Silicone Oil Emulsification in Retina Surgery

Despite its benefits as a tamponade, silicone oil presents a risk to patients when it remains in the eye.

BY AVNI V. PATEL MD, MBA; THANOS D. PAPAKOSTAS, MD; AND DEAN ELIOTT, MD

Silicone oil was introduced by Cibis in the 1960s as an intraocular tamponade prior to the introduction of pars plana vitrectomy.[1] It has become the preferred tamponade agent in cases at high risk for recurrent retinal detachment, such as in eyes with retinal detachment associated with severe proliferative vitreoretinopathy (PVR) or with detachment resulting from viral retinitis.[2] Emulsification is a known complication of silicone oil use and one that is clinically significant due to its adverse affects on all ocular structures (Figure). Understanding the forces and factors that lead to silicone oil emulsification is crucial to minimizing its occurrence.

Dispersion and emulsification are often incorrectly used synonymously. *Dispersion* is the splitting of liquid from a larger bubble into smaller bubbles. *Emulsification*, however, occurs when these smaller bubbles are no longer able to coalesce with the larger bubble due to the presence of surfactants or other factors. Emulsification, in theory, occurs for several reasons: alterations in surface tension, repulsion, and changes in viscosity. Silicone oil emulsification may be further influenced by the duration of silicone oil in the eye and the presence of shear forces or turbulence.

FACTORS LEADING TO SILICONE OIL EMULSIFICATION

Surface tension is the tendency of a liquid to acquire the least surface area possible. At a water-air interface, for example, surface tension results from the greater attraction of water molecules to each other (cohesive forces) than to the molecules in the air (adhesive forces). The net effect is an inward force at the surface of the liquid. Interfacial tension is the surface tension at the interface of two liquids.

Surfactants facilitate emulsification by decreasing the surface tension or lowering the interfacial tension between two media.[3] Reducing the interfacial tension between silicone oil and aqueous prevents small droplets of silicone oil from joining the larger bubble, thus promoting emulsification. Surfactants may also promote emulsification through increased repulsion, creating a film around the silicone oil that causes the globules to repel each other.

Surfactants may be intrinsic or extrinsic. *Intrinsic surfactants* are biologic elements released in the setting of inflammation and hemorrhage. Serum, fibrin, and fibrinogen were found to be the strongest emulsifiers in one in vitro study, followed by gamma globulins, low-density lipoproteins, and alpha-1-glycoproteins.[4] Assuring sufficient hemostasis and using antiinflammatory agents such as nonsteroidal antiinflammatory drugs or steroids may decrease the presence of these intrinsic surfactants. *Extrinsic surfactants* come from the surgical process or in the manufacturing of silicone oil. In one study, contaminants entered the surgical process as sterilization detergents and chemicals present in surgical tubing.[5] Avoiding the repeated use of surgical instruments is one way to decrease the presence of these detergents.

Viscosity and molecular weight are two important physical factors affecting the rate of emulsification. Studies have concluded that less viscous silicone oils emulsify earlier than oils with higher viscosities.[4,6] As molecular weight and viscosity are directly related, with lower molecular weight molecules possessing lower viscosity, studies

At a Glance

- Ensuring sufficient hemostasis and using antiinflammatory agents may decrease the presence of intrinsic surfactants that may facilitate emulsification.
- The adoption of small-gauge vitrectomy has led to the increased use of low-viscosity silicone oils.
- Less viscous silicone oils emulsify earlier than oils with higher viscosities.

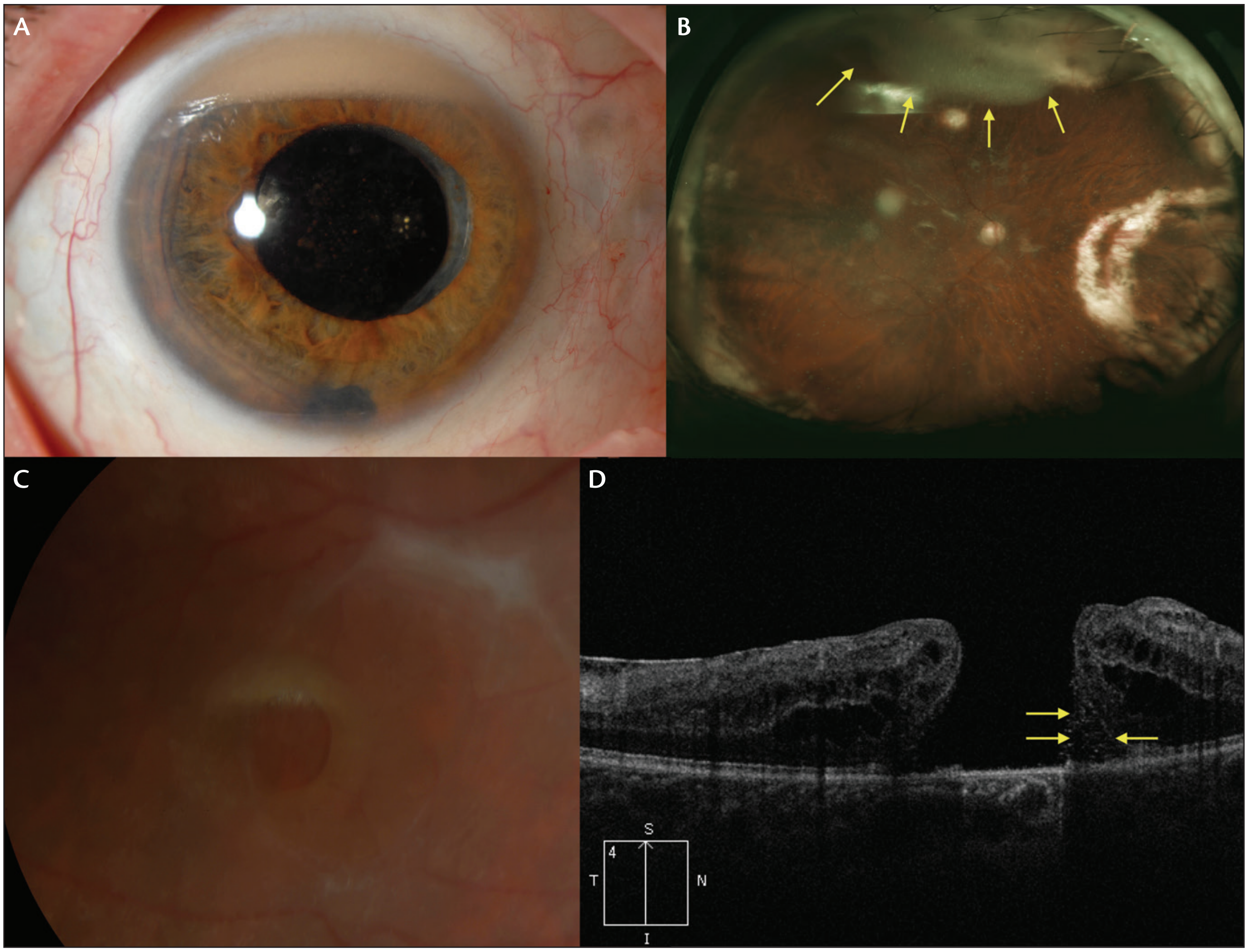

Figure. A pseudophakic 68-year-old man with recurrent retinal detachment due to PVR underwent repair with vitrectomy, membrane peeling, and silicone oil tamponade. At 1 year postoperative, his course was complicated by the development of a full thickness macular hole and silicone oil emulsification, as seen in these images. An inverse pseudohypopyon of silicone oil is seen in the anterior chamber (A). Hyperoleum (outlined in yellow arrows) is seen in the vitreous cavity (B). Droplets of silicone oil are seen superiorly in a full thickness macular hole (C). Hyperreflective dots on OCT (yellow arrows) demonstrate silicone oil droplets within the macular hole (D).

have similarly found that lower molecular weight oils are more prone to emulsification. Theoretically, oils with low molecular weight move more freely due to less long-chain branching and form fewer molecular connections, thus explaining their propensity to emulsify.[6]

Adding polymers with high molecular weight to silicone oil can reduce emulsification of lower viscosity oils. In an experimental model, the addition of such polymers increased the viscosity and viscoelasticity of the oil, rendering it more resistant to emulsification.[7,8] The advent of small-gauge vitrectomy has led to the increased use of low-viscosity silicone oils. These low-viscosity oils are easier and faster to inject and remove via a small-gauge system; however, the advantages of these oils are counterbalanced by their greater propensity for emulsification.

Of all factors studied, the duration of silicone oil in the eye has the strongest correlation with the occurrence of emulsification. In one study, investigators first noted signs of emulsification in eyes between 5 and 24 months after vitrectomy with silicone oil, with an average time of onset of 13 months after surgery.[9] Another study similarly found emulsification in all eyes that had silicone oil present for at least 1 year.[10] Based on these findings, most surgeons recommend removing silicone oil before 1 year postoperative, unless there would be an elevated risk of redetachment without the tamponade.

Shear forces during aqueous and oil movement may also promote emulsification. In an experimental model, a more complete silicone oil fill and an encircling band decreased the rate of emulsification. The authors hypothesized that this was due to a smaller aqueous-oil interface and to reduced shearing forces. Similarly, silicone oil emulsification has been shown to be more common in eyes with nystagmus, likely due to increased shearing forces in this setting. In a study of eight eyes with nystagmus, all developed emulsification within 3 months.[11]

The use of perfluorocarbon liquid (PFCL) in a direct PFCL-oil exchange may promote oil emulsification. This is hypothesized to occur due to turbulence at the interface of the PFCL and silicone oil. A shorter duration of contact between PFCL and oil and decreased turbulence during the PFCL-oil exchange may minimize emulsification.[12]

One study examined the effect of mechanical energy from intraocular instruments on silicone oil emulsification in an experimental model and found that higher power and duration during the use of phacofragmentation, phacoemulsification, and high-speed vitrectomy were associated with increased emulsification.[13] However, this may not be clinically relevant, as silicone oil is usually injected after the use of these instruments.

COMPLICATIONS CAUSED BY SILICONE OIL EMULSIFICATION

Silicone oil can lead to complications affecting nearly all ocular structures; complications can include corneal decompensation, band keratopathy, acute and chronic changes in intraocular pressure (IOP), lens opacities, epiretinal membrane, retinopathy, optic neuropathy, and extraocular extension.[14] We focus here on the major complications related to emulsification of silicone oil.

Corneal decompensation may occur when silicone oil comes in contact with the corneal endothelium.[15] Silicone oil–induced keratopathy is marked by decreased endothelial cell density, pleomorphism of remaining endothelial cells, resulting corneal edema and bullous keratopathy, stromal hypercellularity, superficial stromal calcification, and retrocorneal membrane formation.[16] These findings are not limited to emulsified silicone oil. A retrospective case series of 164 eyes with silicone oil showed that oil-induced corneal decompensation occurred in 29% of eyes (35% of aphakic eyes, 26% of pseudophakic eyes, and 20% of eyes that remained phakic at the last follow-up).[17] Similarly, the Silicone Oil Study reported corneal abnormalities in 27% of eyes with silicone oil.[18] Other corneal complications of emulsified silicone oil include a droplet-like endotheliopathy and band keratopathy.[19,20]

Secondary glaucoma is a complication in which emulsified silicone oil droplets migrate into the anterior chamber and block flow through the trabecular meshwork or cause inflammatory cells to impede outflow through the meshwork.[21] The reported incidence of secondary glaucoma due to silicone oil ranges from 11% to 56%.[22-24] The amount of emulsified oil in the anterior chamber and the use of heavy oils are risk factors for postoperative elevation of IOP.[21] The benefit of silicone oil removal following the increase in IOP is controversial. One study showed normalization of IOP after removal of oil in 93% of patients,[25] and another study showed persistent elevated IOP after oil removal.[26] Persistent IOP elevation may be explained by small remaining emulsified oil droplets continuing to obstruct the trabecular meshwork or by persistent inflammation.[21]

Emulsified silicone oil can cause retinopathy, which is becoming more evident with new imaging modalities. Until the introduction of optical coherence tomography (OCT), there was no way to assess the presence of emulsified silicone oil within the retina and optic nerve in vivo. Using OCT, investigators have identified silicone oil droplets within the retina after macular hole surgery with internal limiting membrane (ILM) peel and silicone oil tamponade.[27] More recently, there have been additional reports of silicone oil infiltration of the retina and optic nerve head using swept-source OCT and adaptive optics.[28,29] Studies using spectral-domain OCT (SD-OCT) have shown hyperreflective spherical bodies underneath epiretinal membranes, within the retina, and in the subretinal space.[28,30] The proposed mechanisms include iatrogenic defects in the ILM that may increase the ability of emulsified oil to penetrate retinal tissues or retinal breaks, in turn allowing migration into the subretinal space.[27]

In a study of 24 eyes that underwent vitrectomy with silicone oil for retinal detachment with PVR, SD-OCT performed 3 months after surgery showed emulsified oil in intraretinal cystoid spaces in five eyes (21%) and between the hyperreflective line of silicone oil and the optic disc in one eye (4%). These changes persisted at 6 months, at which time an additional three eyes showed emulsified oil droplets between the hyperreflective line of oil and the optic disc.[30] The long-term impact of emulsified silicone oil in these locations is unknown. In rare cases, silicone oil emulsification may be a cause of reversible vision loss, as demonstrated by visual recovery after oil removal.[31]

CONCLUSION

Silicone oil emulsification is a clinically significant complication of silicone oil use and one that is difficult to manage, as it may affect all ocular structures. Emulsification is influenced by the physical properties of the oil, the surgical procedure and environment, and postoperative factors. With new imaging modalities, clinicians are able to identify silicone oil emulsification and its complications earlier. ■



Dean Eliott, MD, is the associate director of the retina service at the Massachusetts Eye and Ear Infirmary in Boston, Mass., and is the Stelios Evangelos Gragoudas Associate Professor of Ophthalmology at Harvard Medical School in Boston, Mass. Dr. Eliott may be reached at dean_eliott@meei.harvard.edu.

Thanos D. Papakostas, MD, is a first-year fellow at the Massachusetts Eye and Ear Infirmary in Boston, Mass. Dr. Papakostas may be reached at thanosp@me.com.

Avni V. Patel, MD, MBA, is a third-year resident at the Massachusetts Eye and Ear Infirmary in Boston, Mass.Dr. Patel may be reached at Avni_Patel@meei.harvard.edu.

1. Cibis PA, Becker B, Okun E, Canaan, S. The use of liquid silicone in retinal detachment surgery. *Arch Ophthalmol*. 1962;68:590-599.
2. Gallemore RP, McCuen BW II. Silicone oil in vitreoretinal surgery. In: Ryan SJ, ed. Retina. 4th ed. Philadelphia: Elsevier Mosby; 2006: 2211-2234.
3. Feynman RP, Leighton RB, Sands M. The Feynman Lectures on Physics. 7th ed. Reading, MA; Addison-Wesley; 1972. Volume I, Chapters 40,43; Volume II, Chapters 40,41.
4. Heidenkummer HP, Kampik A, Thierfelder S. Emulsification of silicone oils with specific physicochemical characteristics. *Graefes Arch Clin Exp Ophthalmol*. 1991;229(1):88-94.
5. Dresp JH, Menz D-H. Preparation and processing of vitreoretinal instrumentation and equipment as a risk factor for silicone oil emulsification. *Retina*. 2004;24(1):110-115.
6. Crisp A, de Juan E, Tiedeman J. Effect of silicone oil viscosity on emulsification. *Arch Ophthalmol*. 1987;105(4):546-550.
7. Williams RL, Kearns VR, Lo AC, et al. Novel heavy tamponade for vitreoretinal surgery. *Invest Ophthalmol Vis Sci*. 2013;54(12):7284-7292.
8. Caramoy A, Kearns VR, Chan YK, et al. Development of emulsification resistant heavier-than-water tamponades using high molecular weight silicone oil polymers. *J Biomater Appl*. 2015;30(2):212-220.
9. Toklu Y, Cakmak HB, Ergun SB, et al. Time course of silicone oil emulsification. *Retina*. 2012;32(10):2039-2044.
10. Federman JL, Schubert HD. Complications associated with the use of silicone oil in 150 eyes after retina-vitreous surgery. *Ophthalmology*. 1988;95(7):870-876.
11. Yilmaz T, Güler M. The role of nystagmus in silicone oil emulsification after pars plana vitrectomy and silicone oil injection for complex retinal detachment. *Eur J Ophthalmol*. 18(1):150-154.
12. Dresp JH, Menz D-H. Interaction of different ocular endotamponades as a risk factor for silicone oil emulsification. *Retina*. 25(7):902-910.
13. Francis JH, Latkany PA, Rosenthal JL. Mechanical energy from intraocular instruments cause emulsification of silicone oil. *Br J Ophthalmol*. 2007;91(6):818-821.
14. Miller JB, Papakostas TD, Vavvas DG. Complications of emulsified silicone oil after retinal detachment repair. *Semin Ophthalmol*. 29(5-6):312-318.
15. Sternberg P, Hatchell DL, Foulks GN, Landers MB. The effect of silicone oil on the cornea. *Arch Ophthalmol*. 1985;103(1):90-94.
16. Foulks GN, Hatchell DL, Proia AD, Klintworth GK. Histopathology of silicone oil keratopathy in humans. *Cornea*. 1991;10(1):29-37.
17. McCuen BW, de Juan E, Landers MB, Machemer R. Silicone oil in vitreoretinal surgery. Part 2: results and complications. *Retina*. 1985;5(4):198-205.
18. Abrams GW, Azen SP, Barr CC, et al. The incidence of corneal abnormalities in the Silicone Study. Silicone Study Report 7. *Arch Ophthalmol*. 1995;113(6):764-769.
19. Bennett SR. Band keratopathy from emulsified silicone oil. *Arch Ophthalmol*. 1990;108(10):1387.
20. Azuara-Blanco A, Dua HS, Pillai CT. Pseudo-endothelial dystrophy associated with emulsified silicone oil. *Cornea*. 1999;18(4):493-494.
21. Ichhpujani P, Jindal A, Jay Katz L. Silicone oil induced glaucoma: a review. *Graefes Arch Clin Exp Ophthalmol*. 2009;247(12):1585-1593.
22. Al-Jazzaf AM, Netland PA, Charles S. Incidence and management of elevated intraocular pressure after silicone oil injection. *J Glaucoma*. 2005;14(1):40-46.
23. De Corral LR, Cohen SB, Peyman GA. Effect of intravitreal silicone oil on intraocular pressure. *Ophthalmic Surg*. 1987;18(6):446-449.
24. Honavar SG, Goyal M, Majji AB, et al. Glaucoma after pars plana vitrectomy and silicone oil injection for complicated retinal detachments. *Ophthalmology*. 1999;106(1):169-176, discussion 177.
25. Jonas JB, Knorr HL, Rank RM, Budde WM. Intraocular pressure and silicone oil endotamponade. *J Glaucoma*. 2001;10(2):102-108.
26. Budenz DL, Taba KE, Feuer WJ, et al. Surgical management of secondary glaucoma after pars plana vitrectomy and silicone oil injection for complex retinal detachment. *Ophthalmology*. 2001;108(9):1628-1632.
27. Chung J, Spaide R. Intraretinal silicone oil vacuoles after macular hole surgery with internal limiting membrane peeling. *Am J Ophthalmol*. 2003;136(4):766-767.
28. Errera M-H, Liyanage SE, Elgohary M, et al. Using spectral-domain optical coherence tomography imaging to identify the presence of retinal silicone oil emulsification after silicone oil tamponade. *Retina*. 2013;33(8):1567-1573.
29. Mrejen S, Sato T, Fisher Y, Spaide RF. Intraretinal and intra-optic nerve head silicone oil vacuoles using adaptive optics. *Ophthalmic Surg Lasers Imaging Retina*. 2015;45(1):71-73.
30. Odrobina D, Laudaska-Olszewska I. Analysis of the time and location of the silicone oil emulsification by spectral-domain optical coherence tomography after silicone oil tamponade. *Biomed Res Int*. 2014;2014:372045.
31. Nicholson BP, Bakri SJ. Silicone oil emulsification at the fovea as a reversible cause of vision loss. *JAMA Ophthalmol*. 2015;133(4):484-486.