Adhesion of Asian Dust Particles to Verofilcon A Soft Contact Lenses

Tatsuya Mimura¹, Hiroshi Fujishima², Eichi Uchio³, Kazumi Fukagawa⁴, Kazuma Kitsu⁴, Makoto Kawashima¹, Yuji Inoue⁴, Kazumi Fukagawa⁴

¹Department of Ophthalmology, Teiyo University School of Medicine, Tokyo, Japan; ²Department of Ophthalmology, Tsurumi University School of Dental Medicine, Kanagawa, Japan; ³Department of Ophthalmology, Fukuoka University School of Medicine, Fukuoka, Japan; ⁴Ryogoku Eye Clinic, Sumida-Ku, Tokyo, Japan; ⁵Department of Ophthalmology, Keio University School of Medicine, Tokyo, Japan

Correspondence: Tatsuya Mimura, Tel +81-3-3964-1211, Fax +81-3-3964-1402, Email mimurat-tky@umin.ac.jp

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 vortexing). 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, and 387 ± 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 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...
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. A previous study also showed that the number of patients with allergic conjunctivitis increases when the airborne concentration of PM2.5 increases. 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. Pollen adhesion to 1DSCLs was lower for silicone hydrogel SCLs than for hydroxyethyl methacrylate (HEMA) CLs. 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; $90 \times 10^{-11}$ 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). 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. 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 polydimethylsiloxane; 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](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 consistently on the SCL surface.

![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.](https://doi.org/10.2147/OPTO.S381763)](https://doi.org/10.2147/OPTO.S381763)
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
particles adhering to HCL and 2-week replacement SCLs, disinfection with hydrogen peroxide is effective in removing likely to adhere to various foreign constituents, including Asian dust (Alcon, Data on File; 2019).

Asian dust particle surface can easily pierce and adhere to soft materials such as SCLs. The second reason is that the particles on the Asian dust surface are negatively charged. 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. 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. Asian dust is mainly composed of quartz, calcite (calcium carbonate), gypsum (calcium sulfate), and ammonium sulfate. Asian dust is characterized by a higher content of silicon dioxide, calcium, and aluminum than ordinary Japanese topsoil. 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. 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. 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. 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. 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. 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 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/mm² on the surface of SCLs) than the general amount of common particles suspended in the air (averaging about 10–20 μg/m³/1 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.

**Funding**

This work was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan [grant number 20H04347] and an unrestricted investigator-initiated grant from Alcon Japan Ltd. to Tatsuya Mimura, MD. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Disclosure**

The authors report no conflicts of interest in this work.

**References**

1. Alemany A, Redal A. Giant papillary conjunctivitis in soft and rigid lens wear. Contactology. 1991;13:14–17.
2. Kenny SE, Tye CB, Johnson DA, Kheirkhah A. Giant papillary conjunctivitis: a review. Ocul Surf. 2020;18(3):396–402. PMID: 32339665. doi:10.1016/j.jtos.2020.03.007
3. Stapleton F, Bakkar M, Carnt N, et al. CLEAR - Contact lens complications. Cont Lens Anterior Eye. 2021;44(2):330–367. PMID: 33775382. doi:10.1016/j.clae.2021.02.010
4. Uno T, Fukuda M, Ohashi Y, et al. Survey of severe contact lens-associated microbial keratitis in Japan. Nippon Ganka Gakkai Zasshi. 2011;115 (2):107–115.
5. Sapkota K, Lira M, Martin R, Bhattachar S. Ocular complications of soft contact lens wearers in a tertiary eye care centre of Nepal. Cont Lens Anterior Eye. 2013;36(3):113–117.
6. Ozkan J, Rath J, de la Jara PL, Willcox MD. Effect of daily contact lens cleaning on ocular adverse events during extended wear. Optom Vis Sci. 2015;92(2):157–166.
7. Mimura T. Easy-to-understand clinical course: environmental factors and allergic conjunctivitis. Japanese Ophthalmol. 2017;88(3):13–25.
8. Fujishima H, Satake Y, Okada N, Kawashima S, Matsumoto K, Saito H. Effects of diesel exhaust particles on primary cultured healthy human conjunctival epithelium. Ann Allergy Asthma Immunol. 2013;110:39–43.
9. Mimura T, Yamagami S, Fujishima H, et al. Sensitization to Asian dust and allergic rhinoconjunctivitis. Environ Res. 2014;132:220–225. PMID: 24815334. doi:10.1016/j.envres.2014.04.014
10. Ko R, Hayashi M, Hayashi H, et al. Correlation between acute conjunctivitis and Asian dust on ocular surfaces. J Toxicol Environ Health A. 2016;79(8):367–375. PMID: 27142484. doi:10.1080/15287394.2016.1162248
11. Mimura T, Ichinose T, Yamagami S, et al. Airborne particulate matter (PM2.5) and the prevalence of allergic conjunctivitis in Japan. Sci Total Environ. 2014;487:493–499. PMID: 24802272. doi:10.1016/j.scitotenv.2014.04.057
12. Ueda K, Sahashi N, Takahashi Y, Abe E. Adherence of cedar pollen and the antigen of cedar pollen to soft contact lenses. J Jpn Contact Lens Soc. 2010;52(2):127–130.
13. Mimura T, Fujishima H, Uchio E, et al. Adhesion of pollen particles to daily disposable soft contact lenses. Clin Optom. 2021;13:93–101. doi:10.2147/CPT.S257531
14. Tyler’s quarterly soft contact lens parameter guide. Tyler’s Q soft contact lens Param Guid; 2019.
15. Mimura T, Fujishima H, Uchio E, et al. Evaluations of pollen adhesion to verofilcon-A soft contact lenses. Open Ophthalmol J. 2021;15:305–313.
16. Nishikawa M, Hao Q, Morita M. Preparation and evaluation of certified reference materials for Asian mineral dust. Global Environ Res. 2020;4:103–113.
17. Mimura T, Sunaga T, Mizota A. Clinical Academic Topics. Cleaning effect of hydrogen peroxide solution on cedar pollen attached to contact lens. Rinsho Allergy. 2020;40(3):70–79.
18. Ministry of the Environment. 2006–2007 report on the investigation into the actual conditions of asian dust; 2009.
19. Sato T. Characteristics and applications of clays. Clay Sci. 2001;41(1):26–33.
20. Zhang XY, Gong SL, Shen ZX, et al. Characterization of soil dust aerosol in China and its transport and distribution during 2001 ACE-Asia: 1. Network observations. J Geophys Res. 2003;108:4261. doi:10.1029/2002JD002652
21. Ministry of the Environment. Overseas Environmental Cooperation Center, Asian dust problem study group, Interim report of the Asian dust problem study group; 2004.

22. Mori I, Nishikawa M, Shimizu A, Hayasaki M, Takasuga T. Solubility of iron in the aerosol collected during Kosa (Asian Dust) events in Japan. SOLA. 2011;7:5–8.

23. Sunaga T, Mimura T, Matsuoka H, Horikawa H, Kitsu K, Mizota A. Is hydrogen peroxide disinfection effective for cleaning pollen particles attached to contact lenses? Clin Optom. 2020;12:123–128. PMID: 32904467; PMCID: PMC7455597. doi:10.2147/OPTO.S267871