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ORIGINAL RESEARCH

Adhesion of Asian Dust Particles to Verofilcon a Soft Contact Lenses

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Purpose: Asian dust poses a serious global health hazard. Airborne particles adhering to contact lenses may cause substantial damage to the ocular surface. The recently released one-day disposable silicone hydrogel soft contact lens (SCL), the verofilcon A, has a smooth surface with SMARTSURFACE® technology, which is designed to prevent adhesion of protein components and foreign bodies. The purpose of this study was to verify the protective quality of verofilcon A SCL against adhesion of Asian dust particles to its surface.

Methods: Verofilcon A and etafilcon A (control lens) SCLs were used (n=16 per group), and 0.2 mL of physiological saline containing 0.01 mg/mL of Asian dust particles was dropped on the surface of SCLs, allowed to stand for 1 hour, shaken for 1 minute, and rinsed three times with saline (after rinsing). In addition, the samples were agitated by a vortex mixer for 1 minute and rinsed three times with saline (after vortex). The number of Asian dust particles adhering to the SCLs and percentage of the surface area occupied by the Asian dust particles was determined before washing, after rinsing, and after vortexing.

Results: The number of adherent Asian dust particles was lower on verofilcon A SCL (297 ± 116 after rinsing, and 5 ± 14 after vortexing) than on etafilcon A SCL (523 ± 212 after rinsing, p=0.003, and 378 ± 268 after vortexing, p<0.001). The Asian dust adhesion area was also lower on verofilcon A SCL (3.6 ± 2.3% after rinsing and 0.0 ± 0.1% after vortexing than on etafilcon A (10.2 ± 2.1% after rinsing, p=0.002, and 5.2 ± 3.0% after vortexing, p<0.001).

Conclusion: These findings indicate that verofilcon A SCL has the property of low adhesion of Asian dust particles. Verofilcon A SCL can be recommended for SCL wearers during windy and Asian dust days.

Keywords: Asian dust, daily soft contact lens, etafilcon A, silicone hydrogel, verofilcon A

Introduction

Contact lenses (CLs) are popular medical devices that are used for correcting the vision and are in direct contact with the corneal surface. CLs are divided into hard CLs (HCLs) and soft CLs (SCLs) according to their material and shape. The CLs adsorb proteins and lipids present in the tear fluid and on the ocular surface as they are in contact with the cornea and conjunctival sac. Proteins and foreign particles adhering to the CLs can cause inflammation of the ocular surface and allergic conjunctivitis.[1–3] SCLs, in particular, have a high moisture content to increase the oxygen permeability, which allows lipids and proteins to be easily adsorbed, and a variety of airborne allergens such as tree and grass pollen, dust, smoke, and cosmetic powders to be easily trapped.[4–6] These allergens can exacerbate the symptoms of allergic conjunctivitis and cause inflammation of the conjunctiva.[4–6]

During the pollen season, Asian dust is blown into the atmosphere from the Taklamakan and Gobi deserts in the interior of mainland China by winds up to an altitude of several thousand meters, and is then blown into Asian countries by westerly winds.[7] Atmospheric particles cause health hazards when they enter the body; in particular, diesel factors,[8] Asian dust,[9,10] and particulate matter less than 2.5 μm in diameter (PM2.5)[11] can exacerbate allergic conjunctivitis and should be treated with caution. Asian dust particles contain a large amount of minerals such as quartz and feldspar, as well as clay minerals. The particle size distribution of Asian dust reaching Japan has a peak around 4–7 microns in diameter.[7] DSS particles contain

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ammonium, sulfate, and nitrate ions that are not thought to be of soil origin, and they take up air pollutants of anthropogenic origin during transport from mainland China to Japan.[7] Our previous study also showed that the number of patients with allergic conjunctivitis increases when the airborne concentration of PM2.5 increases.[11] These airborne particles, like pollen, can adhere to CLs while they are worn and exacerbate ocular symptoms.

A previous study suggested that the adhesion of Cryptomeria japonica allergen 1 (Cryj 1), the major Japanese cedar pollen allergen, to SCLs was higher on monthly replacement SCLs than on daily disposable SCLs (1DSCLs) or frequent 2-week replacement SCLs.[12] Pollen adhesion to 1DSCLs was lower for silicone hydrogel SCLs than for hydroxyethyl methacrylate (HEMA) CLs.[13] These results suggest that daily disposable silicone hydrogel-type SCLs may be suitable for patients with allergic conjunctivitis, especially during the pollen allergy season.

Very recently, a new 1DSCL made of silicone hydrogel called verofilcon A (PRECISION1™, Alcon Japan Ltd. Tokyo, Japan) was introduced in Japan. Verofilcon A is made from a new high oxygen permeability (Dk; 90×10^{-11} barriers) material with a 2–3 μm thick surface with more than 80% water content, and is a Class 1 ultraviolet blocker (≥ 90% of UVA, ≥ 99% of UVB) (Tyler's quarterly soft contact lens parameter guide).[14] Verofilcon A SCL has a smooth surface created by SMARTSURFACE® technology. Therefore, the SCL has characteristics that make it difficult for pollen and protein components to adhere to its surface. In fact, our previous paper demonstrated very little pollen adhesion to velofilcon A SCL.[15] This result raises the hypothesis that atmospheric particles, including Asian dust, may also be less likely to adhere to verofilcon A SCL.

Therefore, the purpose of this study is to verify the adhesion of Asian dust particles to the surface of verofilcon A SCLs. Furthermore, we compared the degree of adhesion of Asian dust particles to verofilcon A 1DSCL with that to another type of 1DSCL available in Japan.

Methods

Research Design

This was a non-clinical comparative effectiveness study. The procedures used were approved by the Ethics Committee of Teikyo University (#Teirin 18–227), and this study was conducted at an ophthalmology laboratory of the Teikyo University School of Medicine from October 2021 to April 2022.

Two types of commercial 1DSCLs (all −4.0 diopters, each n = 16) were evaluated (Table 1). The number of SCLs was calculated with error (difference in the effect = 20%, confidence level = 95%, power = 0.8, and standard deviation = 10),

Table 1 Characteristics of the Contact Lenses

	Etafilcon A	**Verofilcon A**
Water Content (%)	58	Core 51 / Surface 80
Oxygen Permeability (Dk)	28	90
Oxygen Transmissibility (Dk/L)	33.3	100
Diameter (mm)	14.2	14.2
Base Curve (mm)	9.0/8.5	8.7/8.3
CT (mm)	0.084	0.09
Color	Blue	Light blue
Surface (Ionic/Non-ionic)	Ionic	Non-ionic
FDA group	IV	II
USAN Nomenclature	Etafilcon A	Verofilcon A
Principal Components	2-HEMA, MA	mPDMS, GPDMS, NVP

Abbreviations: CT, Center thickness of contact lens; FDA, Food and Drug Administration; USAN, United States adopted names; HEMA, 2-Hydroxyethyl methacrylate; MA, methacrylic acid; mPDMS, mono-methacrylate poly dimethylsiloxane; GPDMS, Glycerol-functionalized polydimethylsiloxane; NVP, N-vinyl pyrrolidone.

and the number of SCLs with a significant difference in the effect between the two groups was eight. Therefore, each of the 16 SCLs is a sufficient sample for inspection. One was etafilcon A DSCL (One Day Acuvue® Moist®, Johnson & Johnson Vision Care, Inc. Jacksonville, FL, USA) and the other was verofilcon A 1DSCL (PRECISION1™, Alcon Japan Ltd. Tokyo, Japan). Etafilcon A was selected because, like Verofilcon A, it is made of silicone hydrogel and is one of the most popular lenses in Japan. Thus, a total of 32 contact lenses were studied. Standard Asian dust particles (CJ-2) prepared by Nishikawa et al at the National Institute for Environmental Studies were used.[16]

Adhesion of Asian Dust Particles to SCLs

One drop (0.2 mL) of physiological saline containing 0.01 mg/mL of Asian dust particles was dropped on the anterior surface of an unused SCL (n = 16) and kept at room temperature for one hour as reported previously.[17] Then, the SCL was placed in a tube containing 10.0 mL of phosphate buffered saline (PBS) and shaken in a shaker three times for 1 minute to try to remove the Asian dust from the surface of the SCLs. The SCL was further rinsed three times in PBS (after washing). Furthermore, the samples were vibrated and agitated for 1 minute by a vortex mixer and washed three times with PBS (after vortexing). The central part of the anterior surface of the SCL, before washing, after rinsing, and after vortexing, was examined and photographed under a microscope. The number of particles adhering to a 200 μm × 200 μm area in the central part of the SCL and the proportion of the adhering area were determined by analyses of the photographic images by ImageJ analysis software (version 1.52a; Wayne Rasband, NIH, Bethesda, MD, http://imagej.nih.gov/ij/docs/index. html). We evaluated the adhesion of Asian dust particles in the central part of the SCL because the central part of the SCL is the part of the SCLs that is in most contact with the surface of the ocular surface and is also critical for vision.

Statistical Analyses

Two-tailed unpaired Student's *t*-test was used to determine the significance of the difference in the mean number of adherent Asian dust particles between the two groups of SCLs. The data were expressed as means ± standard deviations or percentages. Statistical analyses were performed with SAS System software version 9.1 (SAS Institute Inc., Cary, NC, USA), and significance was accepted at $P < 0.05$.

Results

Numbers of Pollen Particles Adhering to the SCLs

Representative photographs of the Asian dust particles adhering to the SCLs are shown in Figures 1 and 2 shows the number of Asian dust particles on 200 μm × 200 μm area of SCLs. Asian dust particles were distributed evenly and

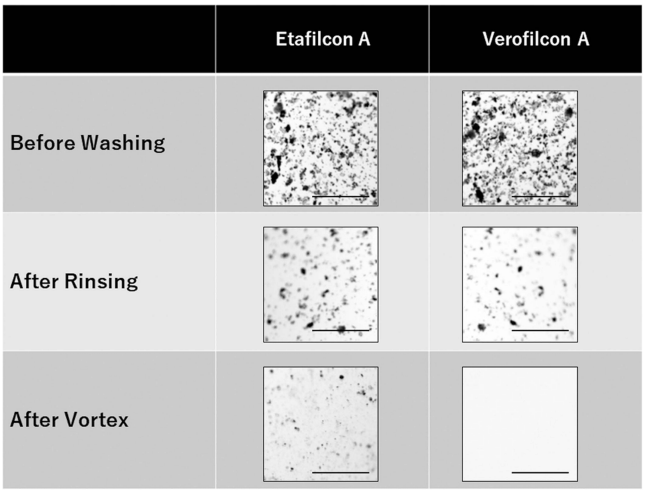

Figure 1 Representative photographs of Asian dust particles on the surface of soft contact lenses (SCLs) before washing, after rinsing, and after vortexing with physiological saline. Bars = 100 μm.

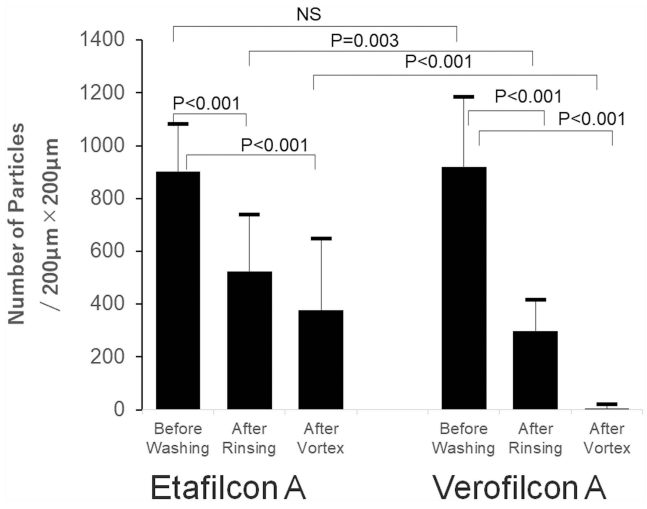

Figure 2 Comparison of the number of Asian dust particles adhering to the soft contact lenses (SCLs) in an area of 200 μm × 200 μm in the central part of the SCL before washing, after rinsing, and after vortexing with physiological saline between etafilcon A and verofilcon A SCLs.

reproducibly across the entire surface of the contact lenses. The number of particles attached to SCLs was 901 ± 178 before washing, 523 ± 212 after rinsing, and 378 ± 268 after vortexing for etafilcon A. On the other hand, for verofilcon A, the number of adherent particles was 919 ± 262 before washing, 297 ± 116 after rinsing, and 5 ± 14 after vortex. There was a significant difference between etafilcon A and verofilcon A in the number of adherent particles after rinsing ($p=0.003$) and after vortexing ($p<0.001$). Compared to before washing, the percentage of particles that remained attached was lower with verofilcon A (32.3% after rinsing and 0.5% after vortexing) than with etafilcon A (58.0% after rinsing and 41.9% after vortexing).

Degree of Asian Dust Particles Adherent to SCLs

Figure 3 shows the percentage of the 200×200 μm surface area of a SCL that was covered by Asian dust particles. The percentage of the surface area of the SCL with adherent Asian dust particles was 23.0 ± 3.2% before washing, 10.2 ± 2.1% after rinsing, and 5.2 ± 3.0% after vortexing for etafilcon A. For verofilcon A, the percentage was 22.8 ± 6.5% before washing, 3.6 ± 2.3% after rinsing, and 0.0 ± 0.1% after vortexing. There was a significant difference between

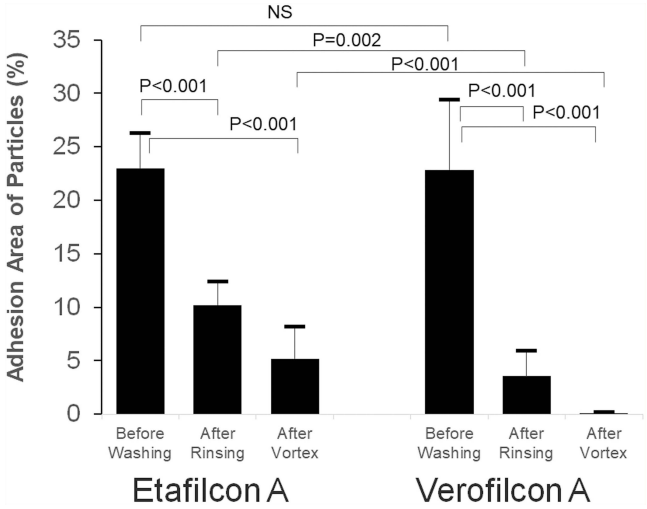

Figure 3 Percentage of the 200×200 μm surface area with adherent Asian dust particles for each soft contact lens (%).

etafilcon A and verofilcon A in the percentage of the surface area with adherent Asian dust particles adhesion after rinsing ($p=0.002$) and after vortexing ($p<0.001$).

The ratio of the area to which the particles remained attached to the adhesive area of the particles before washing was less for verofilcon A (15.6% after rinsing and 0.1% after vortexing) than for etafilcon A (44.3% after rinsing and 22.6% after vortexing).

Discussion

In this study, artificially deposited Asian dust particles on verofilcon A were mostly removed by washing. Compared to etafilcon A, which is widely used in the market, the number and area of Asian dust particles adhering to verofilcon A after washing was lower. This result suggests that verofilcon A is a lens with less adhesion of Asian dust particles.

In order to understand why Asian dust particles are less likely to adhere to verofilcon A, the results of studies that have investigated the adhesion of pollen to verofilcon were reviewed.[13,15] Basically, SCLs made of silicone hydrogel material are nonionic, so the lens surface is electrically positive or negative zero. Ionic lenses, on the other hand, are charged with negative ions, so they easily attract proteins and stains that are charged with positive ions. Previous studies have examined the adhesion of pollen particles to different types of contact lenses and the factors involved in particle adhesion to contact lens materials[13,15] The number of particles adhering to the SCL was lowest for delefilcon A and verofilcon A SCLs among the various SCLs.[13,15] The number of adherent pollen particles correlated with the SCL water content, oxygen permeability (Dk), and oxygen transmissibility[13,15] The water content, oxygen permeability, and oxygen transmission rate of verofilcon A are extremely high and meet all these requirements. These results suggest that verofilcon A is made of a material that is less likely to adhere to not only pollen particles but also to Asian dust particles.

Next, we investigated the mechanism by which Asian dust particles adhere to SCLs. Asian dust is formed from clay and mineral components. Of these, the clay component in Asian dust is considered important as a substance related to adhesion to contact lenses. Asian dust particles are formed by the aggregation of clay particles or by the adhesion and aggregation of clay particles with slightly larger mineral particles.[18] Thus, the first reason is that the clay component of Asian dust can physically adhere to SCL. The second reason is that the particles on the Asian dust surface are negatively charged.[19] Clay particle surfaces in Asian dust are negatively charged due to isomorphic substitution and protonation of the crystal end faces, so that they adsorb a variety of substances, including inorganic and organic ions, polar molecules, and organic acids.[19] Atomic composition analysis of Asian dust showed that silicon (24–30%), calcium (7–12%), aluminum (7%), iron (4–6%), potassium (2–3%), and magnesium (1–3%) were present in a descending order of mass.[20] Asian dust is mainly composed of quartz, calcite (calcium carbonate), gypsum (calcium sulfate), and ammonium sulfate.[21] Asian dust is characterized by a higher content of silicon dioxide, calcium, and aluminum than ordinary Japanese topsoil.[21] Furthermore, silicon dioxide, the main component of Asian dust, is a fine, sharp quartz-like material with a rugged surface; therefore, the protrusions on the Asian dust particle surface can easily pierce and adhere to soft materials such as SCLs.

We used the standard Asian dust particles (CJ-2) prepared by Nishikawa. The composition of CJ-2 refined Asian dust was 5.88% Al, 5.33% Ca, and 244 ug/g Sr, while that of CJ-2 Asian dust was 6.01% Al, 5.83% Ca, and 277 ug/g Sr.[16] Mori et al reported that the solubility of particulate iron, a representative of air pollution in Asian dust particles, ranged from less than 1% to 6%. Particles consisting mainly of pure Asian dust aerosol had low iron composition, while Asian dust particles consisted mainly of pollutants and had high iron concentrations.[22] Asian dust arises from the desert, and adsorbs various chemicals and adhesive molecules in the atmosphere of industrial areas as it moves across the continent.[7] Thus, chemical components adsorbed on Asian dust particles may also help the Asian dust itself to adhere to the SCLs. Verofilcon A is treated with a hydrophilic polymer layer on its surface by SMARTSURFACE® technology (Alcon, Data on File; 2019). This surface treatment makes the structure less likely to adhere to various foreign constituents, including Asian dust (Alcon, Data on File; 2019).

Nevertheless, what should SCL users do if Asian dust adheres to their SCL? For cleaning Asian dust and pollen particles adhering to HCL and 2-week replacement SCLs, disinfection with hydrogen peroxide is effective in removing the foreign substances.[17,23] A previous study demonstrated that hydrogen peroxide disinfection has the effect of physically removing proteins and foreign substances by the generation of foaming oxygen by decomposition of the hydrogen peroxide solution.[17,23] However, unfortunately, 1DSCLs cannot be reused, even if cleaned with a cleaning solution. When Asian dust adheres to the 1DSCL while outside, the basic rule is to discard the 1DSCL as it is and replace

it with a new 1DSCL, rather than rinse it out. However, SCL users may find it inconvenient to frequently change 1DSCLs while on the go. From this perspective, the use of 1DSCLs such as verofilcon A SCL can be recommended on days when pollen and other airborne particles are in high abundance, as foreign particles are less likely to adhere to them.

There are several limitations of this study. First, the amount of Asian dust particles used was much higher (about 100 μg of Asian dust particles /mm^2 on the surface of SCLs) than the general amount of common particles suspended in the air (averaging about 10–20 μg/m^3/1 hr in Tokyo in March-April 2022) (Tokyo Metropolitan Air Quality Information: http://www.taiki.kankyo.metro.tokyo.lg.jp/taikikankyo/realtime/). Second, experiments verifying the rate of Asian dust particle adhesion to the SCLs were validated only with two types of 1DSCLs. Future studies on Asian dust particle adhesion to other 1DSCLs or 2-week frequent replacement SCLs are needed.

In conclusion, there was very little adhesion of Asian dust particles to the 1DSCL of velofilcon A treated with SMARTSURFACE® technology. Therefore, verofilcon A may be an effective SCL option during periods of high Asian dust abundance, windy days, and in areas with severe air pollution.

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Disclosure

The authors report no conflicts of interest in this work.

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