Graefe's Arch Clin Exp Ophthalmol (1999)
237:870–874

Rachel Williams
David Wong

The influence of explants on the physical efficiency of tamponade agents

Received: 9 December 1998
Revised version received: 9 February 1999
Accepted: 10 February 1999

R. Williams (✉)
Department of Clinical Engineering,
University of Liverpool, Duncan Building,
Daulby Street, Liverpool L60 3GA, UK
e-mail: rlw@liv.ac.uk
Fax: +44-151-7065803

D. Wong
St Paul's Eye Unit,
Royal Liverpool University Hospital Trust,
Liverpool, UK

Abstract ● Background: The effectiveness of tamponade agents depends on the interfacial energies of the surfaces involved, the buoyancy of the tamponade agent and its volume. The ability of gas or silicone oil to tamponade retinal breaks may also depend on the shape of the vitreous cavity, and this in turn may be altered by the application of surgical explants or encircling bands.
● Method: We have constructed a model eye chamber (using surface-modified polymethylmethacrylate) to study the influence of indentations on the overall tamponade effect.
● Results: We show that in the case of silicone oil, the presence of indentations may enhance the tamponade to specific areas of the model eye cavity, namely inferiorly and posteriorly, and may diminish the tamponade to areas immediately adjacent to the indentations. This modification of the tamponade effect is not observed when air is used.
● Conclusion: The position of explants is critical to the efficiency of tamponade agents.

Introduction

In the repair of retinal detachment, the only measures for closure of retinal breaks consists of external tamponade in the form of scleral buckling and internal tamponade using the surface energies of, principally, silicone oil and gas mixtures [4, 5, 10]. In the cases of retinal detachment complicated by large retinal tears or by epiretinal membranes, the choice of tamponade agents has been the subject of extensive clinical investigations. The Silicone Oil Studies set out to investigate, using prospective randomized clinical trials, the efficacy of inert gases versus silicone oil [12, 13]. In the treatment of many of these cases a combination of surgical explants and internal tamponade agents is used [1, 2]. The separate roles of the explants and the internal tamponade are not clearly defined and in particular, whether explants are helpful, or in the case of giant retinal tears or retinotomies, for example, whether explants are indeed necessary [8]. Scleral indentations in themselves may be responsible for complications such as interference of extraocular muscle function and slippage of giant retinal tears [7, 14, 11]. Another area of controversy is whether it is advantageous to leave the eye phakic or whether there may be theoretical benefits in removing the crystalline lens [3, 9].

In a previous paper [6], we have discussed the importance of the interfacial energies to the tamponade effect. We have shown that the retinal surface is hydrophilic and justified the use of surface modified polymethylmethracylate (PMMA) to construct a spherical model to mimic the eye cavity and to study the tamponade effect. We established the relationship between the area of the cavity covered and the volume of silicone oil and air used as internal tamponade agent. In this paper, we will explore the interaction of surface energies with the shape of the eye cavity.

Materials and method

To allow clear visualisation of the spatial positioning of the silicone oil bubble we manufactured a cylindrical model from polymethylmethacrylate (Fig. 1). It had a internal diameter of 20 mm and a

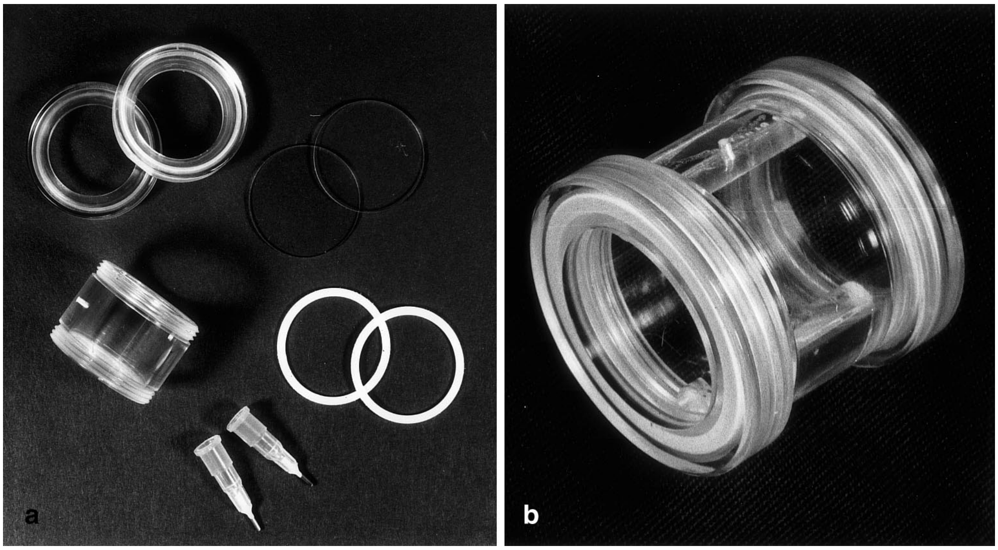


Fig. 1 The cylindrical model eye chamber: **a** as its components; **b** fully constructed

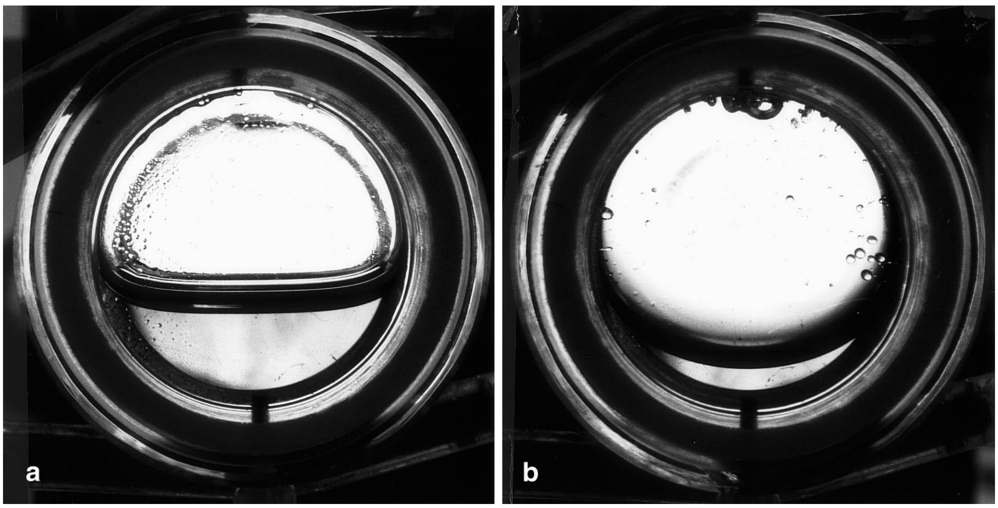


Fig. 2 The model eye chamber without indents: **a** with an air bubble; **b** with a silicone oil bubble

length of 20 mm. The ends could be unscewed to allow cleaning between experiments. There were input ports in the top and bottom of the chamber to allow filling and exchange of fluid. The cylinder was held horizontally on an optical bench with a light at one end to provide even illumination and a camera set up at the other end to record the interaction of the fluids.

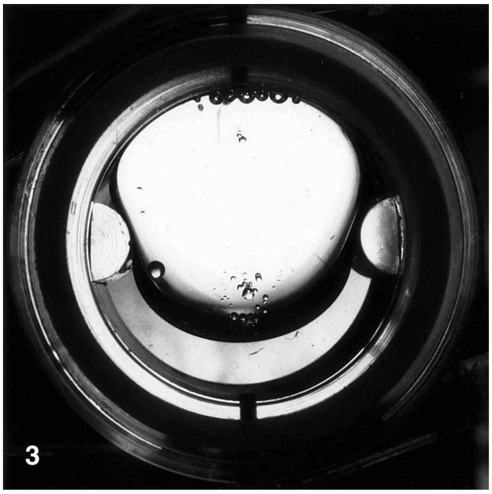
The model was filled initially with a 5% bovine albumin solution in phosphate-buffered saline (PBS) and the albumin allowed to adsorb onto the internal surface of the model for approximately 10 min. This rendered the surface hydrophilic. Air or silicone oil was injected through the upper port in approximately 0.5-ml increments while the protein solution was allowed to flow out through the lower port. Photographs were taken after each increment.

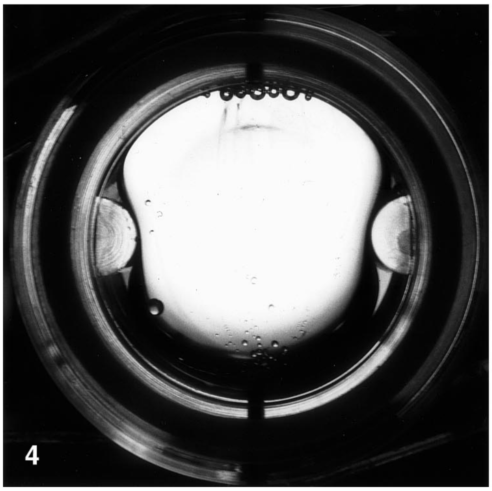
Two other models were examined. One had a semicircular indent with a radius of 2.5 mm placed along the length of the cylinder at 90° to the vertical to model the influence of a crystalline lens. The other had similar indents placed opposite each other at 90° and 270° to model an encircling band. A similar filling and exchange procedure was followed for these models.

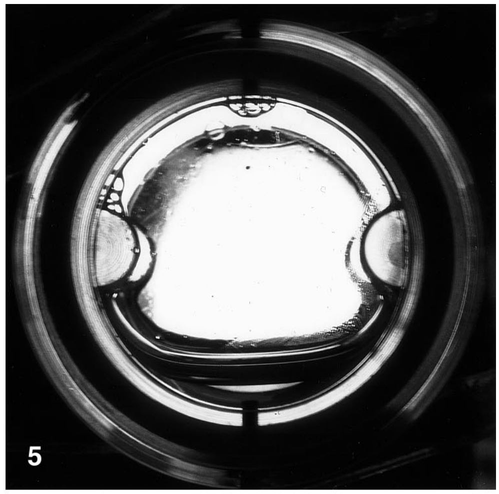
Results

Model with no indent

For small bubbles of air or silicone oil the shape is rounded and little contact is made between the bubble and the internal surface of the model. As the bubbles increase in size the shape of the air and silicone oil bubbles becomes increasingly different. Figure 2 presents the appearance of relatively large bubbles of air and silicone oil. It is clearly demonstrated that the air bubble had a flat-bottomed shape and made good contact with the internal surface of the model. The silicone oil bubble, on the other hand, clearly had a rounded bottom and therefore, for the same volume, does not contact as much of the internal surface of the model as for air.







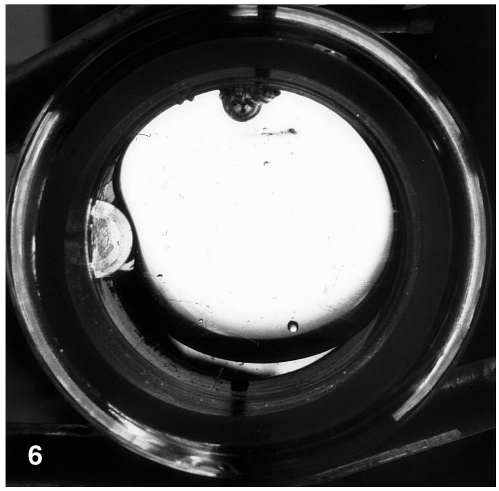


Fig. 3 The model eye chamber with two indents partially filled with a silicone oil bubble

Fig. 4 The modle eye chamber with two indents nearly filled with a silicone oil bubble

Fig. 5 The model eye chamber with two indents nearly filled with an air bubble

Fig. 6 The model eye chamber with one indent partially filled with a silicone oil bubble

Models with two indents at 90° and 270°

Figures 3 and 4 present the appearance of silicone oil bubbles in the model with two indents. It is shown that the indents cause a change in shape of the bubble such that the oil makes contact only with the tip of the indent, leaving a substantial area above the indent without any tamponade effect. As the silicone oil bubble increased in size it was pinched into an hourglass shape, preferentially contacting the model at the top and bottom rather than the sides. In contrast, the air bubbles appeared to wrap neatly around the indents and maintained a flat-bottomed shape (Fig. 5).

Model with one indent at 90°

When the silicone oil bubble came into contact with the indent, the position of the bubble was shifted away from the indent towards the opposite side of the model (Fig. 6). As the bubble increased in volume the area of contact with the internal surface of the model increased on the side opposite the indent and the area of the model surface either side of the indent remained in contact with the aqueous environment until the very last incremental increase in volume.

Discussion

The effectiveness of an internal tamponade agent relies on its ability to make contact with the internal surface of the vitreous cavity. Theoretically, the shape of a small bubble can be predicted solely by the surface interaction of the three phases in contact, namely vitreous fluid, tamponade agent and the retina. For larger bubbles, however, buoyancy plays an important part. In the case of gas or air, the difference in specific gravity between it and water is very large. Therefore, small bubbles are rounded and larger bubbles have a flat bottom surface (Fig. 2a). This flattening of the bubble increases the tamponade efficiency in that more of the volume contributes towards making contact with the internal cavity. A small bubble of silicone oil is rounded when in contact with water and with the retina because of its hydrophobicity. In the case of silicone oil, however, the specific gravity (0.97) is close to that of water (1.0) and therefore, as expected, a larger bubble of silicone oil is also rounded because there is little buoyancy to modify its shape (Fig. 2b). The overall tamponade efficiency is decreased because part of the volume is used to form the meniscus instead of making contact with the eye cavity. This difference in efficiency between silicone oil and gas is inherent in their physical properties in terms of surface energy and buoyancy and cannot be altered by any surgical strategies. Of course, clinically this difference may be of little significance if the eye cavity can be totally filled with the tamponade agent.

In practice, a total fill of the vitreous cavity is difficult to achieve. We have shown in a previous publication [6] that because the eye approximates a spherical cavity it is difficult to achieve a total tamponade effect. Whether with silicone oil or gas, a slight under-fill results in relatively large areas of the cavity uncovered. When silicone oil is used, under-fill may arise either as a result of poor fluid / air exchange technique per-operatively or by compression of vitreous gel remnants by the tamponade and by choroidal decongestion in the post-operative period. Scleral buckling is therefore considered important and has been shown to be effective when used in combination with silicone oil tamponade. In the case of gas, the use of slightly expansile inert gas mixtures may ensure a total fill in the early post-operative phase. In practice, the precise concentration of expansile and non-expansile gas mixtures is difficult to determine in man. Up to 30% sulfahexafluoride and 20% perfluoropropane have been used, although volumetric studies using A-mode ultrasound biometry have shown tremendous variation in the bubble size in the early post-operative period.

In this study, we used a cylindrical transparent chamber because it facilitates photographic recording of the interactions. We recognized that a cylindrical chamber provides more of a two-dimensional representation of a three-dimensional situation. Further work involving ex vivo vitrectomized pig's eyes is in progress, employing nuclear magnetic resonance to image the interactions of the intraocular fluids. We believe that our model is valid and offers some insight into the influence of indents with bubbles of internal tamponade agents, in particular, how surgical strategies may be used to enhance the tamponade effect of silicone oil.

When the chamber containing indents is filled with silicone oil and aqueous, the oil is seen not to fill the recesses formed by the indents and the model eye cavity wall (Fig. 3). This observation may have an important clinical implication for the use of external scleral buckling to support retinal breaks. Our results indicate that care should be taken to ensure maximal fill and that the entire retinal break should be mounted on the summit of the indent, since the parts of the retinal break which fall on the slopes of the indent may not be subject to internal tamponade effect of the silicone oil. It may also be reasonable to extrapolate that a gentle broad buckle may be more appropriate than narrow deep indents when silicone oil is used. Further work in this area may be indicated.

Another observation is that the presence of the indent alters the shape of the bubble of silicone oil inside the eye model. When two indents are present (one on each side in the horizontal meridian) the bubble is seen to conform to the shape of the eye chamber such that it adopts a shape more closely resembling an hourglass or figure-of-eight (Fig. 4). We have already pointed out that the recesses around the indent are not in contact with silicone oil, and the fill is therefore subtotal. The inferior part of the eye cavity, because of the hourglass shape of the oil bubble, is, however, in contact with the oil, which it otherwise might not be (compare Fig. 2b and Fig. 4). This observation leads us to generalize that any alteration of the shape of the eye cavity from a sphere to any other geometric shape may be an advantage promoting contact between the oil the cavity wall. Indeed, the worse situation may be that of a spherical bubble of oil inside a spherical eye cavity, in which case the contact is at a minimum. On this basis, leaving a natural indent inside the eye by preserving the lens is at least a theoretical advantage to lens removal routinely. Without the indentation of the lens, a silicone oil bubble is free to adopt a more spherical shape, partly by moving the iris lens diaphragm forwards or by herniation of part of the bubble into the anterior chamber. Similarly, the use of segmental local indentations or of encircling elements may alter the shape of the globe, and therefore of the silicone oil bubble, to enhance the tamponade effect inferiorly (Fig. 4) or posteriorly (Fig. 6). In other words, the use of locally placed explants may enhance the overall internal tamponade effect of an oil bubble to parts of the retina remote from the site of the indent. For example, it might be visualized that the use of an encirclement at the vitreous base may enhance oil tamponade effect to a posterior retinal break or an inferior and posterior retinotomy edge even though the indent is not directly supporting these breaks.

When the model eye is filled with air and aqueous in the presence of indents, the air bubble is seen to cover the entire indent (Fig. 5) including the recesses between the indents and the eye wall. Thus the internal tamponade effect is not seen to be influenced by the presence of external scleral buckling. There appear to be no specific surgical strategies in the application of explants that can enhance the overall tamponade effect. Specifically, from the point of view of internal tamponade there is no theoretical advantage in leaving the eye phakic or rendering it aphakic, or in the use of explants other than to support retinal breaks and to relieve vitreoretinal tractions.

In conclusion, the model eye chamber constructed of surface-modified PMMA allowed us to visualize the interaction of silicone oil or gas as an internal tamponade. We have shown how the internal tamponade effect may be influenced by scleral buckling, and in the case of silicone oil, the observations suggest the following surgical strategies:

1. Theoretically it may be advantageous to leave an eye phakic.
2. Care should be taken when using scleral buckling to support a retinal break, in order to ensure maximal filling, and that the buckle is accurately mounted so that the break is positioned at the apex of the indent into the oil bubble.
3. External scleral buckling may enhance the tamponade effect of silicone oil to areas of the retina remote from the vicinity of the indent(s).
4. Scleral buckling may be useful to improve silicone tamponade for retinal breaks in the inferior retina.

We believe that these suggestions are of clinical importance and that further work using ex vivo eyes to corroborate our observations from the model eye will be worthwhile.

References

1. Aaberg TM (1988) Management of anterior and posterior proliferative vitreoretinopathy. XLV Edward Jackson Memorial Lecture. Am J Ophthalmol 106:519–532
2. Azen SP, Boone DC, Barlow W, et al (1991) Methods, statistical features and baseline results of a standardized, multicentered ophthalmologic surgical trial: the Silicone Study. Control Clin Trials 12:438–455
3. Bottoni F, Sborgia M, Arpa P, et al (1993) Perfluorocarbon liquids as postoperative short-term vitreous substitutes in complicated retinal detachmnet. Graefe’s Arch Clin Exp Ophthalmol 231:619–28
4. Cibis PA, Becker B, Okun E, Canaan S (1962) The use of liquid silicone in retinal detachment. Arch Ophthalmol 68:590–599
5. Custodis E (1953) Bedeutet die Plombenaufnahung und die Sklera einen Fortschritt in der operativen Behandlung der Netzhautablösung? Ber Dtsch Ophthalmol Ges 58:102–105
6. Fawcett I, Williams R, Wong D (1994) Contact angles of substances used for internal tamponade in retinal detachment surgery. Graefe’s Arch Clin Exp Ophthalmol 232:438–444
7. Grizzard WS, Hilton GF, Hammer ME, Taren D (1994) A multivariate analysis of anatomic success of retinal detachments treated with scleral buckling. Graefe’s Arch Clin Exp Ophthalmol 232:1–7
8. Kreiger A, Lewis H (1992) Management of giant retinal tears without scleral buckling. Use of radical dissection of the vitreous base and perfluoro-octane and intraocular tamponade. Ophthalmology 99:491–497
9. Leaver P, Billington B (1989) Vitrectomy and fluid/silicone oil exchange for giant retinal tears: 5 years follow-up. Graefe’s Arch Clin Exp Ophthalmol 227:323–327
10. Lincoff H, Coleman J, Kreissig I, et al (1983) The perfluorocarbon gases in the treatment of retinal detachment. Ophthalmology 90:546–551
11. Mathis A, Pagot V, Gazagne C, Malecaze F (1992) Giant retinal tears. Surgical techniques and results using perfluorodecalin and silicone oil tamponade. Retina 12 [Suppl 3]:S7–10
12. Silicone Study Report 1 (1992) Vitrectomy with silicone oil or sulfur hexafluoride gas in eyes with severe proliferative vitreoretinopathy: results of a randomized clinical trial. Arch Ophthalmol 110:770–779
13. Silicone Study Report 2 (1992) Vitrectomy with silicone oil or perfluoropropane gas in eyes with severe proliferative vitreoretinopathy: results of a randomized clinical trial. Arch Ophthalmol 110:780–792
14. Wong D, Williams R, German M (1998) Gas or oil/perfluorodecalin exchange: a model to avoid slippage. Graefe’s Arch Clin Exp Ophthalmol 236(3):234–237