.9*	-3.3 to -2.2*
Hippia Multi Plus	-0.6 to 0.6	-12.8 to -11.7*	-2.7 to -1.5*	2.9 to 4.0*	-10.1 to -8.9*	-4.5 to -3.4*
Biomedics	-3.5 to -2.2*	-14.5 to -13.2*	-3.2 to -1.9*	1.5 to 2.7	-10.1 to -8.8*	1.8 to 3.0*

**Difference significant for α = 0.05. Results of post hoc analysis of one way Analysis of variance (ANOVA) using Dunnett Multiple Comparisons Test between control Contact lens (day zero) and contact lens stored in each solution at day 1 to day 6, in the entire UV spectrum excluding UVC (200nm – 400 nm)*

Table 6. Mean Difference (95% Limits of confidence interval) between visible light transmitted through the control/lens and multipurpose solution/lens combinations, for days one – six

Mean Difference (95% Limits of confidence interval) in Visible light transmittance of CL (control minus solutions)						
Solution Brands	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
ReNuMultiPlus	-3.8(-4/-4)*	-15.4(-16/-15)*	-3.0(-3/-3)*	0.4(-0/1)*	-28.5(-29/-28)*	-4.6(-5/-4)*
Complete RevitaLens	-7.0(-7/-7)	-23.2(-23/-23)*	-5.8(-6/-6)	-0.2(-0/-0)	-24.9(-25/-25)*	-8.9(-9/-9)*
All In One Light	2.1(2/2)*	-19.6(-20/-19)*	-0.8(-1/-1)*	3.2(3/3)*	-17.0(-17/-17)*	-0.2(-1/0)
SOLO-care AQUA™	-2.9(-3/-3)*	-19.6(-20/-19)*	0.4(0/1)*	3.5(3/4)*	-21.5(-22/-21)*	-3.4(-4/-3)*
Hippia Multi Plus	-1.3(-2/-1)*	-16.3(-17/-16)*	-3.2(-4/-3)*	5.5(5/6)*	-17.8(-18/-18)*	-2.6(-3/-2)*
Biomedics	-5.5(-6/-5)*	-19.9(-20/-20)*	-5.3(-6/-5)*	1.9(2/2)*	-18.7(-19/-18)*	2.5(3/4)*

**Difference significant for α = 0.05. Values are expressed in percentages (%)*

4. DISCUSSION

4.1 UV-Visible Transmittances of Contact Lens Multipurpose Solutions (MPSs)

We tested several different CL multipurpose solutions from different manufacturers and observed that, just as there are differences in the rate of disinfection efficacy of CL solutions, [2,17,22] there are also differences in their transmission of UVR and visible light. All the tested MPSs significantly attenuated radiations in the UVC spectrum similar to the BPS. But in comparison to the other MPSs, the HippiaMultiPlus performed the best by attenuating on the average 28.2 %, 25.2%, 20.4%, and 20.1% significantly more UVC than All In One Light, RevitaLens, Biomedics, and RenuMPs, respectively. It transmitted statistically similar amount of UVC with SOLO-care Aqua. However, protection from radiation in this spectra waveband may not be clinically relevant because, only an insignificant amount actually reach the earth's surface due to the filtering effects of the ozone layer [23].

In the UVA and UVB regions of the spectrum, with the exception of the Hippi MultiPlus, all other MPSs transmitted the entire radiation in these spectra waveband, while BPS showed a minimal attenuation of about 10% in the UVB spectrum. On the contrary, the Hippia MultiPlus significantly attenuated UVA (38%) and some amount of UVB (19.7%) making it the only solution with attenuating properties in these spectra waveband. Whereas all other MPSs transmitted significantly more UVB and UVA in comparison to the control solution, the HippiaMultiPlus attenuated significantly more UVB (28.7%) and UVA (21.6%) than the control. Considering the fact that appreciable amounts of potentially carcinogenic short UV wavelengths has long been reported to be present in the sunlight in Riyadh,[14] and the continuous constant depletion of the ozone layer, [11] protection from this wavelength of radiation is beneficial. However, the attenuating effect of Hippia MultiPlus occurs only on storage but while the lens is on the eye, there may not be any solution transferred except for a minimal amount of time since biocides are absorbed by the lens but not the entire solution. In the light of this, it cannot be said that any MPS is capable of transferring its UV-attenuating property to the contact lens when worn on the eyes.

In addition, as a requirement during the nonclinical/preclinical testing of CL MPSs, [24] all MPSs are to be completely transparent. The study also observed that, all the tested MPSs, including the BPS, were completely transparent. Within the MPSs, the mean transmittance value in the visible light spectrum exceeded 100% for all MPSs and about 90.6% for the BPS. The fact that the transmittance values exceeded 100% especially at certain wavelength could only be attributed to the solutions' excited reactivity with the light within those wavelengths, though these was also less noticeable in the Hippia MultiPlus, a subject that demands further study.

4.2 Effect of Multipurpose Solutions (MPSs) on Transmittance Values of a Silicone-hydrogel CL

We investigated the CLs stored in different MPSs to determine any change in the ability of the lens/solution combination to transmit UV and visible light. The results show that, the amount of UVR transmitted through the hydrogel CLs increased significantly after 6 days of storage in the different MPSs. Whereas this increase was statistically significant across the three UV wavebands (*p<.0001* for all), it was only considered to be clinically significant in the UVC spectrum, because in that spectra band it transmitted an average of 52% more radiation than the control lens. Concerning the Hippia MultiPlus which showed an exceptionally good attenuation of UVR in the first experiment when the solution only was tested, the SiH/solution combination resulted in a statistically significant increase in transmitted UVR ranging from 17.5 to 28.7%, in relation to control CL showing the inability of the MPS to transfer its UV attenuating property to the CLs stored in it. However, lenses that were stored in ReNuMultiPlus showed the greatest increase in UVR transmission by reaching 39.5% in relation to the control lens. The observed differences in UV transmittance of the CL after storage in various MPSs are due to the differences in the chemical composition of MPSs as shown in Table 1.

On the other end of the spectrum, the transparency of the control lens was slightly less than the >96% transparency claimed by the manufacturers of the lotrafilcon B lens (Ciba Vision) used in the experiment, a result that corroborates with the value (83.90%) reported in a previous study which analyzed this lens before and after been worn. [25] The methodology utilized in this experiment may have differed from that which the manufacturers use in testing the transparency of the CLs, and as such could account for the slight variation in lens transmittance values reported here. However, the lens transparency was statistically significantly improved from between 81.6% and 89.5%, to between 92.9% and 94.8%, after storage in the different MPSs. In a previous report more than 2 decades ago, [8] incubating different CL materials in Ultra Tears (an artificial tear preparation) for 6 months resulted in a statistical significant decrease in light transmission and a small but non-statistical significant decrease was observed when other artificial tear preparations such as Murotears, Tears Plus, hypo tears and an anti allergic preparation (Opticrom 4%) were used to incubate the lens. The study therefore concluded that the use of compatible solution/hydrogel combinations produce no alteration in the ability of the hydrogel lens to transmit visible light. However, contrary to the current study, the previous study [8] utilized hydrogel lenses of different materials, ophthalmic solutions not including MPSs, and they incubated the lenses for a period of 6 months which was much longer than that used in the current study (6 days).

We have shown that, aside from the reported differences in the disinfection characteristics of MPSs, their transmittance properties in the UV and visible light spectrum also varies significantly. Although unlike the true clinical situation, our in vitro storage of SiH CL in various MPSs for six days was done to determine whether the transmittance of the lens material would be significantly affected. We did not investigate the possible binding of the solutions to the SiH materials which may have occurred looking at the transmittance values observed at some wavelengths. Attempts at removing any solution remnant on the stored lenses using normal saline was not done in this study because we needed to assess only the effect of tested solutions on CL transmittance values

4.3 Study Limitations

The measurement of UVC in this study and the result that Hyppia MultiPlus adds some additional UVR protection to CLs, may be of interest to practitioners and CL wearers in our region. Although, the absorption by the ozone layer ensures that the radiation in the UVC region is cut off, this layer is under constant depletion predisposing humans to short wavelength radiations which have already been detected in the sunlight in our region.[14] However, the current study is limited by the fact that only one CL material have been studied and thus, caution is advised in the interpretation of the current findings in relation to other CL materials and in cases of known UV-blocking CLs. More importantly because the results cannot be extrapolated in a real life scenario since these solutions properties are not transferred when the lenses are worn (solution adsorbed is rapidly washed away) and only UVCs are really affected by one solution. A similar study on different CLs materials is being undertaken in our laboratory. Again, contact lens MPSs in general provide disinfection and hydrated storage of lenses as their intent is not providing UVR protection. It remains unclear how long the UV protection afforded by the contact lens solution studied here would last when the lenses are worn. Further in vivo studies are needed to verify this. In the mean time, the study has shown for the first time that the transmittance properties of the various MPSs vary significantly, a finding that can be used by manufacturers in modifying the transmittance properties of the MPSs, even as debate on UV protection heats up.

5. CONCLUSION

The transmission in the 200-700 nm wavelengths varied significantly across contact lens MPSs. While other tested MPSs attenuated significant amounts of UVC, the Hippia MultiPlus attenuated significantly more UVB (38%) and UVA (19.7%), than the control solution. All the solution/ SiH lens combinations resulted in a statistically significant increase in transmitted UVR and visible light, after storage. The Hippia MultiPlus solution/SiH lens combination increased the transmitted UVR by between 17.5% and 28.7%, while this increase reached 39.5% in the ReNuMultiPlus solution/SiH lens combination. The findings of this study does not in any way suggest that MPSs should be avoided and/or that one should be favored than others, rather it provides new information that could be used by manufacturers in enhancing the transmissibility properties of the MPSs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Buck SL, Rosenthal RA, Schlech BA. Amoebicidal activity of multipurpose contact lens solutions. Eye & Contact Lens: Science & Clinical Practice. 2005;31(2):62-66.
2. Santodomingo-Rubido J, Mori O, Kawaminami S. Cytotoxicity and antimicrobial activity of six multipurpose soft contact lens disinfecting solutions. Ophthalmic & Physiological Optics. 2006;26(5):476-482.
3. Rosenthal RA, Dassanayake NL, Schlitzer RL, Schlech BA, Meadows DL, Stone RP. Biocide uptake in contact lenses and loss of fungicidal activity during storage of contact lenses. Eye & Contact Lens: Science & Clinical Practice. 2006;32(6):262-266.
4. Efron N, Morgan PB. Soft contact lens care regimens in the UK. Contact Lens & Anterior Eye. 2008;31(6):283-284.
5. Dalton K, Subbaraman LN, Rogers R, Jones L. Physical properties of soft contact lens solutions. Optometry & Vision Science. 2008;85(2):122-128.
6. Hart DE, Shih KL. Surface interactions on hydrogel extended wear contact lenses: microflora and microfauna. American Journal of Optometry and Physiological Optics. 1987;64(10):739-748.

7. Rakow PL. Current contact lens care systems. Ophthalmology Clinics of North America. 2003;16(3):415-432.
8. Bergen G, Slonim CB. The effects of ophthalmic solutions on the transmission of light through hydrogel lenses. Contact Lens Association of Ophthalmologists. 1990;16(2):114-116.
9. Pitts DG, Cullen AP, Hacker PD. Ocular effects of near ultraviolet radiation: Literature review. Am J Optom Physiol Opt. 1977;54:542–549.
10. Bergmanson JP, Söderberg PG. The significance of ultraviolet radiation for eyediseases. A review with comments on the efficacy of UV-blocking contact lenses. Ophthalmic Physiol Opt. 1995;15:83–91.[Review].
11. Ayala MN, Michael R, Söderberg PG. *In vivo* cataract after repeated exposure to ultraviolet radiation. Exp Eye Res. 2000;70:451–456.
12. Lu L, Wang L, Shell B. UV-induced signaling pathways associated with corneal epithelial cell apoptosis. Invest Ophthalmol Vis Sci. 2003;44(12):5102-9.
13. Gaton DD, Lichter H, Avisar I, Slodonovic D. Solomon As. Lymphocytic reaction to ultraviolet radiation on rabbit conjunctiva. Ann Ophthalmol (Skokie). 2007;39(2):128-33.
14. Hannan MA, Paul M, Amer MH, Al-Watban FH. Study of ultraviolet radiation and genotoxic effects of natural sunlight in relation to skin cancer in Saudi Arabia. Cancer Research. 1984;44(5):2192-2197.
15. International Commission on Non-Ionizing Radiation Protection. Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation). Health Physics. 2004;87(2):171-186.
16. Harris MG, Chin RS, Lee DS, Tam MH, Dobkin CE. Ultraviolet transmittance of the Vistakon disposable contact lenses. Cont Lens Anterior Eye 2000;23(1):10-15. Erratum in: Cont Lens Anterior Eye 2000;23(3):104. Dobkins, CE [corrected to Dobkin, CE].
17. Amiri MA, Mohammadinia M, Tabatabaee M, Askarizadeh F, Behgozin A. Comparative efficacies of contact lens disinfecting solutions against *Pseudomonas aeruginosa.* Clinical & Experimental Optometry. 2011;94(4):348-351.
18. Kilvington S, Huang L,Kao E,Powell CH. Development of a new contact lens multipurpose solution: Comparative analysis of microbiological, biological and clinical performance. Journal of Optometry. 2010;3(3):134-142.
19. Abahussin M, Alanazi M, Ogbuehi KC, Osuagwu UL. Prevalence, use and sale of contact lenses in Saudi Arabia: Survey on university women and non-ophthalmic stores. Cont Lens Anterior Eye; 2013. doi: 10.1016/j.clae.2013.10.001. [Epub ahead of print].
20. Agilent technology. Available: http://www.chem.agilent.com/en-US/products-services/Instruments-Systems/Molecular-Spectroscopy/8453-UV-Vis-Diode-Array System/Pages/default.aspx.
21. American National Standards Institute ANSI Z80.20-2010. Ophthalmics - Contact Lenses - Standard Terminology, Tolerances, Measurements and Physicochemical Properties. Available: http://www.nssn.org/search/IntelSearch.aspx
22. Mohammadinia M, Amiri MA, Delavari F, Yousefzadeh B, Maymeh MH. Antifungal efficacy of soft contact lens disinfecting solutions against *Fusarium solani* and *Candida albicans.* Clinical & Experimental Optometry. 2012;95(2):207-211.

23. Moore L, Ferreira JT. Ultraviolet (UV) transmittance characteristics of daily disposable and silicone hydrogel contact lenses. Cont Lens Anterior Eye. 2006;29(3):115-122.
24. Gleason WJ. Understanding Microbiology and Contact Lens Solutions: Learn how a greater knowledge of microbiology has helped improve the safety and efficacy of contact lenses, solutions and accessories. Vision Care education, 2010. Contact lens spectrum; 2009. Available: http://www.visioncareeducation.com/no-feece/course8.asp
25. Lira M, Dos Santos Castanheira EM, Santos L, Azeredo J, Yebra-Pimentel E, Real Oliveira ME. Changes in UV-visible transmittance of silicone-hydrogel contact lenses induced by wear. Optom Vis Sci. 2009;86(4):332-339.

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