Quantification of Straylight Induced by Silicone Oil Adherent to Intraocular Lenses of Different Materials

MAXIMILIAN HAMMER, LEONI BRITZ, SONJA SCHICKHARDT, INGO LIEBERWIRTH, DONALD MUNRO, PHILIPP UHL, ALEXANDER SCHEUERLE, RAMIN KHORAMNIA, GRZEGORZ ŁABUZ, AND GERD UWE AUFFARTH

• PURPOSE: A complication of using silicone oil as an intraocular endotamponade is its adhesion to intraocular lenses (IOLs). Forward light scattering is a measure to quantify the optical disturbance caused by adherent oil droplets. We tested the straylight caused by silicone oil adhesion to different IOLs and examined whether an approved cleaning solution, F4H5, reverses the induced straylight.

• DESIGN: An experimental study.

• METHODS: Two hydrophobic acrylic IOL models and 1 hydrophilic model with a hydrophobic surface (n = 8 per model: 24 lenses) had straylight measured before contact with silicone oils, providing a baseline for subsequent testing: 12 lenses with lighter-than-water silicone oil (Siluron 2000) and 12 with heavier-than-water oil (Densiron 68). The final measurement was performed after cleansing with F4H5 when we used scanning electron and light microscopy to detect surface changes.

• RESULTS: Straylight was majorly increased in IOLs with adherent silicone oil (baseline vs adherent oil median 3.1 [2.1, 3.9] and 39.7 [22.7, 87.8] deg^2/sr, respectively; $P < .001$). No difference was seen between heavier- and lighter-than-water silicone oils. Between IOL types, induced straylight varied significantly, with 1 hydrophobic model reaching the highest average straylight. F4H5 significantly reduced straylight values in all IOL types (median 9.4 [5.4, 13.8] deg^2/sr). The microscopy revealed surface changes on the IOLs even after cleaning.

• CONCLUSIONS: Silicone oil adhesion to IOLs can induce amounts of straylight known to cause severe optical disturbance. F4H5 cleansing solution reversed straylight values to only slightly increased values. We found no difference in straylight formation between the lighter- and heavier-than-water silicone oils. **(Am J Ophthalmol 2024;262: 192–198.**

Silicone oil was introduced as a vitreous tamponade in 1962 separately by Cibis[1] and Armaly.[2] Over the last 6 decades, extensive research on the oil's viscous, surgical, and pharmacologic properties has improved silicone oil's quality to a point where it is accepted as an essential component of modern vitreoretinal surgery.[3-8]

One complication of silicone oil is the adherence of oil droplets to the intraocular lens (IOL) after surgery. Previously, Apple and associates[9,10] showed that the IOL material strongly determines the coverage area on IOLs after prolonged exposure to lighter-than-water silicone oil.

Many rescue techniques have been proposed to clean the IOLs. Next to mechanical maneuvers, such as cleaning the posterior surface of the IOL with a cutter during silicone oil removal surgery, chemical cleaning of the IOLs has also been evaluated. F4H5 is a semifluorinated alkane Conformité Européenne-approved for the washout of sticky silicone oil and the cleaning of IOLs. During surgery, F4H5 is injected into the anterior chamber onto the surface of the IOL and into the posterior segment to washout possible silicone oil emulsion droplets and oil adhesions to the IOL. It is then again aspirated together with the remnants of silicone oil, often combined with a fluid-air exchange in the vitreous cavity. In a laboratory study, Stappler and associates[11] and Liang and associates[12] found that while the silicone oil could be removed from IOLs using F4H5, the surface of the IOL remained altered.[11] Heavier-than-water silicone oils, a mixture of polydimethylsiloxane (PDMS) and F6H8, another semifluorinated alkane, were introduced as a treatment option for inferior retinal detachments and inferior proliferative vitreoretinopathy. It is unclear if these heavier-than-water silicone oils adhere in a similar fashion and if F4H5 can also remove them from IOL surfaces.

Most importantly, no previous study on silicone oil adhesion has dealt with the visual complications of adherent silicone oil droplets. Intraocular straylight, the effect of light

AJO.com Supplemental Material available at AJO.com.

Accepted for publication November 17, 2023.

From the Department of Ophthalmology, University Clinic Heidelberg (M.H., L.B., A.S., R.K., G.Ł., G.U.A.); David J Apple Laboratory for Vision Research (M.H., L.B., S.S., D.M., A.S., R.K., G.Ł., G.U.A.); Heidelberg, Department of Physical Chemistry of Polymers, Max Planck Institute for Polymer Research, Mainz (I.L.); Institute for Pharmacy and Molecular Biotechnology, Heidelberg (P.U.), Germany.

Inquiries to Gerd Uwe Auffarth, David J Apple Laboratory for Vision Research, Heidelberg, Germany; e-mail: Gerd.auffarth@med.uni-heidelberg.de

0002-9394/$36.00
https://doi.org/10.1016/j.ajo.2023.11.018

TABLE 1. The Silicone Oils

Name	Compounds	Density at 25°C
Siluron 2000	95% polydimethylsiloxane (1000 mPa s) and 5% high-molecular-weight component polydimethylsiloxane (2.5 million mPa s)	0.97 g/cm^3
Densiron 68	30.5% F6H8 and 69.5% polydimethylsiloxane	1.06 g/cm^3

TABLE 2. Characteristics of the Studied Intraocular Lenses

IOL Model	Manufacturer	Hydrophobicity	Optic Copolymer	Blue Light Filter	UV Light Filter
AcrySof IQ Monofocal	Alcon Inc	Hydrophobic	Phenylethyl acrylate and phenylethyl methacrylate cross-linked with butanediol diacrylate	Yes	Yes
Micropure 123	BVI Inc	Hydrophobic	Ethylene glycol phenyl ether acrylate (2-phenoxyethyl acrylate) and 2-hydroxyethyl methacrylate copolymer	Yes	Yes
CT Asphina 409 M	Carl Zeiss Meditec AG	Hydrophilic with hydrophobic surface	Hydroxyethylmethacrylat and ethoxyethylmethacrylat at an approximate 3:1 ratio	No	Yes

IOL = intraocular lense.

scattered into a forward direction by the ocular media, is projected on the retina and decreases the contrast of the in-focus image. This forward light scattering was used to good effect to gain an understanding of another IOL complication, calcification.[13] Increased intraocular straylight may worsen the often already guarded visual prognosis in eyes requiring silicone oil tamponade.

We investigated the impact of silicone oil adhesion on forward light scattering of hydrophobic IOLs and a hydrophilic IOL with a hydrophobic surface as well as the efficacy of F4H5 as a cleaning solution for both lighter-than-water silicone oil (Siluron 2000) and heavier-than-water silicone oil (Densiron 68). Electron and light microscopy were applied to document surface changes.

METHODS

• **IOLS AND SILICONE OIL TYPES:** In short, Siluron 2000 is a mixture of conventional 1000 mPa s PDMS with a high-molecular-weight component. The addition of a high-molecular-weight component still allows fast silicone oil removal while lowering the tendency to emulsify in vitro.[4,13] Densiron 68 is a mixture of a 5000 mPa s PDMS with F6H8, a semifluorinated alkane, resulting in a density of 1.06 g/cm^3. The 2 oils were chosen as their viscosity is comparable to eliminate or minimize viscosity as a confounder. Table 1 summarizes the composition of the silicone oils. Three types of IOLs were used in this study: Alcon Acrysof IQ SN60WF (Alcon Inc), Zeiss CT Asphina 409M (Carl Zeiss Meditec AG), and PhysIOL Micropure. All of the studied IOLs are made from acrylate polymers. Table 2 presents the exact polymer constitution of the IOLs as well as the presence of blue and UV light filters. This study does not involve humans or animals; thus, no institutional review board approval was needed.

• **MEASUREMENT PROTOCOL:** Figure 1 depicts the study procedures. The IOLs were evaluated with light microscopy and straylight measurements at 3 points: before the immersion in silicone oil, then with silicone oil adhering to the IOL, and lastly, after the washout with F4H5.

Eight lenses of each model were used, totaling 24. Four of the IOLs of each group were tested with Siluron 2000 (a composite lighter-than-water silicone oil) and 4 with Densiron 68 (heavier-than-water silicone oil) both manufactured by Fluoron GmbH. For each IOL, 2 consecutive measurements were performed at every time point (baseline, adherent silicone oil, after cleaning). If the 2 measurements showed an SD of higher than 0.1 logs, a total of 4 measurements were conducted and averaged. This was the case for 1 of the 24 IOLs at one time point, indicating a small intraindividual variability of forward light scattering measurements. First, all lenses were hydrated at room temperature in balanced salt solution (BSS) for 24 hours to simulate the immersion in the aqueous humor in the eye. After the first round of measurements, the IOLs were immersed in either Siluron 2000 or Densiron 68 (both by Fluoron GmbH) for 12 hours at room temperature. After immersion, the IOLs were carefully rinsed to remove silicone oil that was not adherent to the lens and then once again immersed in BSS to allow light microscopy and forward light scattering measurements. After these measurements, the IOL was immersed in F4H5, a semifluorinated alkane that is approved

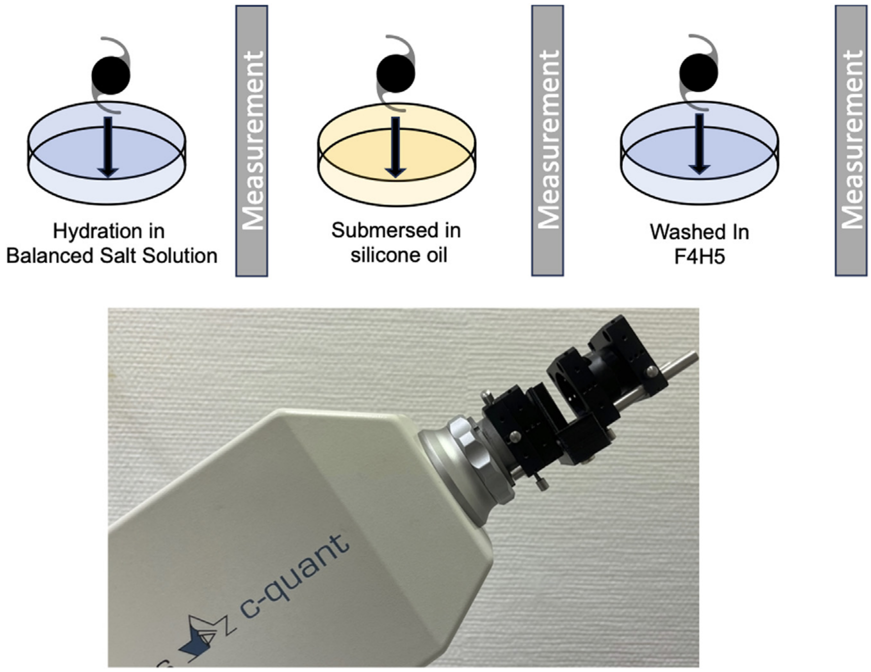

FIGURE 1. Study setup. All lenses were hydrated in balanced salt solution for 24 hours, and light microscopy was used to measure forward light scattering. Subsequently, the IOLs were placed in either Siluron 2000 or Densiron 68 for 12 hours. After conducting another round of measurements, the lenses were gently washed in F4H5 and measured again. In the bottom image, the modified C-Quant setup used to measure the straylight of IOLs is depicted.

for the removal of silicone oil droplets from IOL surfaces and approved as a washout in vitreoretinal surgery. The IOL was gently moved within the F4H5 and then rinsed with BSS, and a final measurement was made.

• **STRAYLIGHT EVALUATION—FORWARD LIGHT SCATTERING:** Light scattering was quantified with the C-Quant straylight meter (Oculus GmbH) using an established in vitro setup as previously published.[14-16] The C-Quant allows the measurement of ocular straylight by a psychophysical compensation comparison method. A custom mount on the C-Quant device was designed to only expose the IOL to be tested to the straylight source, not the observer's eye using a field stop. As such, the observer only judges the light scattered by the object without any contribution to the straylight by the observer's eye. A single operator (L.B.) conducted all measurements, was not informed about the current IOL model being measured, which oil was used, and was not advised of what time point of the protocol the IOL had reached. For more methodological details, refer to Łabuz and associates.[16]

• **LIGHT AND ELECTRON MICROSCOPY:** Light microscopy was performed to give an overview of the silicone oil distribution pattern for all the lens types. For scanning electron microscopy (SEM), lenses from 2 models (Zeiss and PhysIOL) underwent SEM at the time points (baseline and after cleaning, after contact with oil). A single operator (I.L.) conducted SEM of the anterior and posterior surfaces to detect surface changes. Before performing SEM, the lenses were dried for 12 hours at room temperature. IOLs (baseline, cleaned after contact with either D68 or Siluron 2000) of 2 models (Zeiss and PhysIOL) underwent SEM of the anterior and posterior surfaces to detect any remaining surface changes. Before SEM can be performed, the lenses need to be kept at room temperature for 12 to 24 hours until dried. Similar methodological SEM parameters as previously published[17] were used.

• **STATISTICAL ANALYSIS:** Normality was evaluated using the Kolmogorov-Smirnov test. Parametric or nonparametric tests (Mann-Whitney *U* tests or *t* tests) were then used as appropriate.

RESULTS

• **ELECTRON AND LIGHT MICROSCOPY:** Figure 2 depicts exemplary light microscopy of all 3 IOL models. Washing with F4H5 significantly lowered the covered area for all 3 IOL models; however, for the PhysIOL and Zeiss models, smaller droplets continued to adhere to the IOL. Electron microscopy revealed surface changes and remnants of remaining silicone oil. An exemplary finding is presented in Figure 2, D—an IOL that was in contact with Densiron 68.

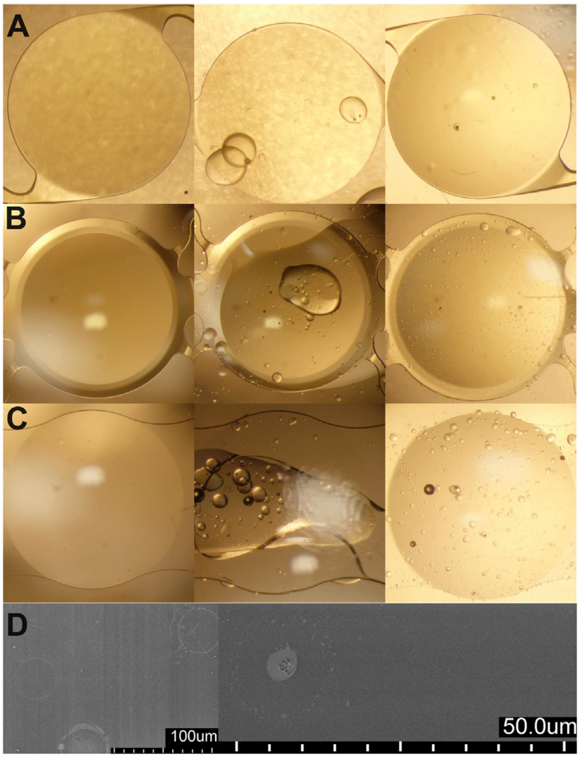

FIGURE 2. Evaluation of adherent silicone oil using light and scanning electron microscopy. Baseline, adherent silicone oil, and after washing with F4H5 for Alcon Acrysof (A), PhysIOL Micropure (B), and Zeiss CT Asphina (C). (D) Remnants of silicone oil on the lenses after drying for electron microscopy; as F4H5 is volatile, only the remaining silicone oil is visible. Exemplary pictures from the PhysIOL Micropure IOL.

- **BASELINE STRAYLIGHT OF ALL THE TESTED IOLS IS COMPARABLE:** Figure 3, A, shows the straylight results of all IOLs at the first time point, after hydration. The 2 lens models made of hydrophobic polymers were comparable, whereas the hydrophilic polymer showed a slightly but significantly greater baseline straylight (Alcon vs Zeiss, $P = .01$).

- **SILICONE OIL ADHESION INDUCES A GREAT AMOUNT OF STRAYLIGHT DEPENDING ON THE IOL MATERIAL AND SURFACE:** Next, we analyzed the impact of silicone oil adhesion over all IOL materials. Silicone oil adhesion induced a great amount of straylight ($P < .001$, Figure 3, B and D). Even though baseline straylight parameters between different IOL materials were comparable, a differentiated effect was seen on straylight after submerging the IOL in silicone oil. The greatest difference was apparent between the 2 hydrophobic polymers (median straylight 49.43 vs 15.09 deg^2/sr for PhysIOL vs Alcon, $P = .01$, respectively, Figure 3, B).

- **F4H5 SIGNIFICANTLY REDUCES THE AMOUNT OF STRAYLIGHT INDUCED, DEPENDING ON THE IOL MATERIAL AND SURFACE:** F4H5, a semifluorinated alkane, was used to wash adherent silicone oil off the IOLs. This procedure significantly reduced the straylight caused over all IOL models ($P < .0001$, Figure 3, D). However, straylight values were considerably higher for all IOLs when compared with baseline measurements. Again, a differentiated effect can be seen depending on the IOL model resembling baseline parameters: the hydrophilic IOLs showed higher straylight values (Figure 3, C).

- **NO SIGNIFICANT DIFFERENCE IN INDUCTION OF STRAYLIGHT BETWEEN DIFFERENT OIL TYPES:** Four IOLs of each model were submerged in Siluron 2000 (Fluoron GmbH), a lighter-than-water silicone oil, and 4 in Densiron 68 (Fluoron GmbH), a heavier-than-water silicone oil. No significant difference was found between the straylight induced by either silicone oil when adherent to the IOLs (median 37.1 vs 46.5 deg^2/sr for lighter- and heavier-than-water silicone oil, respectively, $P = .99$) and after cleaning (median 7.3 vs 10.9 deg^2/sr, $P = .36$).

DISCUSSION

We evaluated the straylight induced by silicone oil adherent to different IOLs. We found that silicone oil bubbles increase the straylight dramatically. A differentiated effect based on the IOL material was observed; F4H5, an approved washing solution, led to a major reduction down to nearly baseline levels of straylight for all IOLs. We found no differences between lighter-than-water (Siluron 2000) and heavier-than-water silicone oil (Densiron 68).

- **STRAYLIGHT IN IOLS WITH SILICONE OIL ADHESION (FORWARD LIGHT SCATTERING):** Previously, in vitro straylight measurements have been applied to study different IOL complications, allowing one to compare achieved values with reports of explanted IOLs with glistenings and calcifications removed from the patients with intolerable visual disturbance. In 2017, Łabuz and associates[18] induced glistenings in the same Alcon Acrysof material we examined in the present study. They found that glistenings may lead to straylight values of around 60 deg^2/sr.[18] IOLs with a central opacification after the intraocular injection of gas showed straylight values of around 100 deg^2/sr.[19] Even higher straylight values were observed for homogenously calcified IOLs with 181.8 deg^2/sr. However, while glistenings, opacification after gas, and calcification of IOLs are well known and often a reason for an IOL exchange[20] due to visual disturbance, in this study, we found that, depending on the IOL material, the adhesion of silicone oil shows straylight values similar to those of severe calcifications. This severity of straylight is clinically highly relevant. Relevant retinal comorbidities are almost always present in patients receiving a silicone oil tamponade. Thus, after

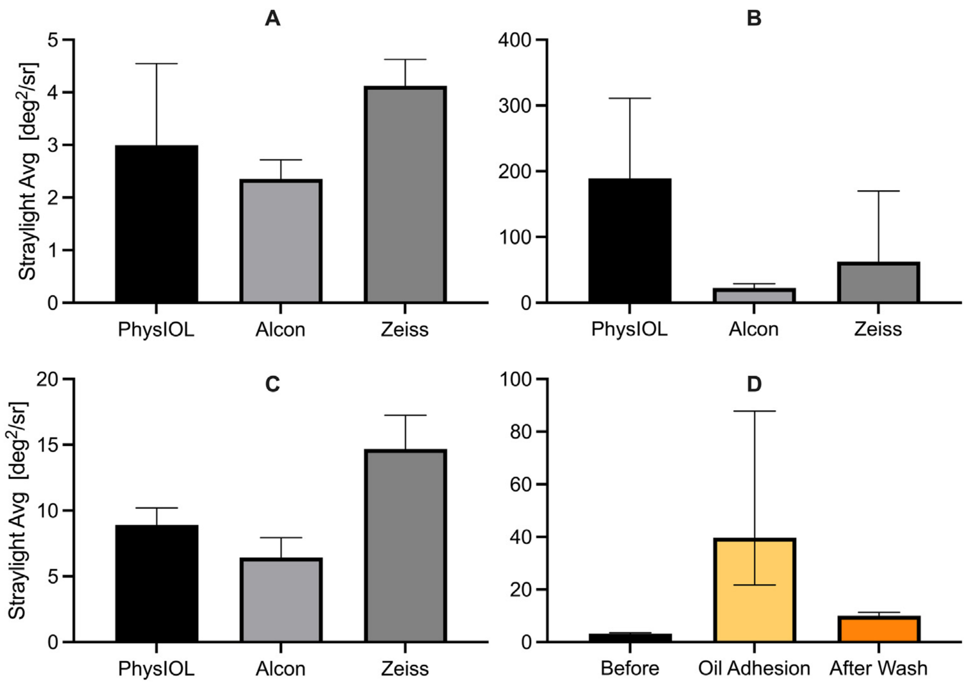

FIGURE 3. Straylight at baseline (A), during silicone oil adhesion (B), and after cleaning (C) stratified by the IOL type, and combined for each study procedure (D). Note the difference in scale between the subfigures. A. At baseline, straylight values between models are comparable. The straylight of hydrophilic acrylic polymer exhibits slightly greater straylight than the hydrophobic polymers. Median with interquartile range. B. One of the hydrophobic polymers (PhysIOL) showed the greatest straylight. Median with interquartile range. C. Straylight of different IOL models after the F4H5 cleaning procedure. Mean with standard error of the mean. D. An increase was observed in straylight after submersing the IOLs in silicone oil. Washing the IOLs with F4H5 brought straylight values back down to near baseline values. Median with interquartile range is shown.

silicone oil removal, visual disturbances may often be attributed to retinal disease and not to the silicone oil droplets adherent to the IOL. Our results indicate that silicone oil adhesion to the IOL may play a bigger role than previously thought. In this patient population, optimizing the eye's optical properties is essential to salvage the remaining retinal function fully.

• **F4H5 AS A RESCUE TOOL:** One option that is proposed to clean silicone oil adherent to IOLs is to use F4H5, a semifluorinated alkane CE-approved for intraocular use. However, only a few scientific articles discuss its use. Stappler and associates[11] in 2010 conducted measurements of the weight of the IOL at a baseline, with adherent silicone oil and after cleaning of the lenses with F4H5. They found that F4H5 was highly effective in removing the bulk of silicone oil off the IOLs. However, the IOL surface was permanently modified, suggesting that the cleaning was incomplete. Although achieving a complete reset of the surface within the eye would be optimal, the surgical goal would be to improve the straylight caused by the silicone oil adhesion. A major improvement with F4H5 was possible, reducing straylight values back down to nearly baseline levels. In addition to optical microscopy, we also analyzed the surface of sample IOLs using SEM. We found that remnants of the silicone oil were visible on the surface of the IOL even after cleaning with F4H5, reinforcing the results of Stappler and associates. We perform SEM using dried lenses, and if one presumes that during the 12-hour desiccation process, all the volatile F4H5 will have evaporated from the lens surface, then what we observe remaining on it in SEM are remnants of PDMS.

More recently, other agents have been proposed, in vitro and ex vivo, to clear the silicone oil off from IOLs by Paschalis and associates;[21] however, we did not include them in our study as these are not currently used in clinical practice. Also, clinicians often try to reduce the amount of adherent silicone oil on the IOL by performing a mechanical debridement using a vitreoretinal cutter. We did not include this technique in this laboratory study because the cutter itself might potentially damage the IOL surface, causing increased straylight. Moreover, establishing a standardized debridement method is challenging, which requires further investigation.

• **DIFFERENCES BETWEEN IOL MODELS:** In this study, the primary selection criterion for the IOLs under investigation was their hydrophobic property. These are considered IOLs of choice for most vitreoretinal surgeons because hydrophilic implants present an increased risk of opacification after coming into contact with intraocular gas.[22] Although silicone IOLs also share hydrophobic properties, previous research has shown that silicone oil adhesion to silicone-IOL surface tends to be irreversible.[10] This prompted us to focus exclusively on acrylic implants. However, hydrophobic acrylic materials differ in their polymer composition,[23] and thus, their interaction with silicone oil may also vary. AcrySof material (Alcon), applied in SN60WF IOLs, is one of the most commonly used hydrophobic materials, which has been implanted over 100 million times over decades worldwide as stated by the manufacturer. The Micropure model (PhysIOL) represents a newer generation hydrophobic material and was also included in our study. Finally, a hydrophilic acrylic lens (CT Asphina) with hydrophobic surface properties, as described by Carl Zeiss, was selected to evaluate the impact of the hydrophobic surface on a hydrophilic polymer when in contact with silicone oil. Interestingly, the greatest difference in straylight was apparent between the 2 hydrophobic models made of an acrylic hydrophobic polymer. This suggests that next to hydrophilicity, other parameters play an important role in determining straylight caused by adherent silicone oil. Surfaces might differ in roughness or have different compositions of chemical functional groups on the lens surface that can influence oil adhesion. In a laboratory study of the Clareon CNA0T0 (Alson Inc), then a prototype lens in 2017, Auffarth and associates[24] found that Clareon material, the successor of the Alcon Acrysof material studied here, had silicone oil adhesion and interaction that were equivalent to the established AcrySof IOL. De Giacinto and associates[25] found that roughness significantly varied between different hydrophobic acrylic IOLs, and the Clareon model had the smoothest surface. In our study, the Alcon Acrysof lenses showed the lowest straylight induction by adherent silicone oil. Surface irregularities are strongly correlated with greater adhesion of inflammatory cells and higher lens epithelial cell migration onto the optic surface of the IOL.[26-28] It is thus likely that these parameters also influence the adhesion of silicone oil droplets as well as the hydrophobicity that is intrinsic in a hydrophobic acrylic polymer. However, further studies are needed to prove this concept.

The intent of this study was to first quantify the visual disturbance caused by IOLs with adherent silicone oil. Of course, this study also has limitations. We examined only 3 IOL models. However, the focus of this study was the general influence of adherent silicone oil on straylight and not the differences between IOLs. In addition, we tested 2 commonly used silicone oils in Europe; further studies should illuminate if other oil types, for example, those with a higher percentage of added high-molecular-weight chain components, behave similarly.

In conclusion, this study reveals the great amount of straylight caused by adherent silicone oil droplets beyond what is clinically recognized. Straylight values of this extent cause severe optical disturbance, a symptom that could be mistakenly attributed to retinal comorbidities. The approved cleanser F4H5 significantly reduced straylight values to near normal values. Lighter- and heavier-than-water silicone oil cause similar straylight when adhering to hydrophobic IOLs.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Maximilian Hammer: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Leoni Britz:** Investigation, Methodology, Writing – review & editing. **Sonja Schickhardt:** Conceptualization, Investigation, Project administration, Writing – review & editing. **Ingo Lieberwirth:** Investigation, Methodology, Writing – review & editing. **Donald Munro:** Data curation, Project administration, Writing – review & editing. **Philipp Uhl:** Conceptualization, Formal analysis, Supervision, Writing – review & editing. **Alexander Scheuerle:** Methodology, Supervision, Writing – review & editing. **Ramin Khoramnia:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Grzegorz Łabuz:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft.

Funding/Support: This study was supported by a grant by the Ernst und Berta Grimmke Foundation to M.H., S.S., and P.U. M.H. is supported by the Add-On fellowship of the Joachim Herz Foundation. This study was supported by the Klaus Tschira Foundation (G.U.A.). Financial Disclosures: R.K. reports research grants and lecture fees from Alcon, Hoya, PhysIOL, Rayner, 1stQ, and Johnson & Johnson; lecture fees from Kowa, Ophtec, Teleon, Santen, Acufocus, and Bausch&Lomb; and travel grants from Alcon, Teleon, Johnson & Johnson, Rayner, and 1stQ. G.U.A. reports research grants, travel grants, and lecture fees from Alcon, Hoya, Kowa, and SIFI; research grants and lecture fees from Johnson & Johnson and Santen; and research grants from Zeiss, PhysIOL, and Acufocus. The other authors have no conflict of interest to disclose. All authors attest that they meet the current ICMJE criteria for authorship.

REFERENCES

1. Cibis PA, Becker B, Okun E, Canaan S. The use of liquid silicone in retinal detachment surgery. *Arch Ophthalmol.* 1962;68:590–599. doi:10.1001/archopht.1962.00960030594005.
2. Armaly MF. Ocular tolerance to silicones. I. Replacement of aqueous and vitreous by silicone fluids. *Arch*

Ophthalmol. 1962;68:390–395. doi:10.1001/archopht.1962.00960030394013.
3. Williams RL, Day MJ, Garvey MJ, et al. Injectability of silicone oil-based tamponade agents. *Br J Ophthalmol*. 2011;95(2):273–276. doi:10.1136/bjo.2010.192344.
4. Williams RL, Day M, Garvey MJ, English R, Wong D. Increasing the extensional viscosity of silicone oil reduces the tendency for emulsification. *Retina*. 2010;30(2):300–304. doi:10.1097/IAE.0b013e3181babe0c.
5. Hammer M, Schickhardt SK, Munro D, et al. The novel use of high-flow polyimide cannulas to improve silicone oil injectability in vitreoretinal surgery. *Retina*. 2022;42(6):1170–1175. doi:10.1097/IAE.0000000000003432.
6. Hammer M, Schickhardt SK, Merz PR, et al. Intravitreal application: physicochemical properties of drugs dissolved in silicone oils of different density in comparison to the porcine vitreous body. *Pharmaceutics*. 2022;14(7):1364. doi:10.3390/pharmaceutics14071364.
7. Caramoy A, Schröder S, Fauser S, Kirchhof B. In vitro emulsification assessment of new silicone oils. *Br J Ophthalmol*. 2010;94(4):509–512. doi:10.1136/bjo.2009.170852.
8. Hammer M, Schickhardt S, Munro DJ, Scheuerle A, Mayer CS, Auffarth GU. Physicochemical properties of explanted silicone oil after use as an intraocular tamponade. *Trans Vis Sci Tech*. 2022;11(2):3. doi:10.1167/tvst.11.2.3.
9. Apple DJ, Isaacs RT, Kent DG, et al. Silicone oil adhesion to intraocular lenses: an experimental study comparing various biomaterials. *J Cataract Refract Surg*. 1997;23(4):536–544. doi:10.1016/s0886-3350(97)80210-6.
10. Apple DJ, Federman JL, Krolicki TJ, et al. Irreversible silicone oil adhesion to silicone intraocular lenses. A clinicopathologic analysis. *Ophthalmology*. 1996;103(10):1555–1561 [discussion: 1561-1562]. doi:10.1016/s0161-6420(96)30463-6.
11. Stappler T, Williams R, Wong D. F4H5: a novel substance for the removal of silicone oil from intraocular lenses. *Br J Ophthalmol*. 2010;94(3):364–367. doi:10.1136/bjo.2009.161489.
12. Liang Y, Kociok N, Leszczuk M, et al. A cleaning solution for silicone intraocular lenses: "sticky silicone oil. *Br J Ophthal*. 2008;92(11):1522–1527. doi:10.1136/bjo.2008.143750.
13. Hammer M, Schickhardt S, Munro D, et al. New approaches to explanting high-viscosity silicone oil in retinal surgery—polyimide cannulas vs extraction sleeves vs a luer-trocar. *Int J Retin Vitr*. 2023;9(1):43. doi:10.1186/s40942-023-00481-w.
14. Yildirim TM, Łabuz G, Hammer M, et al. A novel approach for assessing visual impairment caused by intraocular lens opacification: high-resolution optical coherence tomography. *Am J Ophthalmol*. 2021;226:108–116. doi:10.1016/j.ajo.2021.02.001.
15. Łabuz G, Reus NJ, van den Berg TJTP. Light scattering levels from intraocular lenses extracted from donor eyes. *J Cataract Refract Surg*. 2017;43(9):1207–1212. doi:10.1016/j.jcrs.2017.06.044.
16. Łabuz G, Vargas-Martín F, van den Berg TJTP, López-Gil N. Method for in vitro assessment of straylight from intraocular lenses. *Biomed Opt Express*. 2015;6(11):4457. doi:10.1364/BOE.6.004457.
17. Britz L, Schickhardt SK, Yildirim TM, Auffarth GU, Lieberwirth I, Khoramnia R. Development of a standardized in vitro model to reproduce hydrophilic acrylic intraocular lens calcification. *Sci Rep.*. 2022;12(1):7685. doi:10.1038/s41598-022-11486-0.
18. Łabuz G, Reus NJ, Van Den Berg TJTP. Straylight from glistenings in intraocular lenses: in vitro study. *J Cataract Refract Surg*. 2017;43(1):102–108. doi:10.1016/j.jcrs.2016.10.027.
19. Łabuz G, Yildirim TM, Van Den Berg TJTP, Khoramnia R, Auffarth GU. Assessment of straylight and the modulation transfer function of intraocular lenses with centrally localized opacification associated with the intraocular injection of gas. *J Cataract Refract Surg*. 2018;44(5):615–622. doi:10.1016/j.jcrs.2018.01.033.
20. Neuhann T, Yildirim TM, Son HS, Merz PR, Khoramnia R, Auffarth GU. Reasons for explantation, demographics, and material analysis of 200 intraocular lens explants. *J Cataract Refract Surg*. 2020;46(1):20–26. doi:10.1016/j.jcrs.2019.08.045.
21. Paschalis EI, Eliott D, Vavvas DG. Removal of silicone oil from intraocular lens using novel surgical materials. *Trans Vis Sci Tech*. 2014;3(5):4. doi:10.1167/tvst.3.5.4.
22. Yildirim TM, Auffarth GU, Łabuz G, Bopp S, Son HS, Khoramnia R. Material analysis and optical quality assessment of opacified hydrophilic acrylic intraocular lenses after pars plana vitrectomy. *Am J Ophthalmol*. 2018;193:10–19. doi:10.1016/j.ajo.2018.06.002.
23. Łabuz G, Knebel D, Auffarth GU, et al. Glistening formation and light scattering in six hydrophobic-acrylic intraocular lenses. *Am J Ophthalmol*. 2018;196:112–120. doi:10.1016/j.ajo.2018.08.032.
24. Auffarth GU, Fang H, Wang Q, et al. Silicone oil adhesion to hydrophobic acrylic intraocular lenses: a comparative laboratory study of a new versus an established hydrophobic acrylic intraocular lens material. *J Ophthalmol*. 2021;2021:1387987. doi:10.1155/2021/1387987.
25. De Giacinto C, Porrelli D, Turco G, Pastore MR, D'Aloisio R, Tognetto D. Surface properties of commercially available hydrophobic acrylic intraocular lenses: comparative study. *J Cataract Refract Surg*. 2019;45(9):1330–1334. doi:10.1016/j.jcrs.2019.04.011.
26. Saika S. Relationship between posterior capsule opacification and intraocular lens biocompatibility. *Prog Retin Eye Res*. 2004;23(3):283–305. doi:10.1016/j.preteyeres.2004.02.004.
27. Tanaka T, Shigeta M, Yamakawa N, Usui M. Cell adhesion to acrylic intraocular lens associated with lens surface properties. *J Cataract Refract Surg*. 2005;31(8):1648–1651. doi:10.1016/j.jcrs.2004.11.050.
28. Mukherjee R, Chaudhury K, Das S, Sengupta S, Biswas P. Posterior capsular opacification and intraocular lens surface micro-roughness characteristics: an atomic force microscopy study. *Micron*. 2012;43(9):937–947. doi:10.1016/j.micron.2012.03.015.