



Videokeratoscopic assessment of silicone hydrogel contact lens wettability using a new in-vitro method



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ABSTRACT

Purpose: The aim of the study was to assess the surface wettability of new-generation silicone hydrogel (SiH) contact lenses (CLs) videokeratoscopically using a new in-vitro method under office conditions.

Method: Videokeratoscopic methodology was used to compare time-dependent CL wettability on an in-vitro cornea model. The model cornea was a polished chrome surface coating a Teflon form. It was prepared with a base curve of 8.7 mm and a diameter of 15 mm. Laboratory temperature and humidity were controlled. Before and after placing CLs on the model cornea, Bausch + Lomb Biotrue® multi-purpose solution (MPS) was dropped to simulate the pre-lens and post-lens film layer. Fanfilcon A, Senofilcon A, Samfilcon A, and Lotrafilcon B CLs with -3.00D were used, and images were taken with the videokeratoscopic method for testing. In the control group, the same procedure was performed without placing CLs. The images of CLs at 0, 60, 90, 120, 150, and 180 s were taken. Distortions and gaps seen in rings were recorded. The areas in rings were calculated in pixels using ImageJ.

Results: When CLs were examined, statistical differences were found among average pixel values ($p < 0.001$). The average pixel value was 131877.4 in the Samfilcon group, 116125.5 in the Senofilcon group, 137893.2 in the Fanfilcon group, 125578.3 in the Lotrafilcon group, and 124984.6 in the control group. No difference was found between the average values of the Lotrafilcon group and the control group. Differences were found between the average values of all other groups.

Discussion: The results obtained showed that videokeratoscopy was an effective method for in-vitro testing of CL wettability. It was found that SiH lenses displayed different performance under office conditions depending on materials and technologies used for wetting the lens surface. It was shown that lens surface wettability could be measured with a repeatable and new method when the factors affecting surface wetness and image quality were ruled out.

1. Introduction

Although clinicians are choosing the most suitable contact lenses (CLs) for their patients in terms of various factors such as corneal geometry, CL material, refraction defects, personal priorities, and lens wearing habits, they cannot change some factors such as pre-corneal tear layer and lens wettability [1–3].

CL wettability is a concept that can be measured when liquid-air surfaces form in solid areas and, it depends on intermolecular attraction [4,5]. Pre-lens tear film on the CL surface provides a consistent wetness, good vision, comfort, and lubrication [3]. While non-invasive in-vivo methods such as interferometry [6,7], Tearscope [8], and slitlamp biomicroscope [9] are used to show wettability, in-vitro studies have been conducted with Axisymmetric Drop Shape Analysis (ADSA) [10], a

captive-bubble technique [11], adherent liquid/laser method (ALLM), adherent liquid/balance method (ALBM) [4], keratography [12], and spectral domain optical coherence tomography (SD-OCT) [13] methods. In CL surface and tear studies conducted in individuals using in-vivo videokeratoscopic methods, pupil diameter, tear quality, eyelash and eye movements [14], gravitational movement of tears, evaporation depending on palpebral fissure [15], and the mechanical influence of the palpebra can affect the results [1]. Placido discs used in keratoscopic methods are reflected on the surface functioning as a mirror and enable the detection of changes on the surface. The area examined with the keratoscopic method is wider than that examined with the other methods. Examination can be made from the corneal apex to the peripheral area [16]. In addition, keratoscopic methods provide better information for surface quality dynamics [17].

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Silicone hydrogel (SiH) CLs have been shown to have decreased surface wettability since they have hydrophobic features [5,8]. To overcome this problem, manufacturers have added moisturising components on the CLs. The surface characteristics of CLs are altered by surface plasma treatment and incorporating hydrophilic wetting agents, which make the CLs more hydrophilic and wettable. The surface treatment can be achieved by plasma oxidation or plasma activation. To increase hydrophilicity, an internal wetting hydrogel monomer such as polyvinyl pyrrolidone or hydroxyethyl methacrylate is needed [18]. In some studies examining CL wettability, topographic images have been used [15,19]. While pre-lens tear film is always associated with the underlying CL, pre-corneal tear film is influenced by the features of the individual's anterior cornea [2]. The aim of the present study, was to present CL wettability with quantitative data by using a new image processing program. This study was planned with an experimental cornea model to show surface wettability more accurately by removing all the factors related to the individual.

2. Material Method

2.1. Preparing the system

The CSO® (Costruzione Strumenti Oftalmici, Firenze, Italy) videokeratoscopic device can catch 24 frames in one second. This device was used to compare CL wettability on an in-vitro cornea model. The device used Phonic V 2.5 software had 24 Placido discs. The artificial cornea model was prepared from Teflon with a base curve (BC) of 8.7 mm and diameter of 15 mm (Fig. 1). To observe the topographic rings more clearly, material made from chrome was placed on the Teflon model. Minimal irregularities on the chrome model were removed with ultrasonic polishing.

To simulate office conditions, the laboratory temperature was adjusted to $24\text{ }^{\circ}\text{C} \pm 1.0\text{ }^{\circ}\text{C}$ and a humidity of $55\% \pm 5\%$. New-generation SiH lenses such as Fanfilcon A, Senofilcon A, Samfilcon A, and Lotrafilcon B were tested (Table 1). For each group of material, five CLs were tested separately. Since the references CLs used in previous wettability and oxygen permeability studies were -3.00D , the same dioptre lenses were used in this study. In the control group, the tests were performed without placing on CLs. Thus, the change pattern on models and how surface dryness occurred without CLs were observed. The tests were performed five times to decrease the fluctuations in images for each CL group and the control group.

2.2. Preparing the lenses

After the CLs were taken out of their blister packs and the lens solution inside was removed, they were washed with 0.9% preservative-free saline for 30 s to remove potential ions and surface contents from the lens surfaces. Next, they were kept in different containers in saline water for 12 h. Thus, the CLs were well absorbed in saline. As the last step, after they were washed with preservative-free saline again, they were kept for 12 h in a different container with Bausch + Lomb Biotrue® multi-purpose solution (MPS) (Bausch & Lomb, Rochester, NY,

USA). Care was taken not to exceed time in the aforementioned processes. The purpose was to remove the effect of different contact lens solutions in the blister packs.

Later, when the CLs were being kept in the container, the model cornea apparatus was slowly being lowered vertically to the container including the CL. Since the model cornea approached the CL, the post-lens tear film formation was made up of capillary attraction. It was seen that when the model cornea came closer to the CL without applying any pressure, the CL stuck to the model. Next, the model cornea was installed in front of the videokeratoscope, a change from its previous vertical position.

To simulate pre-lens tear film on the cornea, two drops of Biotrue® MPS were dropped on the cornea model after the CLs were placed. Another researcher removed the extra fluid that gathered on the lower edge of the model with an eye sponge (BD Visispear™ Eye Sponge, Beaver-Visitec International, MA, USA). The same Biotrue® multi-purpose solution was dropped directly on the cornea model in the control group. The images of the rings reflecting stability and homogeneity at first later began to deteriorate due to drying on the CL surface.

2.3. Image analysis

Images in TIFF format at 0, 60, 90, 120, 150, and 180 s were obtained from videokeratoscopy videos. The images taken were analysed by an independent researcher. ImageJ software (ver. 1.46 r) was used for the analysis. The threshold feature of the program was used for both the control group and CL groups. Using the white tone areas in the keratoscope images as a reference, all colour changes from white to black were recorded in pixels. Since the white tone is tracked, both tone changes and area changes in the distortions in black rings change the white ring areas. In addition, the areas and colour changes in black rings were also recorded. All of these changes were analysed with ImageJ software. Since changes in these areas were not clean-cut geometrical shapes, the results were given in pixels instead of mm^2 . While no distortion was seen in the control group, differences in tone were seen in black and white rings on the surface (Fig. 2).

Two black and white rings between the outermost videokeratoscopic images were not assessed due to decentralisation of lenses, because of fluid accumulation below, and the brands of lenses were noted. Toric lenses and multifocal contact lenses were not included in the study.

2.4. Statistical method

The data were analysed with IBM SPSS V23. The Shapiro-Wilk test and skewness and kurtosis values were analysed to assess the normally distributed data. In the comparisons of average values in terms of lenses, one way analysis of variance (ANOVA) and multiple comparisons test using Tamhane's T2 were used. Analysis results were presented as average \pm standard deviation (SD). $p < 0.05$ was taken as the level of significance.

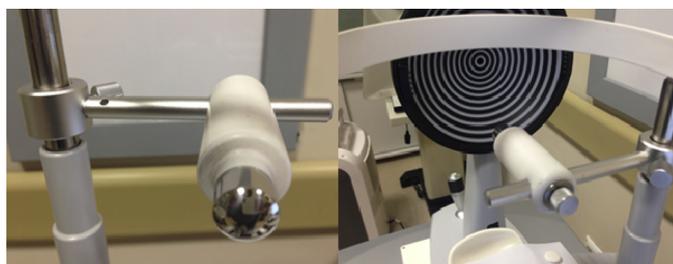


Fig. 1. Artificial cornea model (A) Teflon-chrome material, (B) Setting up on keratoscope.

Table 1
The characteristics of the lenses used in the study.

	Fanfilcon	Samfilcon A	Senofilcon A	Lotrafilcon B
Water content (%)	55	46	38	33
Center thickness at -3.00 D	0,06	0,07	0,07	0,08
Diameter, mm	14,2	14,2	14,0	14,2
Base Curve, mm	8,40	8,50	8,40	8,60
Refractive Index @ 20oC	1,40	1,41	1,42	1,42
Specific Gravity g/mL	1,026	1,048	0,98-1,12	1,080
Oxygen Permeability [11] ^a	90	163	147	138
Wetting agent	None	PVP	PVP	HydraGlyde technology > *
Principal monomers	PDMS+MMA+ VMA	NVP +siloxane copolymer	mPDMS + DMA+ HEMA + siloxane macromer + TEGDMA + PVP	DMA + TRIS +siloxane macromer

Obtained from Food and Drug Administration, **PVP**, polyvinyl pyrrolidone **DMA** N, N-dimethylacrylamide; **PDMS**, polydimethylsiloxane + methacrylated (MMA); **HEMA**, poly-2-hydroxyethylmethacrylate; **MA**, methacrylic acid; **NVP**, N-vinyl pyrrolidone; TPVC, **TRIS**-(trimethylsiloxysilyl) propylvinyl carbamate; **TEGDMA**, tetraethyleneglycol dimethacrylate **mPDMS**, monofunctional polydimethylsiloxane, **VMA**, vinylmethyl acetamide.
Dk units: $\times 10^{-11} \text{ (cm}^2/\text{sec} \times \text{mL O}_2\text{)/(mL} \times \text{mm Hg)}$.

3. Results

Although the control group did not have lenses, it was found that at the moment Biotrue® MPS was dropped, it immediately gathered in the lower edge of the cornea model due to gravity. While extra Biotrue® multi-purpose solution was removed with an eye sponge, an increase in pixel was seen gradually due to drying up on the surface. This increase in the tone difference of colours in black and white rings resulted from the slow evaporation of the remaining fluid on the surface without causing distortion in the rings on the chrome cornea model due to drying up.

In terms of CLs, depending on the lens material and the fluid retention ability of the lens, it was found that Biotrue® MPS on the surface pooled in the lens centre and lower half part in 50 s in Samfilcon and in 105 s in Sanfilcon. Depending on this situation, an increase in pixels was observed at first. Since distortion in rings decreased due to drying up in the upper half, a decrease was found in the number of pixels. The

videokeratoscopic images of CLs are shown in Fig. 3.

When the planned replacement lenses were examined, statistical differences were found among the average pixel values ($p < 0.001$). The average value was 131877.4 in the Samfilcon group, 116125.5 in the Senofilcon group, 137893.2 in the Fanfilcon group, 125578.3 in the Lotrafilcon group, and 124984.6 in the control group. Based on the results, the Senofilcon material outperformed the control. No differences were found among the average values of the Lotrafilcon group and the control group (Table 2). Differences were found in the average values of all other groups. The lowest average value was obtained from the Senofilcon group. The highest average value was obtained from the Fanfilcon group.

4. Discussion

The main purpose of this study is to objectively present CL wettability by putting aside the negative effects of the individual's tear

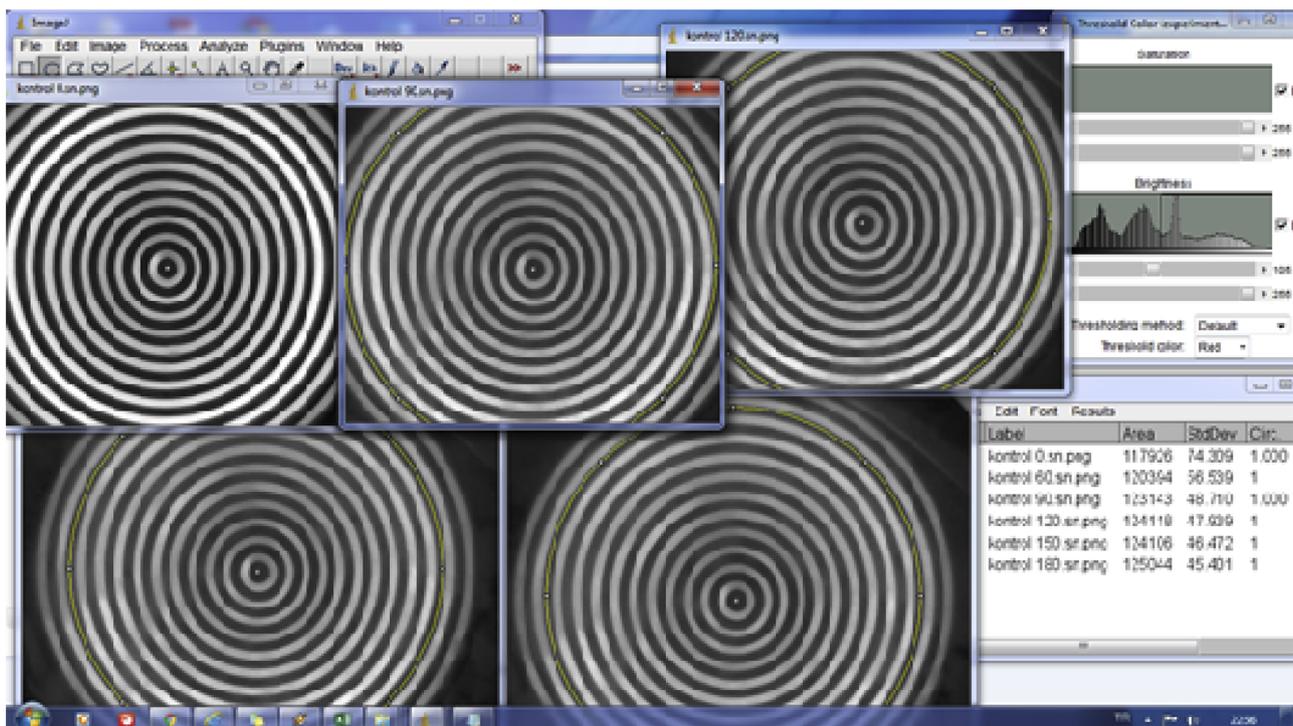


Fig. 2. Videokeratoscopic images of the control group and threshold value.

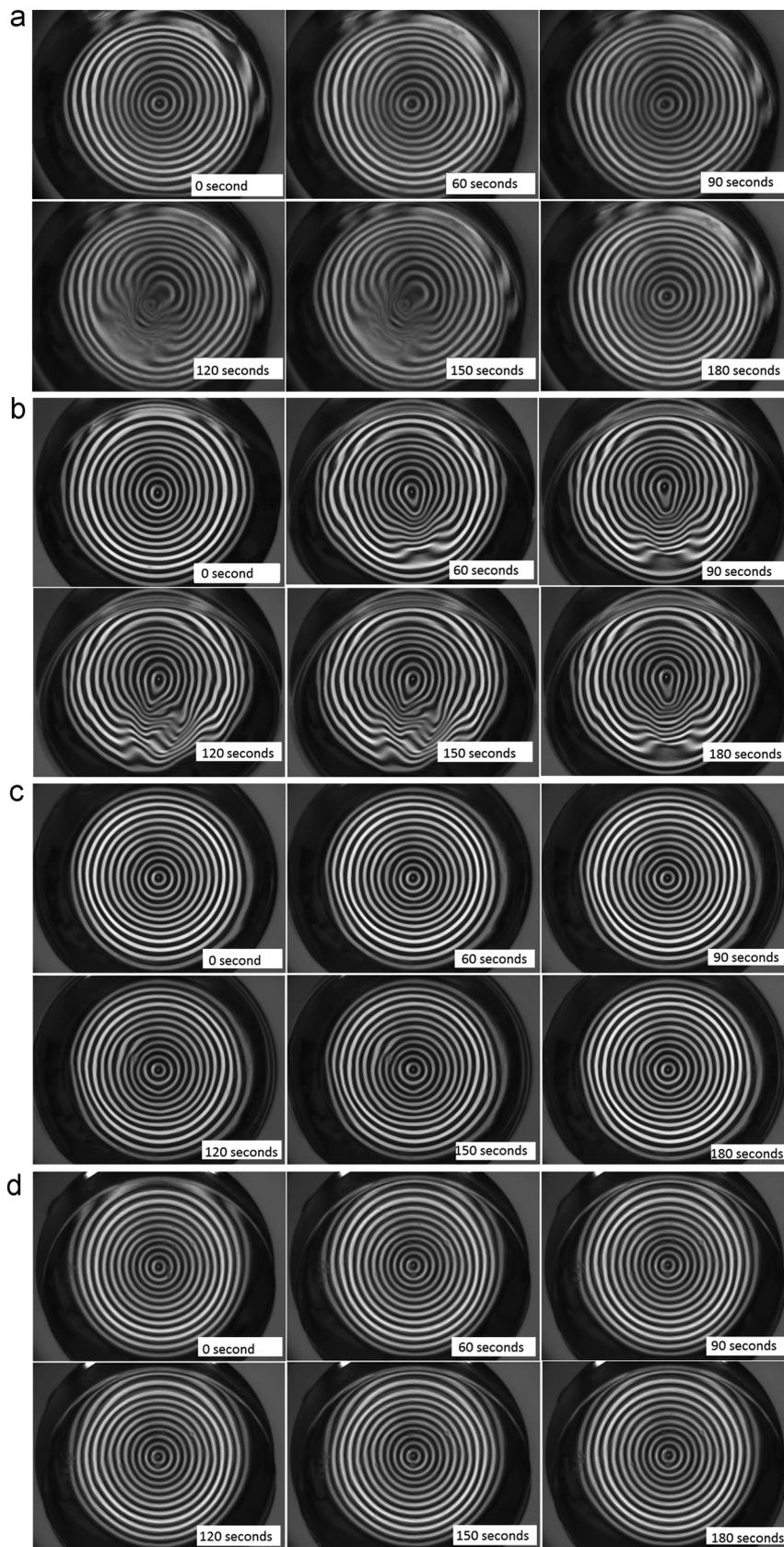


Fig. 3. A) Videokeratographic images of Fanfilcon A. B) Videokeratographic images of Samfilcon A. C) Videokeratographic images of Senofilcon A. D) Videokeratographic images of Lotrafilcon B.

Table 2
Comparison of average area values of lenses.

Period	Lens	Average \pm SD	P value
Planned replacement lenses	Samfilcon A	131877.4 \pm 3003.4 a	< 0.001
	Senofilcon A	116125.5 \pm 5086.8 b	
	Fanfilcon	137893.2 \pm 7372.7 c	
	Lotrafilcon B	125578.3 \pm 3614.9 d	
	Control	124984.6 \pm 3617.6 d	

a,b,c,d: There is no difference between lenses with the same letter in terms of areas.

quality, the movement of eyelashes, and eye movements on the images. Since the tear film layer changes continuously after blinking [20], this in-vitro study, which is more reliable in assessing CL wettability, was conducted. As cornea models were used in this study, the images were not interrupted due to blinking, and there was no need to use mathematical complex linear models, various algorithms, and surface correction techniques [21].

In-vivo studies that are conducted to examine the dynamics of the corneal surface have disadvantages such as the application of various protocols and techniques for the patients to prevent them from blinking [22,23], the influence of individual differences on tear film layer [6], mucus and proteins accumulating on the lens changing CL wettability [24], and lipids on the tear film layer decreasing lens dehydration [25]. The present study is different from other in-vivo studies because such negations were eliminated, and there were no complex interactions between the ocular surface and the CL.

Sometimes, the wettability of soft lenses can increase as they are worn. This situation can be due to deposits similar to a hydrophilic coating resulting from the tear film layer of the individual [24]. Because of this aspect, in-vitro tests are more significant.

To assess CL wettability, the tear film layer has been examined in individuals wearing CLs by using fast videokeratographic methods [21]. In the study by Alonso-Caneiro, while taking the videokeratographic images of individuals, the periods of blinking, 1 s after blinking, and 6 s after blinking were recorded. The first two phases were not analysed; only the last 6 s were analysed. By using mathematical linear models, the study area called region of interest (ROI) in the next 6 s was determined. This study, which is similar to the present study in terms of study design, had video images that were interrupted by blinks and, thus, some parts were not analysed. Because all videokeratographic images in the present study could be analysed, regression analysis was not required.

Similar to the present study, Marx conducted a study in 2017 [12] in which in-vitro lens wettability was examined using the videokeratographic method; however, unlike the present study in which the cornea model was placed vertically, the cornea model in Marx's study was placed horizontally. Horizontal orientation allows the artificial lens tear film to be more symmetrical in rotation. However, the current study is different in that it shows how gravity and natural anatomic position affect the wettability of the CL. Non-uniform wetting is always going to occur due to gravity and no lid interaction. This is a limitation for the present study. The measurement technique used in the present study is different from Marx's study. In the present study, whereas a polished chrome surface coating a Teflon form was used in vertical anatomical position, Marx used a customised stage-made glass material in a horizontal position. It is different in terms of not being in the natural anatomical position and, thus, ignores the effect of gravity on the lens. In the present study, measurements were conducted on a 10-mm wider range, except for the four outermost rings. In Marx's study, the area analysed was determined as 7.5 to 9 mm. In addition, while the measurement range was 192 segments with 16 points each for distortions in Marx's study, the analyses in the present study were based on measurements in all areas. In the present study, the colour changes in rings were analysed both without ring distortions and also without

distortions resulting from the drying of the CL. Although not yet certain, it is thought that the videokeratographic differences of CL wettability in this study are probably due to three reasons. The first reason is wetting agents. The addition of agents such as PVP in polymers inside the lens has been reported to be important in clinical and commercial success [26]. Two of the four CLs tested, Senofilcon A and Samfilcon A, had PVP as a surface wetting agent. The reason why the wettability of these two lenses appeared different videokeratographically can be due to the internal monomers they include because, although they have the same surface wetting agent (PVP), Senofilcon includes mPDMS + DMA + HEMA + siloxane macromer + TEGDMA + PVP, whereas Samfilcon includes NVP + siloxane copolymer, as stated in Table 1. It is thought that these differences exist as a result of the aforementioned polymers and the lens's own properties. In addition, the differences in wettability of Senofilcon and Senofilcon, which include PVP, may be due to both the amount of PVP that the CLs contain and also to differences in production processes. In CL production phases, whereas PVP is added, it is added in the molecule from the start in Senofilcon, but it is added following the silicone matrix in Samfilcon [26]. The present study showed that there were other more important factors why Senofilcon A and Samfilcon A lens wettability including PVP did not show as good a performance as Lotrafilcon B videokeratographically. In a study conducted using the captiva bubble technique, Fagehi et al. found that Lotrafilcon B lens wettability was statistically different when compared with other lenses [7].

The second reason for the difference in wettability is the polymers used in lens production. In SiH lenses, while silicone phase provides oxygen permeability, the hydrophilic hydrogel phase provides the permeability of ions, gases, and eye solutions [27]. The polymers used in lens production influence wettability. Lens hydrations differ in terms of lens parameters and characteristics [25]. HEMA, a hydrophilic monomer, is widely used in CL production, and when applied, it tends to dry up depending on the time [28]. When monomers such as NVP or MA are added to HEMA monomer, this addition causes an increase in the electrostatic negative charges on the CL surface [29]. The interaction between these HEMA-related charges, and the charges inside MPS, can change wettability. Lotrafilcon A and Lotrafilcon B are produced from the same polymers and surface covering. However, in their study, Fagehi et al. showed that the pre-lens liquid break-ups of these two lenses were very different. In this study, it was shown that although polymers were the same, the tendency for drying up increased because Lotrafilcon A contained more silicone [7].

The third reason is the possible ionic interaction between lens polymers and MPS used. MPS contains anti-infective agents to disinfect microbes, surfactants for deposits (typically lipid), agents to buffer the solution, and lubricating agents [30]. To increase lens comfort, CL manufacturers add moisturizing agents such as hydroxypropyl methylcellulose or polyethylene glycol inside the blister packs [31]. After the lenses in blister packs were washed and rinsed, they were kept in Biotrue® MPS to ensure standardisation in the wettability of all lenses. Thus, different wettability characteristics of the solutions included in blister packs by different manufacturers were eliminated.

There are different views regarding the effects of MPSs on wettability. In Jones and Chen's study, it was showed that in-vitro CL wettability was greatly influenced by the combination of CL solutions [10]. Lin et al. found that wettability of SiH lenses kept in surfactant-free MPS was either the same or improved. According to the results of the same study, it was reported that the wettability of SiH lenses resulted from their own surface characteristics [32].

Kitamata-Wong et al examined the CL surface characteristics of MPSs in vitro. They showed that the contact angle, surface tension and adhesion tensions of different MPSs were not different from each other. It was reported that the negatively charged polymethacrylic acid in the structures of SiH CLs interacted with water on the lens and positive charged MPS content [33]. Since Biotrue® MPS containing acationic preservative in the tests, the interaction between lens material and

solution may have changed surface wettability. The wettability in Fanfilcon A, Senofilcon A, and Samfilcon A showed statistically significant differences when compared with the control group and Lotrafilcon B. These differences may have originated from different materials used in lens structure or the negative interaction between hydrogel structure and Biotrue® MPS ions. In terms of Fanfilcon A lens wettability, it can be primarily related to the interaction between methacrylic acid monomer and ions, and secondarily due to not including surface wetting material.

When compared with other tested SiH lenses, better surface wettability of Lotrafilcon B brought to mind that it was due to lens production process-matrix and Lotrafilcon B material in addition to the moisturizing technology on the CL surface. It is thought that surface wettability of Lotrafilcon lenses stayed unchanged since the polar areas including water molecules on the lens surface were stable during the test.

One may argue why toric and multifocals lenses were not included in the study. However, variations in the surface designs of toric lenses, different thicknesses of central optic zone and peripheral comfort zone [34], and their negative influences on images were the reasons why they were not included in the study. Similar reasons are also valid for multifocal lenses.

5. Conclusion

The present study is different from recently published in-vitro CL wettability studies in two aspects. First, a different and simple imaging method, which is anatomically compatible with studies conducted on individuals, was used. It will be useful to know how wettability is affected with the same lenses, the same methodology, but different MPS in future studies. Thus, it should be investigated whether the changes in wettability result from MPS or from the characteristics of the lens itself. Second, the question “which one is more important, raw material or surface wetting technology?” can be answered if wettability can be found in lenses with different covering and moisturising characteristics produced from the same raw material.

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Declaration of Competing Interest

There are no conflicts of interest.

References

- C. Llorens-Quintana, M. Mousavi, D. Szczesna-Iskander, D.R. Iskander, Non-invasive pre-lens tear film assessment with high-speed videokeratography, *Contact Lens Anterior Eye* 41 (1) (2018) 18–22.
- M. Mousavi, D.A. Jesus, I.K. Garaszczuk, D.H. Szczesna-Iskander, D.R. Iskander, The utility of measuring tear film break-up time for prescribing contact lenses, *Contact Lens Anterior Eye* 41 (1) (2018) 105–109.
- J.J. Nichols, L.T. Sinnott, Tear film, contact lens, and patient-related factors associated with contact lens-related dry eye, *Invest Ophthalmol Vis Sci* 47 (4) (2006) 1319–1328.
- A. Shirafkan, E.G. Woodward, M.J. Port, C.C. Hull, Surface wettability and hydrophilicity of soft contact lens materials, before and after wear, *Ophthalmic Physiol Opt* 15 (5) (1995) 529–532.
- N. Keir, L. Jones, Wettability and silicone hydrogel lenses: a review, *Eye Contact Lens* 39 (1) (2013) 100–108.
- D.H. Szczesna-Iskander, D.R. Iskander, S.A. Read, D. Alonso-Caneiro, Noninvasive in vivo assessment of soft contact lens type on tear film surface quality, *Invest Ophthalmol Vis Sci* 53 (1) (2012) 525–531.
- R. Fagehi, A. Tomlinson, V. Manahilov, M. Haddad, Contact lens in vitro wettability by interferometry measures of drying dynamics, *Eye Contact Lens* 39 (6) (2013) 365–375.
- M. Guillon, C. Maissa, S. Wong, T. Patel, R. Garofalo, Effect of lens care system on silicone hydrogel contact lens wettability, *Contact Lens Anterior Eye* 38 (6) (2015) 435–441.
- N.A. Brennan, M.L.C. Coles, J.H.B. Ang, An evaluation of silicone-hydrogel lenses worn on a daily wear basis, *Clin Exp Optom* 89 (1) (2006) 18–25.
- L. Jones, J. Long, P. Chen, The impact of contact lens care regimens on the in vitro wettability of conventional and silicone-hydrogel contact lens materials, *Invest Ophthalmol Vis Sci* 43 (13) (2002) 3097–3097.
- L. Cheng, S.J. Muller, C.J. Radke, Wettability of silicone-hydrogel contact lenses in the presence of tear-film components, *Curr Eye Res* 28 (2) (2004) 93–108.
- S. Marx, W. Sickenberger, A novel in-vitro method for assessing contact lens surface dewetting: non-invasive keratograph dry-up time (NIK-DUT), *Contact Lens Anterior Eye* 40 (6) (2017) 382–388.
- M. Shen, M.R. Wang, J. Wang, Y. Yuan, F. Chen, Entire contact lens imaged in vivo and in vitro with spectral domain optical coherence tomography, *Eye Contact Lens* 36 (2) (2010) 73.
- D. Alonso-Caneiro, D.R. Iskander, M.J. Collins, Assessment of tear film surface quality using dynamic-area high-speed videokeratography, *IEEE Trans Biomed Eng* 56 (5) (2009) 1473–1481.
- R. Montés-Micó, J.L. Alió, G. Munoz, W.N. Charman, Temporal changes in optical quality of air-tear film interface at anterior cornea after blink, *Invest Ophthalmol Vis Sci* 45 (6) (2004) 1752–1757.
- M. Kopf, F. Yi, D.R. Iskander, M.J. Collins, A.J. Shaw, B. Straker, Tear film surface quality with soft contact lenses using dynamic videokeratography, *J Optom* 1 (1) (2008) 14–21.
- D.H. Szczesna-Iskander, D. Alonso-Caneiro, D.R. Iskander, Objective measures of pre-lens tear film dynamics versus visual responses, *Optom Vis Sci* 93 (8) (2016) 872–880.
- C. Maldonado-Codina, P.B. Morgan, In vitro water wettability of silicone hydrogel contact lenses determined using the sessile drop and captive bubble techniques, *J Biomed Mater Res A* 83 (2) (2007) 496–502.
- M. Vidal-Rohr, J.S. Wolffsohn, L.N. Davies, A. Cerviño, Effect of contact lens surface properties on comfort, tear stability and ocular physiology, *Contact Lens Anterior Eye* 41 (1) (2018) 117–121.
- D.R. Iskander, M.J. Collins, Applications of high-speed videokeratography, *Clin Exp Optom* 88 (4) (2005) 223–231.
- D. Alonso-Caneiro, D.R. Iskander, M.J. Collins, Tear film surface quality with soft contact lenses using dynamic-area high-speed videokeratography, *Eye Contact Lens* 35 (5) (2009) 227–231.
- D.H. Szczesna-Iskander, D.R. Iskander, Future directions in non-invasive measurements of tear film surface kinetics, *Optom Vis Sci* 89 (5) (2012) 749–759.
- M.J. Glasson, F. Stapleton, L. Keay, D. Sweeney, M.D. Willcox, Differences in clinical parameters and tear film of tolerant and intolerant contact lens wearers, *Invest Ophthalmol Vis Sci* 44 (12) (2003) 5116–5124.
- S. Tonge, L. Jones, S. Goodall, B. Tighe, The ex vivo wettability of soft contact lenses, *Curr Eye Res* 23 (1) (2001) 51–59.
- M. Lira, L. Santos, J. Azeredo, E. Yebra-Pimentel, M.R. Oliveira, The effect of lens wear on refractive index of conventional hydrogel and silicone-hydrogel contact lenses: a comparative study, *Contact Lens Anterior Eye* 31 (2) (2008) 89–94.
- J. Schafer, W. Reindel, R. Steffen, G. Mosehauer, J. Chinn, Use of a novel extended blink test to evaluate the performance of two polyvinylpyrrolidone-containing, silicone hydrogel contact lenses, *Clin Ophthalmol (Auckland, NZ)* 12 (2018) 819.
- J.A. Green, K.S. Phillips, V.M. Hitchins, A.D. Lucas, M.E. Shoff, J.C. Hutter, et al., Material properties that predict preservative uptake for silicone hydrogel contact lenses, *Eye Contact Lens* 38 (6) (2012) 350–357.
- X. Deng, M. Korogiannaki, B. Rastegari, J. Zhang, M. Chen, Q. Fu, et al., “Click” chemistry-tethered hyaluronic acid-based contact lens coatings improve lens wettability and lower protein adsorption, *ACS Appl Mater Interfaces* 8 (34) (2016) 22064–22073.
- F. Carney, L. Keay, F. Stapleton, C. Morris, M. Willcox, Hydrogel lens wettability and deposition in vivo, *Clin Exp Optom* 81 (2) (1998) 51–55.
- L.C. Thai, A. Tomlinson, P.A. Simmons, In vitro and in vivo effects of a lubricant in a contact lens solution, *Ophthalmic Physiol Opt* 22 (4) (2002) 319–329.
- C.-M. Phan, H. Walther, R.W. Smith, D. Riederer, C. Lau, K.O. Lorenz, et al., Determination of the release of PEG and HPMC from nelfilcon A daily disposable contact lenses using a novel in vitro eye model, *J Biomater Sci Polym Ed* (2018) 1–24 just-accepted.
- M.C. Lin, T.F. Svitova, Contact lenses wettability in vitro: effect of surface-active ingredients, *Optom Vis Sci* 87 (6) (2010) 440.
- B. Kitamata-Wong, T. Yuen, W. Li, T. Svitova, Y. Zhou, M.C. Lin, Effects of lens-care solutions on hydrogel lens performance, *Optom Vis Sci* 94 (11) (2017) 1036–1046.
- N. Efron, *Contact Lens practice, Efron contact Lens practice, second edn*, Butterworth Heinemann Elsevier, China, 2010, pp. 95–102.