SCIENTIFIC REPORT

Mechanical energy from intraocular instruments cause emulsification of silicone oil

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Br J Ophthalmol 2007;**91**:818–821. doi: 10.1136/bjo.2006.103994

Aim: The complications of intraocular silicone oil include emulsification, which may lead to vision-threatening disorders such as keratopathy, secondary glaucoma and retinopathy. The authors study the effect of mechanical energy from surgical instruments on the emulsification of silicone oil.

Methods: Three different handpieces (phacofragmentation, phacoemulsification, high-speed vitrectomy) were placed at the interface of balanced salt solution and silicone oil (1000 and 5000 cst, 200 fluid; Dow Corning). The phacofragmentation handpiece was evaluated over different ultrasound powers and duration. Emulsification was quantified with phase-contrast microscopy and manual counting of digital photographs by a masked examiner. In addition, phacoemulsification was performed in the anterior chamber of a human ex vivo eye with full-fill silicone oil.

Results: Emulsification increases with higher phacofragmentation power and duration and is greater for 1000 cst silicone oil. Emulsification of silicone oil occurs with phacoemulsification and high-speed vitrectomy handpieces.

Conclusions: The energy from surgical handpieces is sufficient to result in silicone oil emulsification.

Silicone oil is useful as a surgical vitreous substitute in a number of vitreoretinal disorders.¹ However, once emulsified, silicone oil can migrate into ocular tissue and may enter the anterior chamber.^{1–3 6 7} Emulsified silicone oil may cause vision-threatening conditions, including keratopathy, secondary glaucoma and retinopathy – and its removal may not reverse its effects.^{1 2 7} Silicone emulsification occurs with a decrease of interfacial surface tension.^{3 8} Many studies have revealed physicochemical properties that facilitate silicone emulsification, such as viscosity, biologic emulsifiers, molecular entanglements and impurities.^{9–11}

The purpose of our experiment was to examine whether mechanical energy from surgical instruments can result in emulsification of silicone oil. We used an in vitro model to assess silicone oil emulsification over power and duration with phacofragmentation, phacoemulsification and high-speed vitrectomy handpieces.

METHODS

For the in vitro model, 1.5 mL of silicone oil (1000 and 5000 cst, fluid 200; Dow Corning) was added to 1.5 mL of balanced salt solution (BSS) in a plastic test-tube. The effect of ultrasound power on silicone emulsification was evaluated by placement of the phacofragmentation handpiece at the BSS/silicone oil interface for 80 seconds over six different ultrasound powers, starting at 10%, with increasing 10% increments. The duration of ultrasound power was evaluated separately by placement of the phacofragmentation handpiece at the BSS/silicone interface (at 40% power) over six increasing time periods, beginning at ten seconds.

The experiment was repeated for the high-speed vitrectomy handpiece (cut rate of 1500 cpm, 5 mm Hg vacuum) for ten minutes and the phacoemulsification handpiece (40% ultrasound, 15 mm Hg vacuum, 80 cm bottle height) for one minute.

All test-tubes were then centrifuged at 3400 rpm for three minutes on a Cygnus CF-VI centrifuge. Controls consisted of silicone oil only and aqueous only for each handpiece parameter and silicone oil/aqueous without any exposure to handpiece parameters. All the above experiments were repeated separately for the 1000 and 5000 cst silicone oil. In addition, each handpiece experiment was duplicated with a more limited set of parameters using medical grade 5000 cst silicone oil (Bausch and Lomb, Rochester, NY, USA) and 1000 cst silicone oil (Alcon, Fort Worth, TX, USA). Due to the infusion effects of phacoemulsification, a closed system was used to permit capture of emulsified silicone. All experiments were conducted using an available clinical Venturi vacuum-based system used for vitrectomy, phacoemulsification and fragmentation.

The degree of emulsification for the different parameters tested in the in vitro model was quantified by phase-contrast microscopy with magnification factor of 10x (Zeiss Axiophot). A masked examiner manually counted the emulsification bubbles in eight random photographs and the mean number of emulsification bubbles for each experiment was calculated, using a previously established technique.^{4 5}

In the ex vivo model, complete vitrectomy was performed and a full-fill of silicone oil was obtained in a human eye. The lens was removed, leaving the posterior capsule intact. A corneoscleral tunnel allowed for the placement of the phacoemulsification handpiece in the anterior chamber, mimicking standard construction. Emulsified bubbles were visualized with 10x magnification.

RESULTS

The Mann-Whitney non-parametric test was used to analyse results compared to silicone oil only at each handpiece parameter. Emulsification of both 1000 cst and 5000 cst silicone oil in vitro increased with greater phacofragmentation power and duration. The mean number of emulsification bubbles was also greater, for 1000 cst versus 5000 cst silicone oil over all conditions. In addition, bubbles were observed to be smaller for the 1000 cst silicone oil. Results are shown in table 1 and fig 1.

Phase-contrast photographs of emulsification over different parameters are shown in fig 2. Furthermore, emulsification was identical using each handpiece in the medical grade 5000 cst and 1000 cst silicone oil.

In vitro, emulsification occurred with both the phacoemulsification and high-speed vitrectomy handpiece in 1000 cst and 5000 cst silicone oil, as confirmed with phase-contrast microscopy. There was no emulsification with either the 1000 cst or 5000 cst silicone oil only, aqueous only or silicone oil/aqueous without phacofragmentation controls, as confirmed with

Table 1 In vitro silicone emulsification with varying phacofragmentation ultrasound power and duration for 1000 cst and 5000 cst

Ultrasound Power (%)	Silicone oil emulsification bubbles, mean (SD)	
	1000 cst	5000 cst
10%	2.75 (2.12)**	1.50 (1.31)**
20%	15.25 (3.65)	6.13 (1.13)
30%	45.88 (7.20)	9.88 (1.55)
40%	64.50 (7.76)	26.00 (3.30)
50%	101.63 (11.15)	34.75 (4.77)
60%	105.13 (11.46)	39.38 (5.85)
Power Duration (s)	1000 cst	5000 cst
	1000 cst	5000 cst
10	3.63 (3.54)	0.88 (0.83)*
20	30.50 (3.42)	1.63 (0.74)
30	45.50 (2.78)	8.50 (2.20)
40	55.00 (5.98)	18.25 (3.15)
50	59.50 (3.30)	20.50 (2.56)
60	99.13 (9.48)	46.88 (8.18)

Mann-Whitney non-parametric test: *: $p < 0.05$; **: $p < 0.01$, all other values are $p < 0.001$

phase-contrast microscopy. All emulsions were stable over at least two weeks.

Emulsification of the silicone oil ex vivo is shown in fig 3.

DISCUSSION

Previous studies have examined the effects of mechanical energy on emulsification: vortex-shaking^{10,11} and rotational orbital shaking.^{4,5} Cataract formation is a common complication of intraocular silicone oil.^{1,13}

In vitro, we show that emulsification of silicone oil with aqueous can occur with phacofragmentation and phacoemulsification. In addition, emulsification increases with increasing ultrasound power (mean 5000 cst silicone oil emulsification bubbles with 10% phacofragmentation power, 1.50 (SD 1.31) versus 60% power 39.38 (SD 5.85) ($p < 0.001$)) and duration of phacofragmentation (mean 5000 cst silicone oil emulsification bubbles with ten seconds phacofragmentation, 0.88 (SD 0.83) versus 60 seconds 46.88 (SD 8.18) ($p < 0.001$)). As a control, we demonstrate that silicone oil without BSS and BSS without silicone oil did not emulsify under any of our handpiece test conditions, and silicone oil with the addition of BSS without mechanical energy did not emulsify. The mechanical and/or cavitation energy,¹⁴ produced by these surgical instruments is likely to disrupt the interfacial surface tension between silicone oil and BSS, thus facilitating emulsification (the vitrectomy handpiece would have mechanical energy alone). Continuous kinetic energy input has been reported to further segregate the droplets,⁹ as confirmed in our study by increasing emulsification with duration of phacofragmentation.

We also show that emulsification is greater with 1000 cst versus 5000 cst silicone oil over all experiments (for eg, mean silicone oil emulsification bubbles at 50% phacofragmentation power with 1000 cst, 101.63 (SD 11.15) versus 5000 cst, 34.75 (SD 4.77) ($p < 0.001$)). These results confirm previous studies that have demonstrated greater emulsification with 1000 cst compared to 5000 cst silicone oil.⁹

Our in vitro model mimics in vivo conditions at aqueous silicone interfaces with decreased aspiration allowing containment of the emulsion (without confounding retrieval of emulsification post-transit through handpiece and tubing) and placement of the handpiece at the silicone oil/aqueous interface where emulsification occurs.⁴ Centrifugation (a process used to determine the amount of emulsification without increasing the amount) was employed to accelerate aggregation of the bubbles and segregate the solution into three visible constituents.^{11,12}

Figure 1 Graphs showing silicone emulsification with increasing increments of (A) phacoemulsification ultrasound power and (B) duration.

Ikeda broadens the definition of emulsification to include large non-dispersed droplets, and suggests surface-active agent interactions are responsible for microscopic suspended oil, while mechanical energy results in large, non-dispersed emulsification.¹⁵ However, we show that mechanical energy in vitro can give a microsuspension, which is comparable to the equivalent mechanical energy giving large non-dispersed droplets ex vivo. The architectural environment present intraocularly in vivo may permit large droplets to form, as we saw ex vivo, or the full-fill effect,⁴ ex vivo may result in a lower level of emulsification in the form of larger bubbles.

Successful extracapsular extraction in nine silicone-filled eyes was reported with simultaneous silicone extraction.¹⁶ Others suggest capsular discission through pars plana may cause emulsification.¹⁷ Small silicone bubbles entering the anterior chamber were removed by aspiration during phacoemulsification in three of 70 patients.¹⁸ While most emulsion bubbles can be suctioned with the handpiece-associated aspirator, even a small residual amount may be toxic and cause vision impairment.¹⁻³ Complete removal of silicone oil droplets can be difficult.¹⁹ Emulsified bubbles can remain hidden for as long as two years post-surgery by lodging anterior to the pars plana.²⁰

There may be conditions where a limited vitrectomy is useful in a silicone-filled eye. However, we show that emulsification during high-speed vitrectomy is possible in vitro. Given our observation of greater emulsification with placement of the handpiece at the BSS/silicone oil interface, these findings may

Figure 2 Phase-contrast photographs (all at 10x) demonstrating effects of phacoemulsification on silicone oil emulsification: (A) 5000 cst silicone oil/BSS at 10% power (B) 5000 cst silicone oil/BSS at 50% power (C) 1000 cst silicone oil/BSS at 50% power demonstrating smaller emulsification bubbles (D) 5000 cst silicone oil only at 50% power.

Figure 3 Photographs (10x) of ex vivo phacoemulsification for at least five minutes with an intact posterior capsule. These droplets were large and stable within the pars plicata over at least three days when images were taken. (A) posterior to pars plicata (B) pars plicata (C) posterior iris.

be more applicable to under-filled eyes with an intraocular interface or eyes that require long durations of vitrectomy.

In vitro, we show that phacoemulsification and phacoemulsification can result in emulsification of silicone oil and can also occur ex vivo with phacoemulsification. However, there are no large case series that demonstrate this in vivo. Posterior designed handpieces, such as the phacoemulsification and vitrectomy handpieces, may result in greater emulsification due to their proximity to the silicone oil/aqueous interface. In complex eyes with intractable retina problems, the clinical plan may require silicone oil to be left in the eye without removal. In these cases, or with some zonular dialysis/dehiscence or other architecturally altered eyes, a silicone oil exchange post-phacoemulsification may be considered to eliminate any increased rate of emulsification caused by surgery.

ACKNOWLEDGEMENTS

We thank Parag Parohit, Chemical Engineering, Columbia University for reviewing the manuscript and experimental plan.

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Competing interests: None.

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Accepted 8 October 2006

Published Online First 11 October 2006

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