3 Principles of Internal Tamponade

Contents

3.1 Gases

3.1.1 Principles

(Also see Appendix: Useful formulae and rules)

It is important to understand Fick's diffusion equation; that is, that two gases on either side of a semipermeable membrane will pass across the semipermeable membrane until their concentrations are equal on both sides. If one gas travels across the membrane at a slower speed than the other, then this causes a difference in size of the gas bubbles on either side of the membrane. For example, if a large molecule gas like sulphahexafluoride (SF_6) is placed within the eye, this passes slowly into the blood stream, to the lungs and out into the atmosphere. However, nitrogen from the atmosphere is highly soluble and passes rapidly through the lungs, blood and into the eye causing the SF_6 gas bubble to enlarge within the eye. For this reason, after a vitrectomy, SF_6 and perfluoropropane (C_3F_8) must be mixed with air to prevent a volumetric increase, which would then cause a rise in intraocular pressure.

Additional surgical steps:

1. Attach the air pump tubing to the three-way tap on the infusion line and switch on the air pump at 30–40 mmHg.
2. With a flat retina, place the tip of a flute cannula close to the optic nerve head to drain the vitreous cavity fluid.
3. Turn the three-way tap to allow insertion of the filtered air.
4. Fill the cavity.
5. Close one sclerotomy.
6. Prepare the long-acting gas (mixed to the desired concentration with filtered air) by inserting into a 50-ml syringe (make sure any tubing for drawing up gas is flushed through with the gas before drawing up onto the syringe). Draw up the gas; for 30 % gas, you need 15 ml of gas followed by 35 ml of air to give a total of 50 ml (you may need more in a high myope; use two syringes). You can usually see how much gas was inserted by holding up the syringe to the light. Look for a condensation line where the syringe stopper was drawn up to with the long-acting gas, for example, a line at 15 ml. Mistakes can occur with gas mixtures with resultant underfill with too little long-acting gas or severe IOP rise with too much. Therefore, it is worth being careful and observing the processes during gas mixing to ensure the correct dosages are used. Use a 100 ml syringe to avoid conversion of ml to percentage, ie 30 mls = 30%.
7. Attach the syringe to the three-way tap, and flush out the air by inserting 35 ml. Keep 15 ml in case of hypotony during closure of the surgical wounds.
8. At the end of the operation, the air in the vitreous cavity must be flushed with a volume of gas to achieve the correct gas concentration.
9. Close the second sclerotomy.
10. With 23 g, remove both upper trochars and insert a 26-g needle through the pars plana to allow exhaust of the gases, attach the 50-ml syringe onto the three-way tap and flush through the gas to 15 ml.

Break closure can be achieved by the use of an internal tamponade such as a gas bubble. This acts in two ways:

1. By 'tamponading' the break (the gas is in contact with the edge of the break) so that an accumulation of fluid is not possible through the break. The RPE pumps out the SRF flattening the retina. This is utilised in pneumatic retinopexy where SRF is not drained by the surgeon, and the

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retina is allowed to flatten spontaneously after intravitreal gas injection.

2. By forcing the retina flat by displacing the retina outwards (except where aqueous persists, e.g. inferiorly). This is primarily reserved for an eye, which has had a vitrectomy, and the retina has already been flattened.

Note: Pneumatic retinopexy, that is, insertion of gas without vitrectomy, has a success rate of approximately 70 % which is lower than conventional or vitrectomy surgery (Zaidi et al. 2006; Yanyali et al. 2007; Lowe et al. 1988; Kulkarni et al. 2007; Hilton et al. 1987). However, it may reduce the need for more extensive surgery if one can accept the relatively low success rates and risk of PVR. In pneumatic retinopexy, rotation of the eye over a number of hours whilst the gas bubble is present may also be used to try to flatten the retina.

A gas bubble must have its effect for at least 5 days because the retinopexy requires time to take effect. For this reason, larger molecule gases are used so that dissipation of the gas bubble from the eye is retarded. The most popular gases are sulphahexafluoride (SF_6) and perfluoropropane (C_3F_8) (Chang et al. 1984, 1985; Lincoff et al. 1983).

Note: If the retina is completely flat (no SRF), then tamponade is not necessary to close the break, and retinopexy is enough. This is exploited when treating a flat retinal break in the clinic (the retina around the break remains flat despite the need for a few days for the retinopexy to reach full adhesion) presumably because the retinopexy confers some mild adhesion immediately. This has been exploited by Martinez-Vasquez (Martinez-Castillo et al. 2007) who has described vitrectomy with aqueous tamponade for pseudophakic RRD. This method requires fastidious removal of all of the SRF during the PPV (the SRF is squeezed out by the use of heavy liquid posteriorly and air anteriorly, with the air removed again at the end of the operation) and heavy diode laser retinopexy. As a proof of principle, the method is of interest, but most surgeons would leave the air inside the eye and tamponade as usual. However, the principle is exploited in RRD with inferior holes where contact of a gas bubble cannot be guaranteed, and the surgeon, with complete removal of SRF,

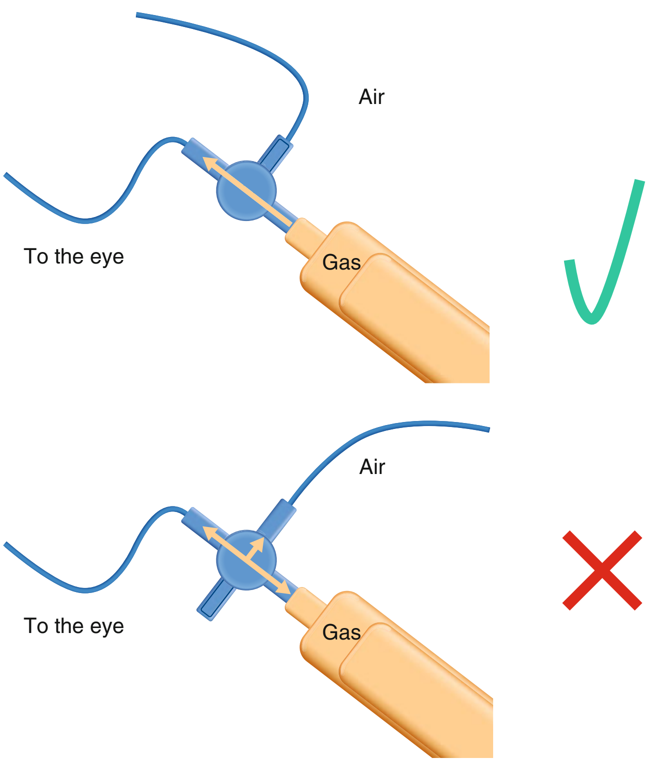


Fig. 3.1 When inserting gas through the three-way tap, make sure the tap is closed to the air infusion line; otherwise, the gas will enter the air infusion line and you will not achieve a full flush out of the air

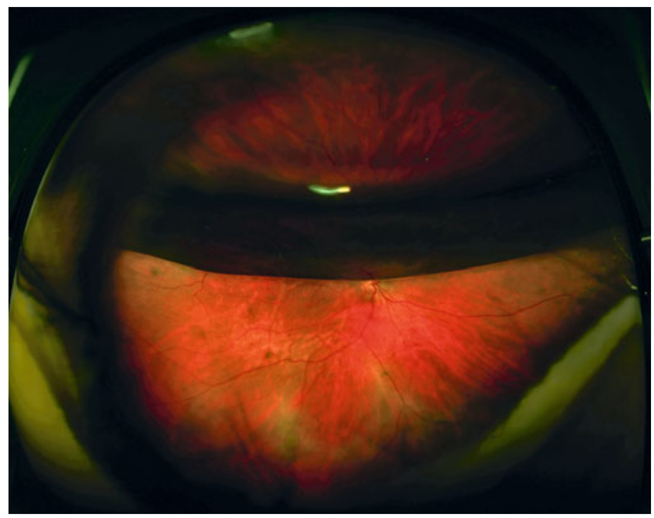


Fig. 3.2 A wide angle view of an intraocular gas bubble; notice the flattened inferior surface of the gas bubble. The gravitational effect of the dense vitreous liquid relative to the less dense gas overcomes the surface tension (which tries to create a spherical gas bubble) thereby distorting the bubble and flattening the inferior surface

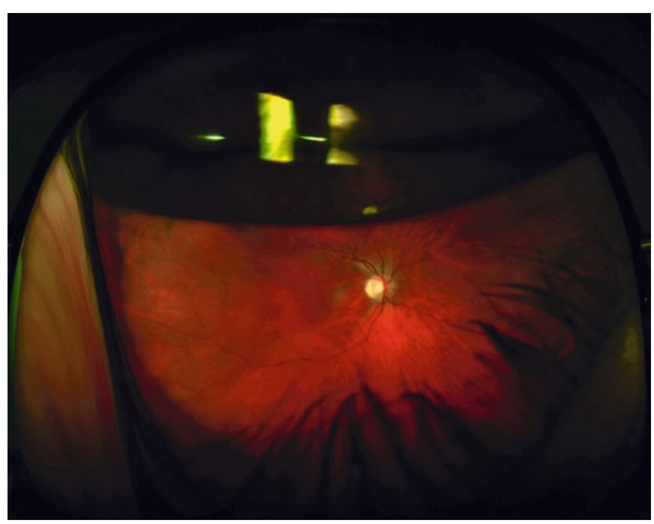


Fig. 3.3 As the gas bubble gets smaller, the inferior surface becomes more curved; when the bubble is very small, it will be spherical

can leave the inferior holes treated with retinopexy and no indentation; see later chapters (Tanner et al. 2001; Martinez-Castillo et al. 2005).

3.1.1.1 Properties

- 100 % SF_6 doubles its volume in 2 days and is present for 2 weeks (Lincoff et al. 1984). Its non-expansible concentration is between 20 and 30 % with air.
- C_3F_8 expands four times at 100 % concentration, lasts 8 weeks and has a non-expansible concentration with air of 12–16 %.

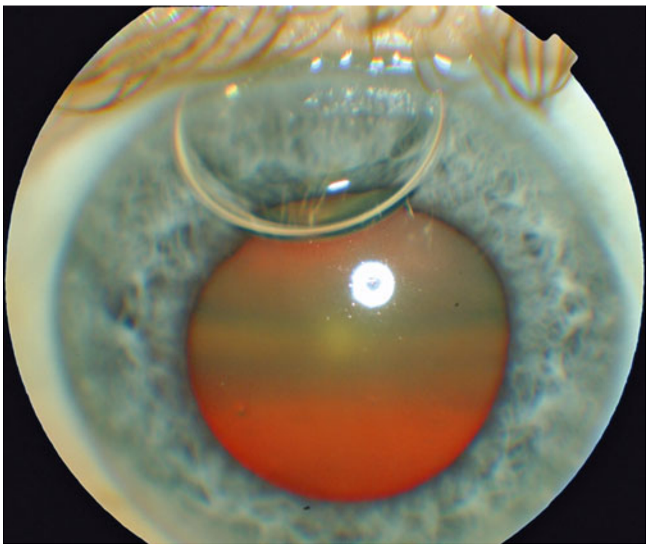


Fig. 3.4 Air can enter the anterior chamber at the end of the operation as in this eye in which there is presumably a defect in the zonule. Attempting to remove the AC gas by aspiration and infusion of fluid can result in a reduced gas fill in the posterior segment because the infusion fluid enters the vitreous cavity (passing with gravity around the lens) and the gas escapes through the sclerotomies. Therefore, it is best to have the sclerotomies closed. Any gas leakage must then occur through the anterior segment and can be monitored by the surgeon. If the gas bubble is not removed, the bubble will be present in the postoperative period usually without any consequences and with gradual absorption

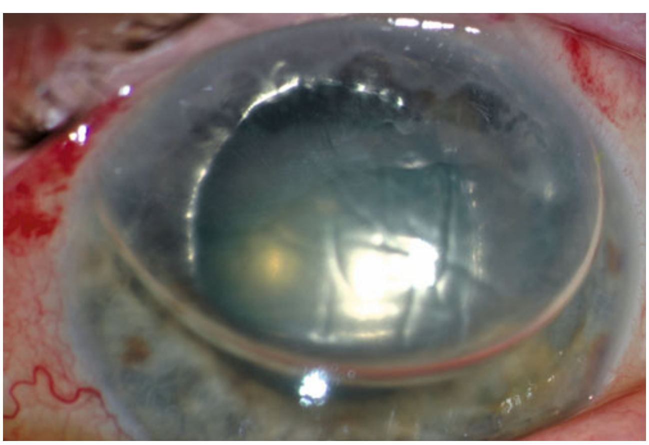


Fig. 3.5 A large air bubble which has leaked into the anterior chamber has caused pupil block

With experience, the concentration most appropriate to the surgeon can be decided upon. 30 % SF_6 and 16 % C_3F_8 may be suitable to start with.

The gases have a high surface tension of 70 mN/m, that is, the gas remains as one sphere and does not break up into smaller bubbles. This stops the gas bubble from going through the retinal break, allowing contact with the edge of large breaks without the gas entering the subretinal space.

Problems with gas bubbles can be determined from the Fick's diffusion equation, for example, during surgery with injection of gas; nitrous dioxide from the anaesthetic will rapidly enter the gas-filled eye. This means that postoperatively, the gas bubble will shrink as the lungs exhale this nitrous dioxide. In practice, this may not have a major effect on the size of the gas bubble, but most surgeons prefer to switch off nitrous dioxide when using gases during surgery. A patient with gas in situ should not have a general anaesthetic using nitrous dioxide because this will enter the gas bubble and cause expansion and a severe rise in IOP potentially resulting in central retinal artery occlusion (Hart et al. 2002).

The inferior border of a gas bubble has a flattened meniscus. Therefore, it is not possible to know reliably that the gas bubble will tamponade detached inferior breaks. For this reason, surgeons often apply a plombage between the 4 and 8 o'clock positions. However, in a vitrectomised situation, this may give a risk of choroidal haemorrhaging because of hypotony, indentation of the choroid and suturing near vortex veins. It is, therefore, sometimes advisable to rely on strict posturing of the patient to tamponade an inferior break. In this circumstance, the patient with an equatorial or pre-equatorial break which is inferiorly placed is postured face up. This may increase the risk of cataract but reliably closes inferior breaks. If an inferior plombage is desired, insert heavy liquids into the eye before placement of the explant. This will limit the size and spread of any haemorrhage should it occur.

3.1.1.2 A Safe Method for Drawing Up Gas

Most gases are provided in disposable canisters, and the assistant fills a 50-ml syringe with the correct percentage of gas and air. Errors can occur, and if the wrong gas is inserted for flushing at the end of surgery, there can be catastrophic visual loss from central retinal artery occlusion. Allowing the assistant to draw up the gas and air has led to 100 % gas fills and CRAO from severe IOP rise in the early postoperative period.

Follow this method to minimise the risk of error:

1. The assistant draws the correct amount of gas into the syringe, for example,
   - 8 ml for a 16 % gas fill in air
   - 15 ml for a 30 % gas fill in air
2. The assistant hands the syringe to the surgeon who draws in the air to make up the volume to 50 ml. Alternatively use a 100ml syringe to avoid the need to convert mls to percentage.

By splitting the responsibility for drawing up the gas by the assistant and the air by the surgeon, it is very difficult to create an error of 100 % gas (the surgeon would not have any space to draw up air if the assistant hands over 50 ml of gas). Both must check the type of gas used. The surgeon can double check if the correct gas volume has been drawn up by observing a tell tale condensation mark, for example, at the 8 ml mark. The only risk of error is that the assistant incorrectly draws up air rather than the long-acting gas (or the wrong number of mls of gas). This will lead to a gas bubble duration which is too short, a problem which can be overcome by reoperation or strict posturing. This is preferable to an erroneous 100 % long-acting gas and subsequent IOP rise and central retinal artery occlusion.

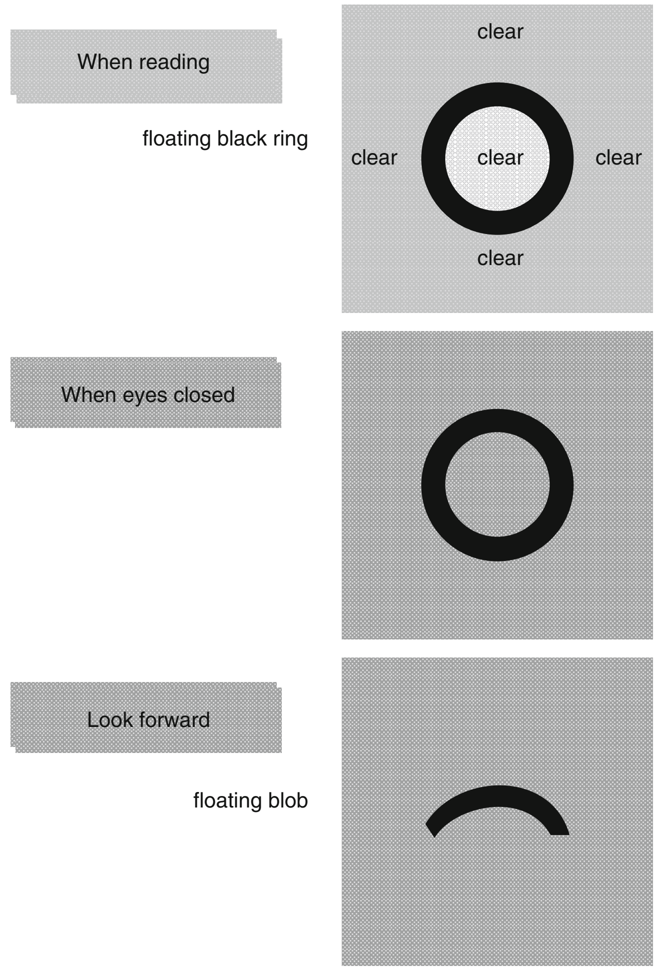


Fig. 3.6 A patient's drawing of visual phenomena around the gas bubble showed diffraction of light and an alteration of colour in the centre of the bubble

3.1.2 Complications

3.1.2.1 Vision

- Postoperatively, the patient with a gas bubble will notice that they have blurred vision from refractive changes in the eye. As it resolves, a dark line (the inferior edge of the bubble) passes horizontally from superiorly to inferiorly, the bubble gets smaller and more spherical, and gradually multiple small bubbles appear and shortly after complete dissipation of the bubble. Once the bubble edge passes above the visual axis (the dark line is now below the patient's central vision), the patient will start to see more clearly.

3.1.2.2 Refraction

- The phakic or pseudophakic patient is made myopic by the gas bubble and can often see more clearly close to the eye and looking down. The aphakic patient is made even more hypermetropic.

3.1.2.3 Cataract

- The gas itself may cause a feathery posterior subcapsular cataract or 'gas cataract' which is temporary (clears once the gas absorbs) but associated with an increased risk of nuclear sclerotic cataract later on.

3.1.2.4 IOP

- Raised intraocular pressure may occur after gas expansion in the early stages but can usually be treated medically.
- Severe IOP elevation suggests an error in the composition of the gas during mixing with air at surgery, that is, the gas is at too high a concentration and is expanding causing an IOP rise. Some gas may need to be removed, but there is a risk of choroidal haemorrhage during this manoeuvre if the IOP cannot be brought down medically before the gas removal.
- What to do: Attach a needle to the air pump, increase the pressure to the patient's IOP level, insert the needle into the eye and gradually reduce the air pump pressure to allow a controlled reduction in IOP. Then you can proceed to PPV and exchange of the gas for the correct concentration. This will require gas fluid exchange and fluid air exchange (if you still need the tamponade agent, the pathology may now have resolved, e.g. check if the macular hole is closed) followed by flushing with the correct gas concentration as described above.

3.1.2.5 Loss of the Gas Bubble

- Gas dissipates early, or the bubble size is too small if the concentration inserted has been too low. This risks failure of the surgery because of reduced tamponade area.
  1. What to do: Some of the error can be compensated for by asking the patient to posture so that the gas bubble contacts the area of pathology, for example, face-down posturing for a macular hole. Occasionally, the gas bubble will need to be replaced by repeat operation.

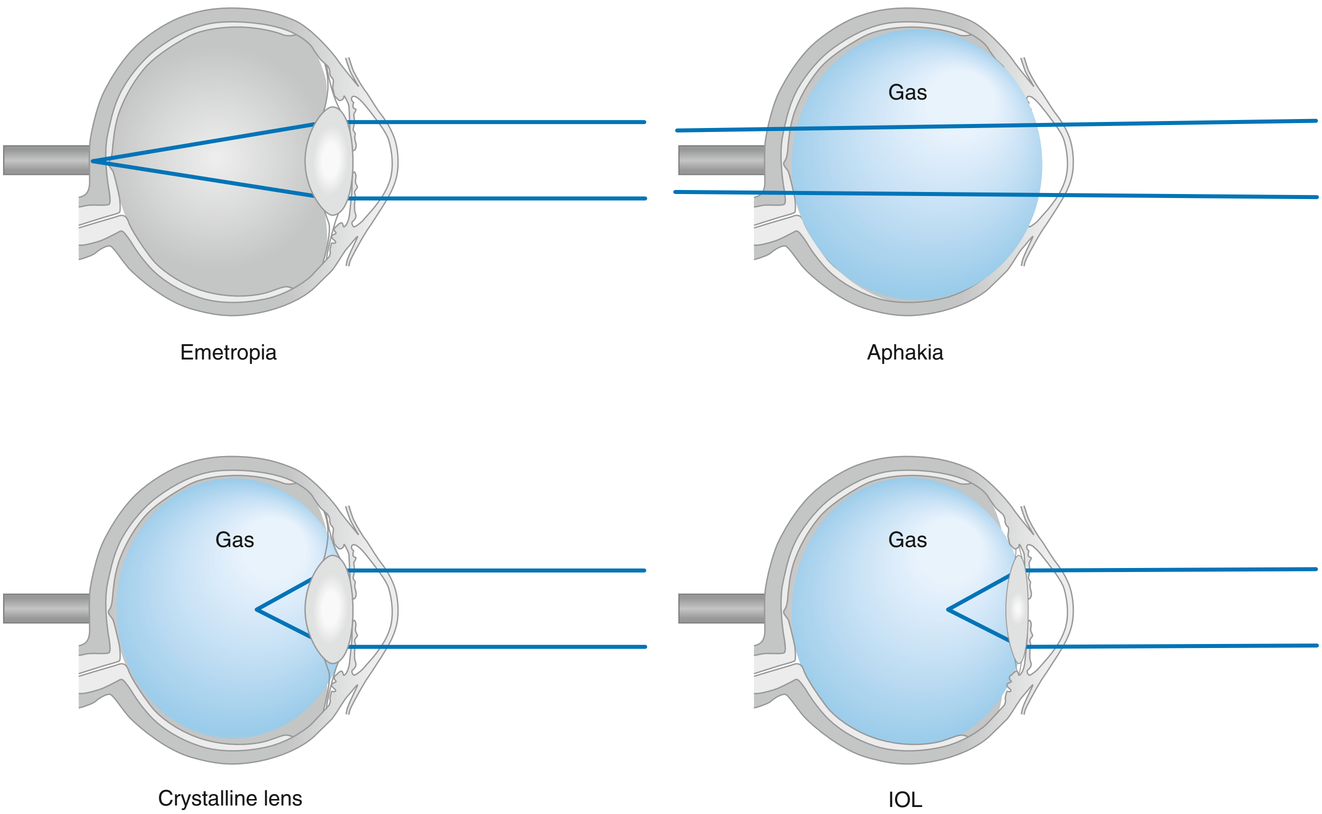


Fig. 3.7 The refraction of the gas-filled phakic or pseudophakic eye is increased because the effective power of the posterior surface of the lens is increased (the difference in the refractive index of air and the lens is greater than the difference between water/vitreous and the lens), causing a large myopic shift. In an aphakic eye, the convexity of the gas bubble in the pupil effectively creates a negative refractive change causing a large hypermetropic shift

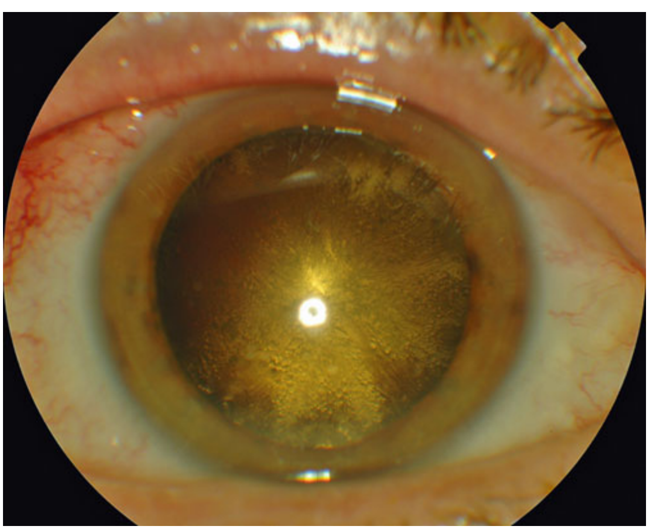


Fig. 3.8 A typical feathery cataract from gas insertion. This will clear but results in an increased chance or early onset nuclear sclerotic cataract formation

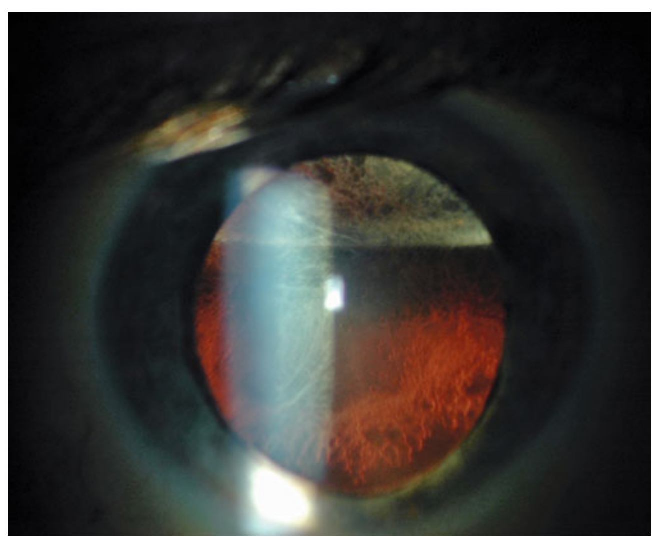


Fig. 3.9 In some patients, gas in the vitreous cavity causes a feathery and bubbly posterior subcapsular cataract in the early postoperative period, for example, 2 weeks. This clears once the gas absorbs but usually leads to early onset nuclear sclerosis

- Gas may vent through an open sclerotomy if the pressure rises significantly leading to underfill.

3.1.2.6 Gas in the Wrong Place

- If the infusion cannula is unstable during surgery, it may angle forwards risking gas insertion through the zonules of the lens and into the anterior chamber. If the hole in the zonules is large, gas may represent through the hole even after removal of the gas from the AC. This can make visualisation of the retina difficult in which case the gas may be displaced by viscoelastic. Removal of the viscoelastic may allow the gas back into the AC. In most circumstances, gas in the AC postoperatively can be allowed to dissipate without problems (the flattened inferior meniscus allows the aqueous to flow without causing pupil block). Occasionally, pupil block glaucoma will occur, which can be temporarily alleviated by YAG peripheral iridectomy and medication until the gas is absorbed.
- Gas in the suprachoroidal or subretinal spaces is very rare. Again movement of the infusion cannula especially in patients with anterior contraction of the vitreous base (as in PVR) or with detachment into the pars plana may allow air to infuse under the retina. To leave gas in postoperatively will cause recurrent retinal detachment with PVR.
  1. What to do: The gas can be removed via retinotomy or via a retinal break or choroidectomy. Alternatively, a fine gauge needle can be inserted transconjunctivally and through the scleral (whilst observing the eye internally) to contact the bubble and allow egress.

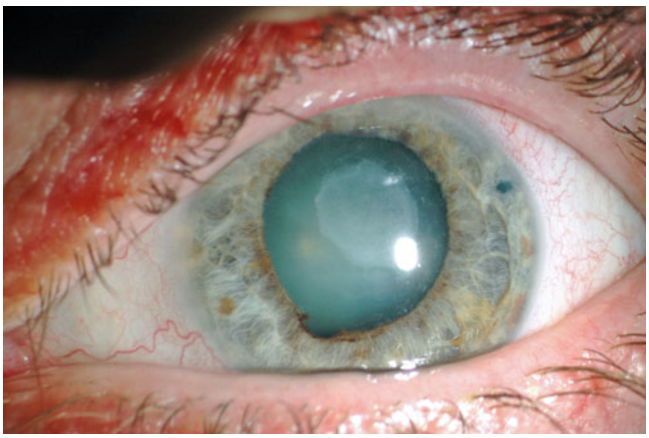


Fig. 3.10 Gas in the anterior chamber postoperatively has led to the formation of an anterior capsular opacity

3.1.3 Important Postoperative Information

3.1.3.1 Flying or Travel to High Altitude

The patient should avoid flying whilst the gas bubble is in situ as the drop in cabin pressure causes increased IOP because the bubble tries to expand (Lincoff et al. 1989a, b)

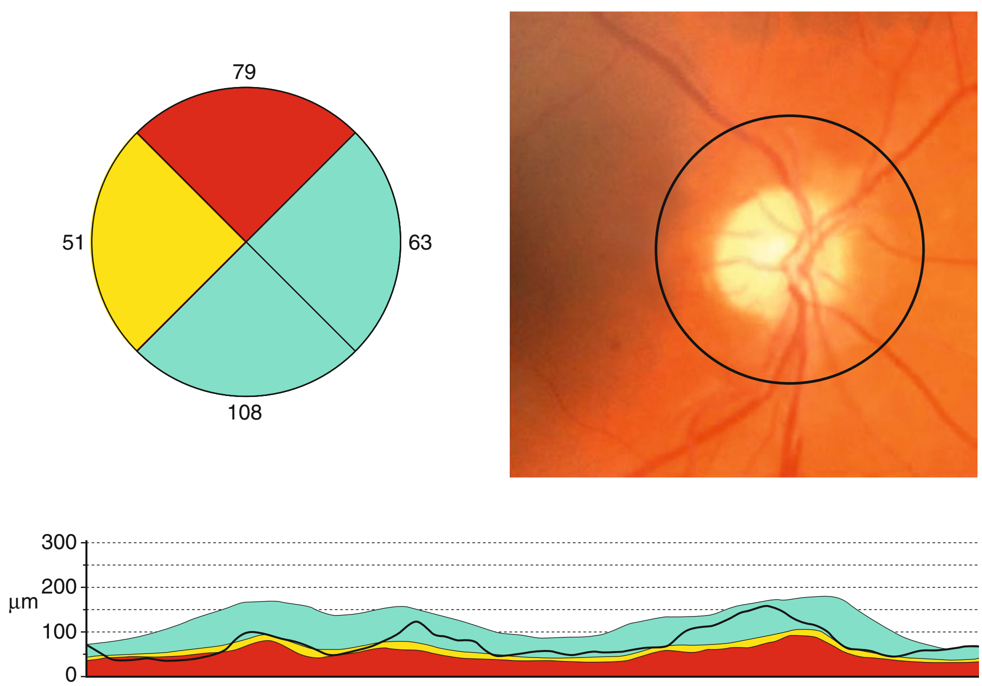


Fig. 3.11 An anterior ischaemic optic neuropathy possibly from IOP rise after PPV showing thinning of the nerve fibre layer superiorly on OCT scan

Table 3.1 Common gases used during pars plana vitrectomy

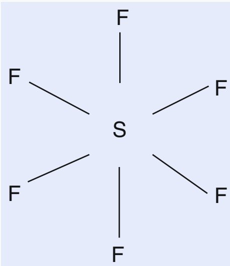
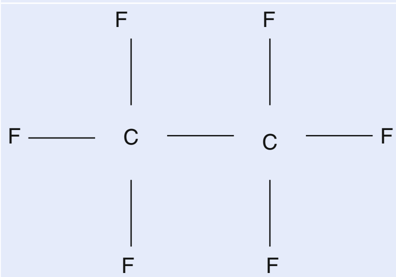
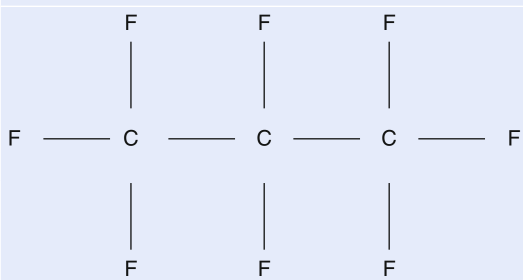
Gas	Structure	Molecular weight	Expansion of 100 % concentration	Duration (days)	Non-expanding concentration (%)	Uses
Air		29	0	5–7	NA	Flat retinal breaks
Sulphur hexafluoride (SF_6)		146	2	14	20	Superior retinal breaks (above 4–8 o'clock)
Perfluoroethane (C_2F_6)		138	3	30	16	Macular hole surgery
Perfluoropropane (C_3F_8)		188	4	60	14	Multiple holes Inferior breaks Macular holes Early PVR Diabetic TRD

Table 3.2 Complications from gas insertion

Complications of gas insertion	Abnormality	Frequency
Cataract and lens	Gas cataract	Occasional
	Nuclear sclerosis	Very common
	Posterior subcapsular cataract	Rare
	Displacement of an intraocular lens implant (especially sulcus fixated lenses or anterior chamber lenses)	Occasional
Glaucoma	Temporary from gas expansion	Common
	Angle closure from gas in the anterior chamber	Very rare
Gas errors	Wrong gas	Very rare
	Wrong concentration	Very rare
	Underfill	Rare
Refraction	Myopic shift whilst gas is in situ	Always
Gas in the wrong place	Subconjunctival gas from wound leakage	Very rare
	Anterior chamber gas from leakage through a zonule dehiscence or capsulotomy	Rare
Visual field loss	Probably from drying of the retinal surface peroperatively; by closing the sclerotomies (valves or plugs) the flow of air over the retina is minimised	Rare

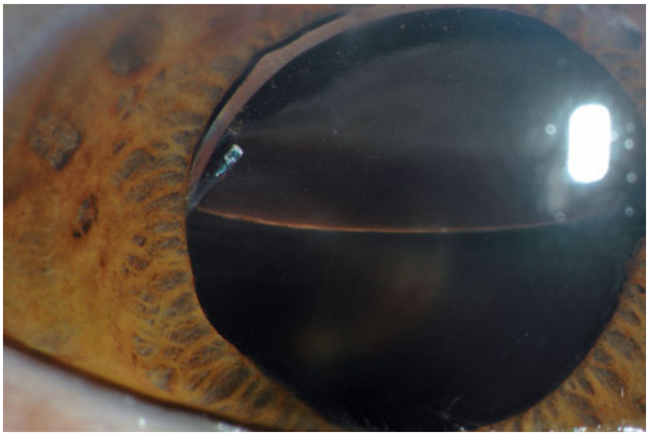


Fig. 3.12 This gas bubble is pushing the IOL forwards at the superior edge which can entrap the edge of the iris. Wait till the gas bubble has gone, and then divide the inevitable posterior synaechiae from the anterior capsule by passing a cannula between the capsule and the iris, free up the iris margin and relocate the IOL edge behind it

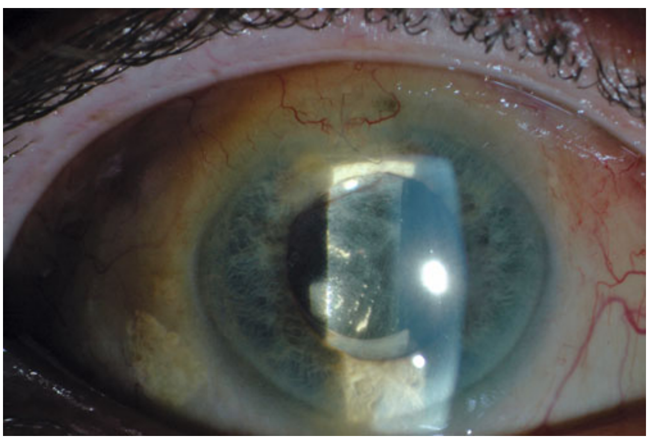


Fig. 3.13 In some patients with combined PPV, gas and cataract extraction, the IOL may be tilted by the gas bubble. The edge of the IOL may move anteriorly to the edge of the pupil causing 'capture' of the pupil margin and adhesion of the iris to the lens capsule. This is associated with rapid posterior capsule opacification. Once the gas bubble has reabsorbed, the pupil should be surgically released from the capsule and replaced in its correct position in front of the IOL. A surgical capsulectomy can be performed with a vitrectomy cutter on low cut rate (200 bpm) introduced through pars plana

resulting in pain and a risk of central retinal artery occlusion. Subsequently, after the eye has adjusted to the raised IOP during the descent of the aircraft, the eye becomes hypotonous with a risk of intraocular haemorrhage. Similarly, the patient should not change altitude (e.g. driving across a high mountain pass) because the variations in atmospheric pressure will increase or decrease the bubble size.

Table 3.3 Pressure changes in a normal-sized eye during air travel and cabin depressurisation (sea level to the equivalent pressure of 2,400 m altitude). Therefore, any volume around 0.50 ml (one-eighth full) or more in a normal-sized eye risks producing an IOP which can occlude ocular circulation

Gas volume (ml)	IOP rise (mmHg) from a baseline of 16 mmHg	Duration to achieve IOP rise (min)
0.125	26	10
0.25	43	10
0.5	70	10
1.0	105	10
2.0	120	8
4.0	140	8

Flying or travelling to high altitude causes a drop in atmospheric pressure which would normally be accompanied by an increase in the volume of the gas bubble (Aronowitz and Brubaker 1976). Within the confines of the eye, this expansion cannot occur without loss of aqueous from the eye. If the aqueous cannot be removed, the IOP elevates; see the table. As aqueous leaves the eye, the IOP will gradually fall; some eyes, for example, glaucomatous eyes with poor aqueous outflow facility, will struggle to reduce their aqueous volume to compensate for the increase in volume required.

The absolute pressure in the eye is atmospheric pressure (760 mmHg) and IOP combined therefore.

At sea level	776 mmHg (760 + 16 mmHg)
At 2,400 m altitude	576 mmHg (560 + 16 mmHg)

It is possible to calculate how much the gas bubble must expand to allow the IOP to normalise:

$$\text{Pressure } 1 \times \text{Volume } 1 = \text{Pressure } 2 \times \text{Volume } 2.$$

$$776 \times V1 = 576 \times V2$$

$P1 = 776$ mmHg, that is, atmospheric pressure plus 16 mmHg and $P2 = 576$ mmHg, atmospheric pressure at 2,400 m plus 16 mmHg after the bubble has expanded to allow the IOP to drop to 16 mmHg.

$$\text{Ratio of } V1 \text{ to } V2 = 776/576$$

$$\text{Ratio of } V1 \text{ to } V2 = 1.35$$

Therefore, the bubble must expand to about 1.35 times its initial volume for the pressure to drop back to normal, that is, the eye will need to lose aqueous to allow the expansion.

How long this will take will depend on the initial gas bubble volume and the rate of aqueous outflow, assuming no wound leak.

Larger volumes will prevent the IOP ever returning to normal; for example, a 3.0-ml bubble cannot expand to 1.35 times its initial volume in a 4-ml eye however much aqueous escapes.

Note: It is the difference in pressure between atmospheric pressure and absolute eye pressure (measured as IOP) which affects the ocular circulation because measured systemic blood pressure is similarly the difference between atmospheric pressure and the pressure in the blood vessel.

3.1.3.2 General Anaesthesia

General anaesthesia should be only performed with the anaesthetist aware of the gas within the eye to allow the avoidance of expansion of the bubble with the anaesthetic gases particularly nitrous dioxide. Patients have lost all vision from central retinal artery occlusion in this circumstance (Hart et al. 2002; Fu et al. 2002; Mostafa et al. 1991). Some surgeons provide a wristband to be worn by the patient warning about gas in the eye and to alter any general anaesthesia agents used.

3.2 Silicone Oil

Additional Surgical Steps

Method 1 (has the advantage that the retina can be manipulated during the oil insertion):

1. Attach a silicone oil-filled syringe linked to the silicone oil pump set to 50 psi to the three-way tap. Reduce the pressure to 30 psi with 23 gauges to avoid separation of tubing from the infusion trochar.
2. Insert a flute needle and drain intraocular fluids (SRF, then vitreous cavity fluids and then heavy liquids) whilst actively inserting the oil.
3. Drain fluid off the disc.
4. Leave the IOP at approximately 10 mmHg.

Method 2 (has the advantage of inserting the oil onto the macula first allowing egress of SRF through anterior retinal breaks and may reduce the risk of subretinal oil):

1. Fill the eye with air.
2. Insert the oil through a sclerotomy allowing the air to egress from another sclerotomy.
3. Leave the IOP approximately at 10 mmHg.

Silicone oil is used when more permanent tamponade is required, for example, for retinal breaks with residual traction from proliferative vitreoretinopathy (PVR), or in trauma. It has a Si–O–Si polymer structure. Two types are in use, 1,000–1,300 and 5,000–5,900 mPas. There are theoretical advantages for the use of the latter for permanent tamponade or to avoid emulsification of the oil, for example, in young patients; however, the former is easier to handle surgically because of its lower viscosity. 1,000–1,300 mPas is recommended in most circumstances. In my experience, there appears to be little advantage in using 5,000 mPas oil (Scott et al. 2005).

Surgical Pearl of Wisdom

There is a simple explanation of why a direct oil/PFCL exchange is less likely to cause slippage, and it is as follows:

When oil is injected and once it makes contact with PFCL, the two liquids join together to make a single bubble. The reason is that both oil and PFCL are hydrophobic and they prefer to be in contact with one another and thus exclude water from the interface. This single bubble at the beginning is in fact a heavy bubble. Any aqueous is therefore displaced superiorly and laterally towards the sclerotomy.

Slippage is the posterior displacement of aqueous under the retina by an incoming bubble (usually air). It results in retinal folds and leaves large area of bare RPE to promote PVR.

The tip I wish to offer is to fill the vitreous cavity as full as possible with PFCL when dealing with giant retinal tear or giant retinotomy after adequate relief of traction. As the oil is injected, pass the draining flute needle through the oil and dip into the PFCL. This way, the two liquids will be forced to make contact. Once they touch, the aqueous will automatically be displaced laterally and superiorly (Li and Wong 2008).

Try it.

Professor David Wong, Dept of Ophthalmology, University of Hong Kong, Hong Kong, China

3.2.1 Properties

1. Viscosity, 1,000–1,300 or 5,000–5,900 mPas
2. Molecular weight 25,000 or 50,000
3. Refractive index 1.4
4. Density 0.97 g/cm^3
5. Surface tension 21.3 mN/m
6. Interfacial tension in water 40 mN/m

Silicone oil is clear, inert and floats in aqueous, and is highly stable in the eye (Lakits et al. 1999). It has a flotation

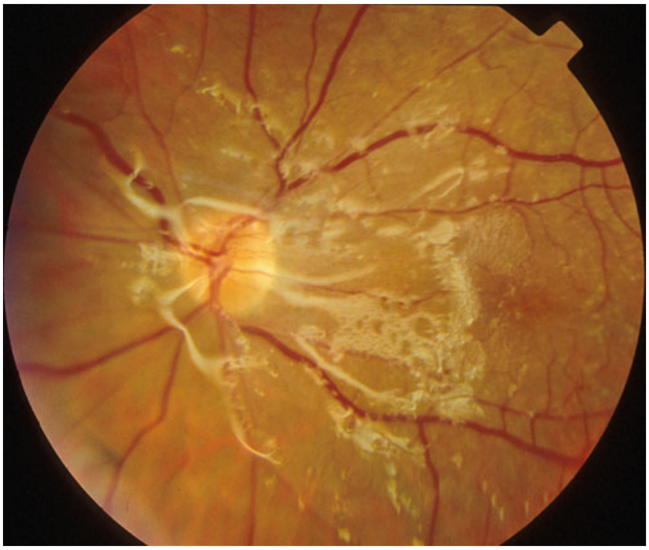


Fig. 3.14 The light reflex from the oil in contact with the retina is visible in an eye with adequate oil fill

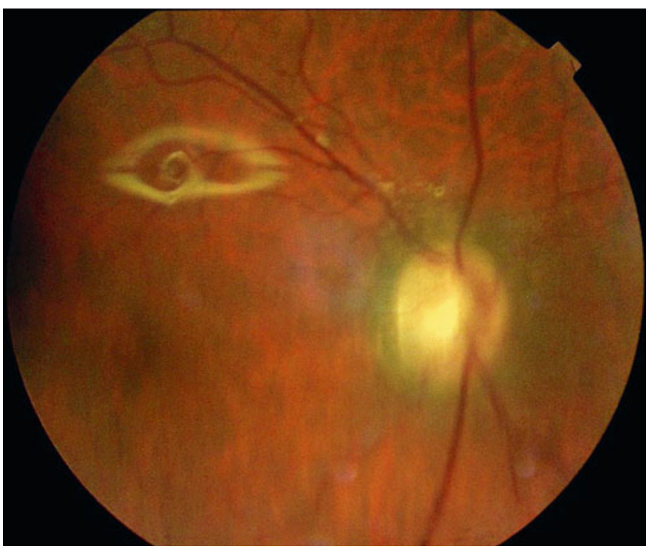


Fig. 3.15 The oil reflex in this patient is on the superior arcade indicating an underfill of oil as the contact area of the silicone oil bubble is superior within the eye

force, but its density is only slightly less than water, so the bubble is dominated by its interfacial tension. Therefore, it has a spherical configuration within the eye. Using the principle of 'a sphere within a sphere', its contact with the retina is less extensive than a gas bubble (see Appendix).

Oil may sometimes be used in complex retinal detachments without PVR when there are multiple breaks requiring multiple retinopexy applications or very large breaks such as giant retinal tears. The risk of missing a small break in such a situation, for example, when 10 or 12 breaks are present, means that using gas could result in early return of the retinal

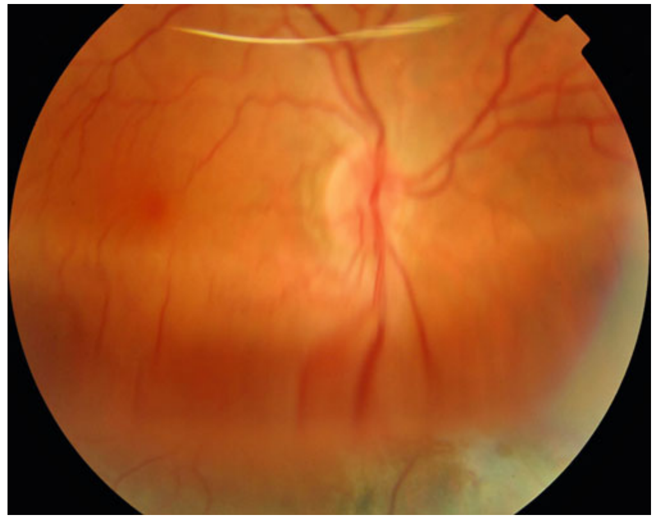


Fig. 3.16 A severe underfill of silicone oil. Note that the oil reflex is above the macula and the diffraction at the edge of the bubble can be seen. Underfills can occur in eyes with choroidal haemorrhage. As the haemorrhage resolves, the space occupied by the haemorrhage is taken up by aqueous, the oil is suspended in the aqueous with minimal contact with the retina. The vision is reduced from the refractive effects of the edge of the bubble

detachment and the onset of PVR. The latter occurs because of the recent operation and the release of cytokines and growth factors from the increased use of retinopexy. A tamponade of silicone oil will prevent retinal redetachment until removal of the oil, thereby allowing the inflammatory mediators in the postoperative period to subside. Thereafter, oil removal may reveal a return of the retinal detachment, but this will be hopefully detected early (or even during the oil out operation; see ROSO plus) and localised to the area of the retinal break and will not have other influences increasing the risk of PVR. Of course, in this situation, there is a risk that the complications of silicone oil may ensue. However, its short-term use in this situation should avoid most of these.

3.2.2 Silicone Oil in the Anterior Chamber During Surgery

Silicone oil has a higher refractive index than BSS which can influence the view during surgery. In the aphake, the oil bulges through the pupil providing a +lens effect. It is better to flute the aqueous out of the anterior chamber allowing the oil to fill the chamber. The optical properties are then improved for posterior segment visualisation. A sudden change in the view during the surgery in a pseudophakic or phakic patient might indicate oil in the anterior chamber. Inspect the anterior chamber and look at the iris. If there are reflections of light in the crypts, you have oil in the AC. If the view is satisfactory, continue with the operation. If it is reduced, use viscoelastic to displace the oil from the visual axis.

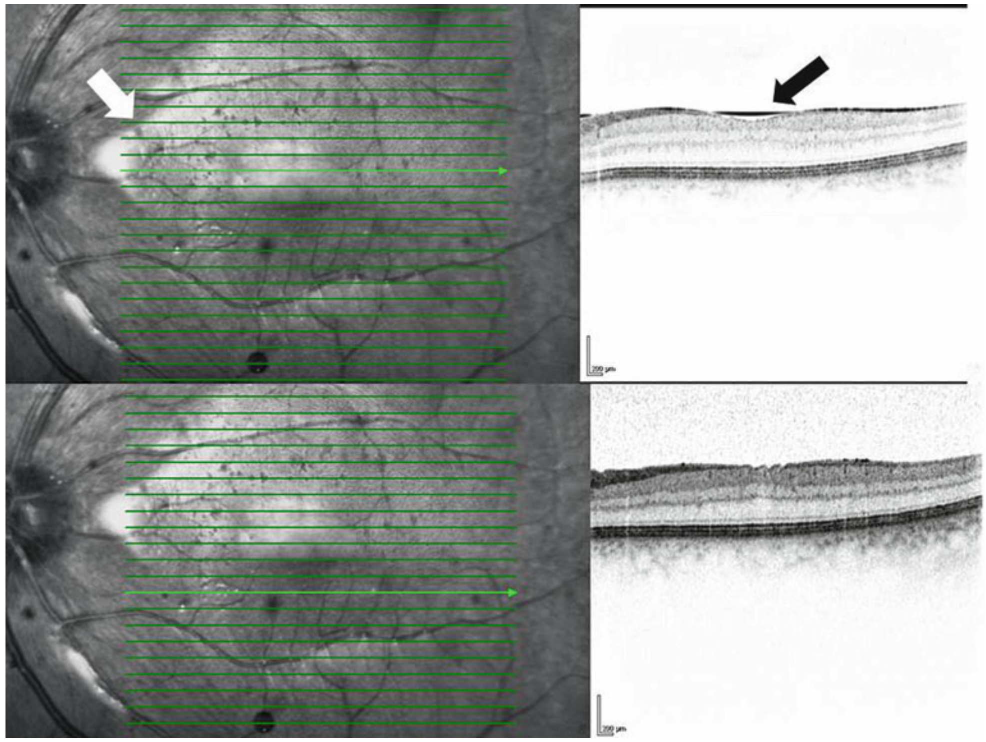


Fig. 3.17 Silicone oil contacts the retina as far inferiorly as the light reflex seen from the retina (*white arrow*). When the OCT scan is taken through the reflex (indicated by the *long green arrow* on the upper scan), the oil interface is detected (*black arrow*). When the scan is taken below the reflex (*green line* on the lower scan), the oil interface is no longer seen

It is important to remove the oil from the AC at the end of the operation to avoid postoperative pupil block. Close the two superior sclerotomies so that there can be no loss of oil from them. The infusion remains so that the correct pressure can be obtained once the anterior chamber has been closed at the end of the procedure.

You are now able to perform manipulations in the anterior chamber to remove the oil knowing that the only oil lost from the eye must come through the anterior chamber. You will be able to see any oil that is lost, able to judge whether you are losing too much and able to determine whether you will need to refill the posterior chamber (extremely unlikely).

1. Create two paracentesis incisions one inferiorly and one superiorly. Insert some BSS (balanced salt solution) into the anterior chamber via the inferior paracentesis incision to deepen the AC. You can then remove the oil by engaging it with a wide-bore cannula (often supplied with oil injection systems) attached to a 2-ml syringe and using manual aspiration through the superior paracentesis. The infusion of BSS can either be by continuous infusion at moderate pressure (i.e. attached to the BSS infusion line) or by intermittent infusion (insert some BSS with a syringe, remove some oil and repeat until the oil is removed).
2. If the whole of the anterior chamber is filled with oil, you may need to insert a viscoelastic to move the oil to the superior wound (and out of the angle), then aspirate the oil with a wide-bore cannula, and then insert BSS to allow aspiration of the viscoelastic.

Note: You do not want a free flow of infusion fluid into the posterior segment whilst oil is egressing from one of the sclerotomies as eventually you will have an underfill of oil; this is why you must close off the superior sclerotomies. If only the oil in the AC is removed, then you have lost only a maximum of 0.2 ml (volume of the AC) which will not have any effect on the total volume of oil in the eye which should be 4–10 ml depending on the eye. Therefore, tamponade is maintained without having to go into the posterior segment to check.

Surgical Tip

The key is pressure; the oil bubble wants to stay as one bubble in the posterior chamber; therefore, it requires a pressure differential in the anterior and posterior chambers, that is, high in the posterior and low in the anterior, to allow a bubble of silicone to separate off (breaking its interfacial tension, see Appendix) and enter the anterior chamber. Every time you insert an instrument into the anterior chamber, the pressure drops, but if the pressure is already low in the posterior chamber and the pressure is maintained adequately in the AC, there is less chance of separation.

Table 3.4 Silicone oil complications

Silicone oil complications	Duration from surgery			
Complication	0–3 months	3–12 months	1–2 years	2–10 years
Overfill glaucoma	Yes	No	No	No
Pupil block glaucoma in aphake	Yes	Occasional if peripheral iridectomy closes		
Open-angle glaucoma	Unlikely	Occasional	Common	Common
Cataract	Unlikely	Occasional	Common	Common
Oil-induced macular visual loss	Occasional	Occasional	Unlikely	Unlikely
Band keratopathy	No	No	Unlikely	More common
Emulsion of oil	Unlikely	Occasional	Common	Common

In some eyes, the defect in the zonule allows a bubble of oil to re-enter the eye during these manipulations (seen first as a bulge in the iris and then the bubble floats into the anterior chamber), but this is usually a small bubble which can be removed by repeating step one above. If the lens is dislocated or very unstable (e.g. in a patient with trauma or a complicated cataract extraction) and oil keeps coming through into the anterior chamber, you may need to remove the lens and capsule leaving the eye aphakic (remember to perform an inferior peripheral iridectomy).

There seems to be a threshold size of bubble in the AC which can cause pupil block; anything less than 2 mm diameter is safe. However, it is not recommended to leave oil in the AC; therefore, by using the techniques above, remove any AC oil at the end of the operation.

Note: When filling the eye with oil, think 'volume rather than pressure'. Once the oil is near a maximal fill in the vitreous cavity, a tiny increase in volume causes a large increase in IOP because you are inserting a noncompressible liquid into a relatively stiff-walled container. To maximise the fill, the key is to remove the residual aqueous layer and SRF. The IOP can be kept at a low level (7 mmHg) without detriment to the fill. The fill is determined by the volumetric removal of the aqueous component and its replacement with a volume of oil and not by increased pressure in the oil bubble (and therefore the aqueous component) which in the rigid container does not increase the volume of the oil.

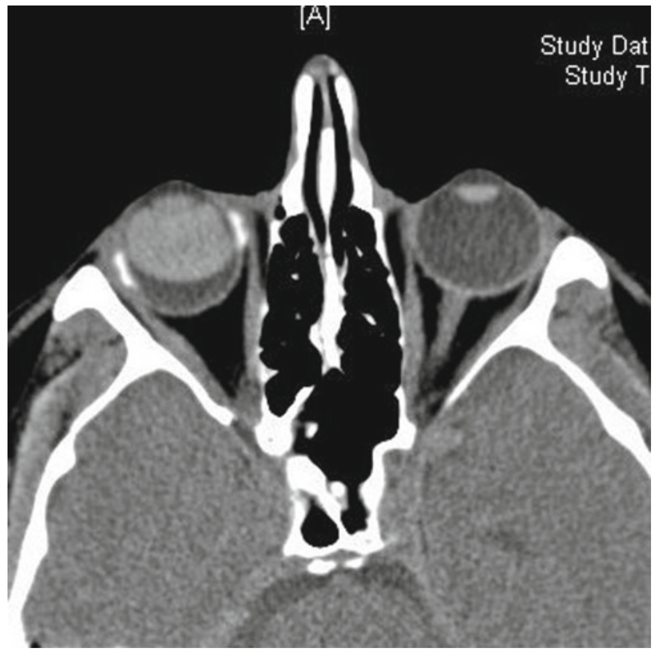


Fig. 3.18 A CT scan of an eye with silicone oil in situ and a silicone encircling band. The curved inferior edge of the oil is apparent demonstrating the lack of contact with the retina in this case posteriorly (patient is face up)

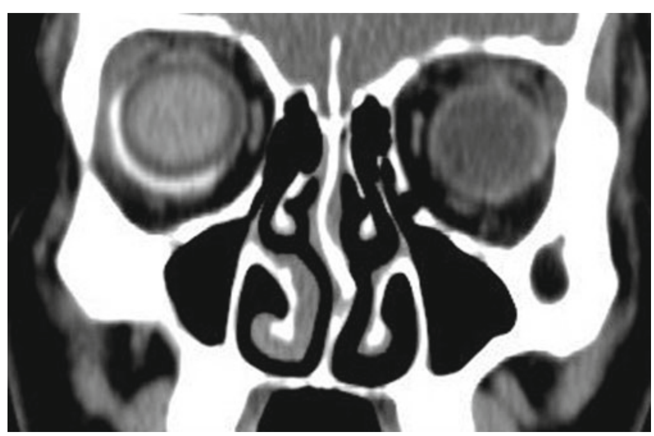


Fig. 3.19 In the face up position, the oil can be seen with little contact with the retina in this section

3.2.3 Complications of Silicone Oil

These are numerous.

3.2.3.1 Refractive Changes

- The oil has a higher refractive index than vitreous or water and therefore induces refractive errors primarily determined on whether the oil surface anteriorly is concave or convex. A concave profile occurs in phakic eyes; radius of the posterior lens is −8.10 mm, effectively reversing the refraction at the posterior lens because the lens and oil have refractive indices of 1.37 for the lens and 1.4 for oil, compared with 1.33 for water/vitreous.

This induces a need for a hypermetropic correction of approximately +5D; therefore, in a high myope, the myopia is reduced. In pseudophakic eyes, the IOL usually has a flatter profile to the posterior lens surface and

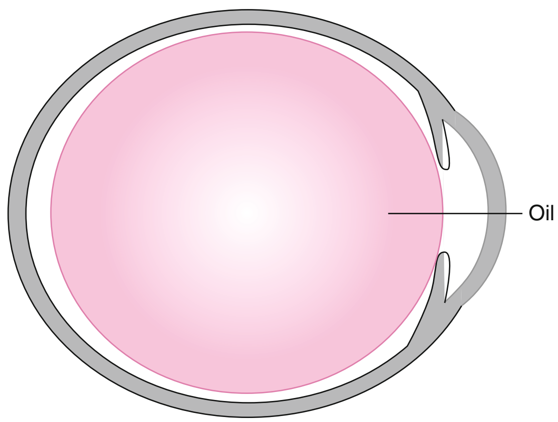


Fig. 3.20 Silicone oil in an aphakic eye produces a convex lens at the point of the pupil, thereby producing a myopic shift. In aphakic eyes, the degree of hypermetropia is reduced by silicone oil insertion

has a refractive index as high as 1.55. When oil is inserted, a hypermetropic shift is again induced. In both, the total refraction of the eye is reduced to approximately +50D. In an aphakic eye, the anterior surface is convex inducing a myopic shift in refraction of approximately +5D, thereby reducing the aphakic correction from +10D to +5D again giving a total refraction of the eye of about +50D.

- Note in a high myope the hypermetropic shift may reduce the degree of myopia. The opposite occurs in aphakic eyes where the oil bulges through the pupil (reducing the aphakic correction by approximately +5D).

3.2.3.2 Cataract

- Silicone is associated with a formation of nuclear sclerotic cataract, which may occur in complex retinal detachments especially with PVR, but is exacerbated by presence of the oil.

3.2.3.3 Capsule Opacification

- A posterior capsule in a pseudophake will thicken severely with oil with time.

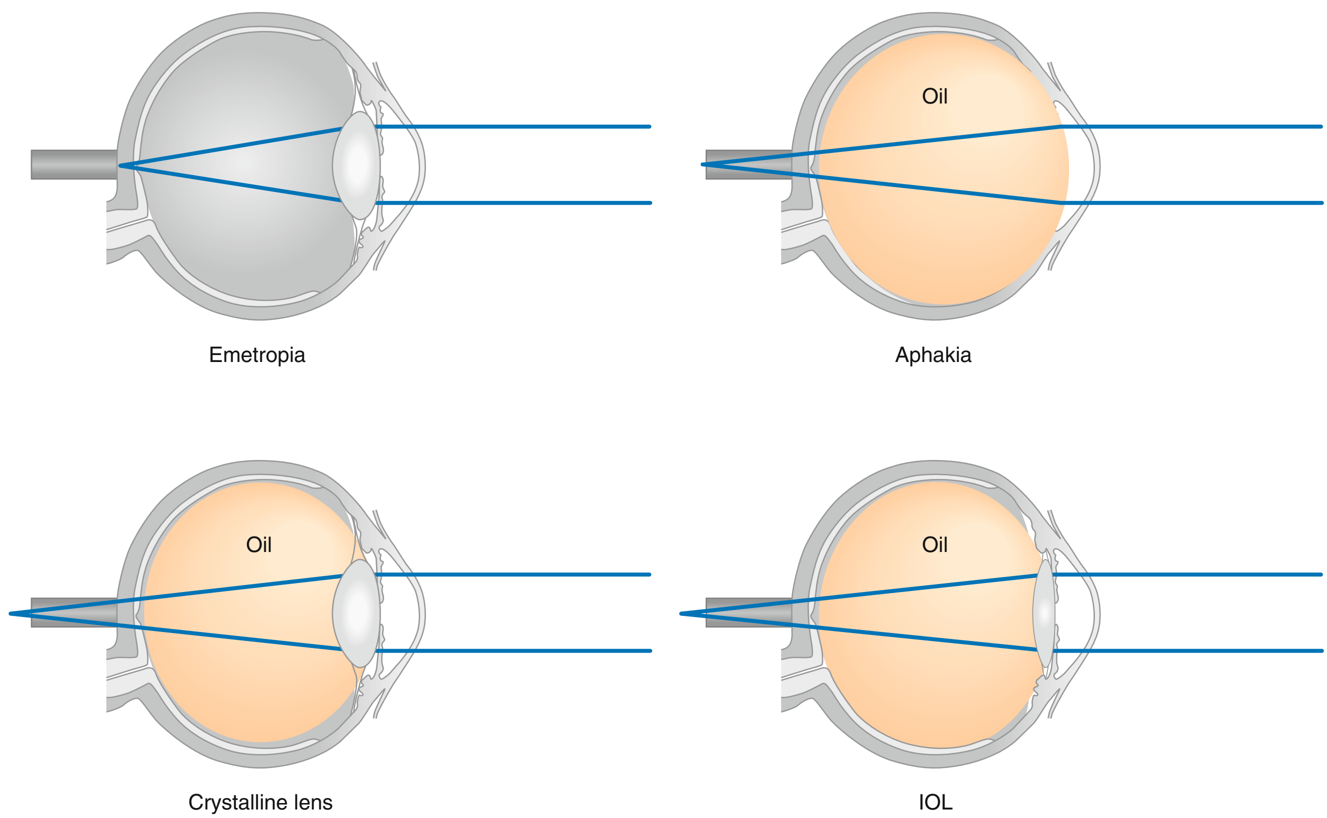


Fig. 3.21 The whole refractive power of the eye is reduced when oil is inserted; therefore, the patient needs a +D spectacle lens to compensate. This is because the refractive power of the posterior surface of the crystalline lens is neutralised by the oil, that is, the difference in refractive index between the oil and the lens is much less than water (vitreous) and the lens. The effect on the refraction of the eye is similar in an eye with aphakia, pseudophakia or with a crystalline lens

3.2.3.4 IOP

- The trabecular meshwork can be filled with silicone oil droplets causing open-angle glaucoma in at least 40 % (Honavar et al. 1999) which is difficult to treat with 28 % remaining refractory to treatment.

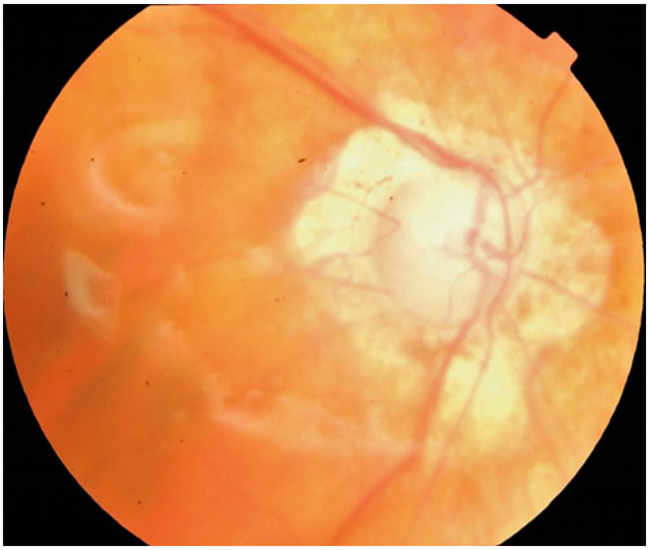


Fig. 3.22 A patient has oil in situ and has low-tension glaucoma. This has exacerbated the glaucoma and caused a severe optic disc cup from additional silicone oil and disc glaucoma

- Angle closure glaucoma in aphakic eyes is produced if a peripheral iridectomy closes (seen in up to 33 %) and the oil bulges through the pupil (Madreperla and McCuen 1995). This can be diagnosed in an eye with a deep anterior chamber, with a clear cornea but a raised intraocular pressure. A sheen may be seen in the iris crypts suggesting oil in the anterior chamber; a cross-sectional slit beam reveals that no cells or flare are present in the anterior chamber and there are no visible convection currents suggesting normal aqueous. Reopening of a peripheral iridectomy will re-establish fluid flow pushing the oil back into the posterior chamber reducing the pressure. YAG peripheral iridectomies tend to close over again in a few weeks; therefore, a surgical iridectomy is preferred. Even the latter may close in 5–33 % of eyes with silicone oil (Madreperla and McCuen 1995; Elliott et al. 1990).
- In phakic or pseudophakic eyes, oil which has dislocated into the anterior chamber, usually peroperatively, can cause an unusual pupil block glaucoma in which the lens is pushed backwards and the iris is pushed anteriorly (Jackson et al. 2001). This causes intermittent angle closure glaucoma which can be difficult to diagnose in the postoperative period. Peripheral iridectomies are usually only temporally effective, and removal of silicone oil is required.

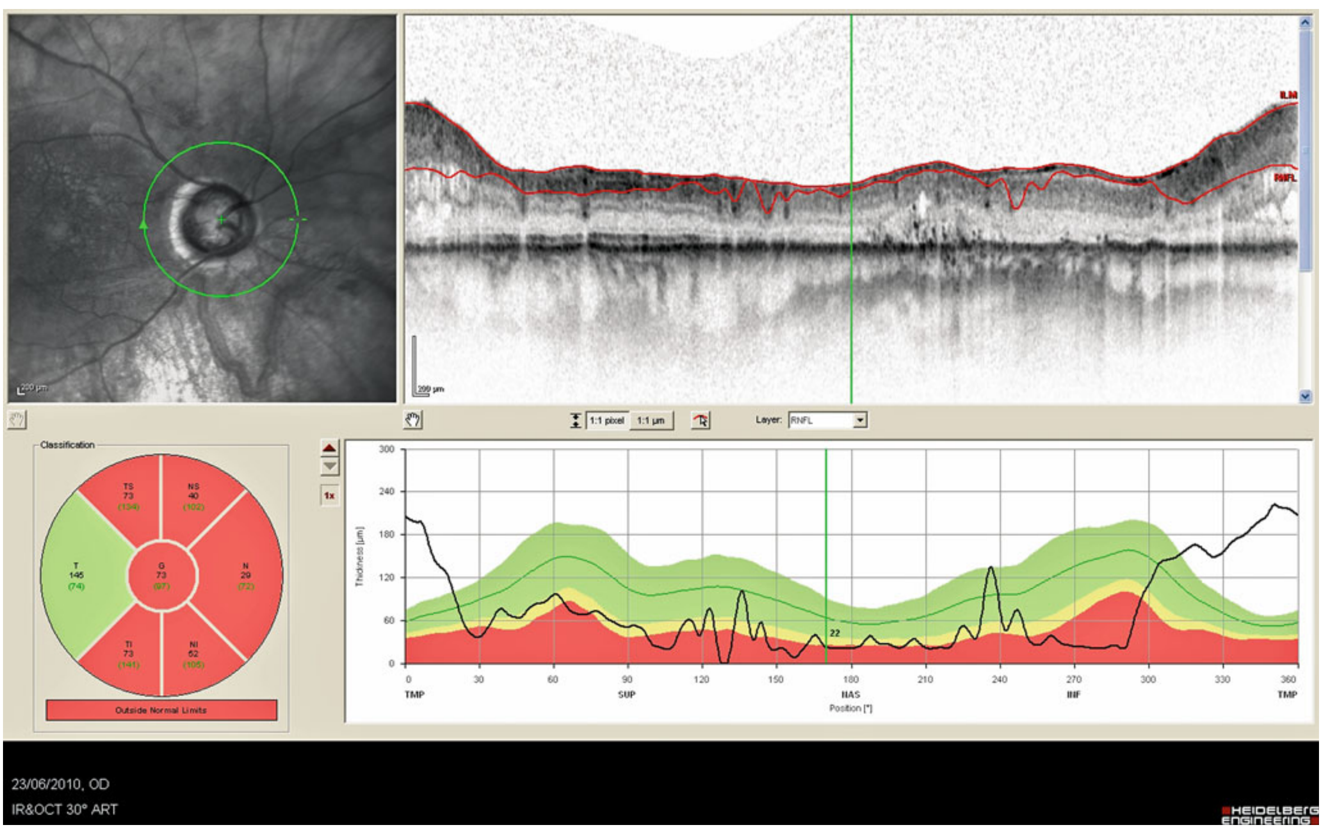


Fig. 3.23 This patient has thinning of the retinal nerve fibre layer from oil-induced glaucoma

If the oil is required for permanent tamponade, the lens capsule complex may need to be removed and an inferior peripheral iridectomy performed in the aphakic eye thus created. Oil presenting into the anterior chamber peroperatively should be evacuated with viscoelastic (see earlier in the chapter, silicone oil in the anterior chamber).

- In some circumstances, there is a deep anterior chamber, and the oil is behind the pupil, but there is still raised intraocular pressure. This may indicate an overfill situation. In an aphakic eye, oil can be removed via a paracentesis reducing the volume of silicone in the eye. In the phakic eye, oil will need to be removed through a sclerotomy. The inexperienced surgeon should avoid the temptation to maximise the fill of oil by leaving the eye 'hard' (high IOP) at the end of the operation. In fact, because of the physical properties of a sphere filled with a liquid, increasing the IOP does not make a significant change in the volume of the filling liquid in the cavity; see Appendix.

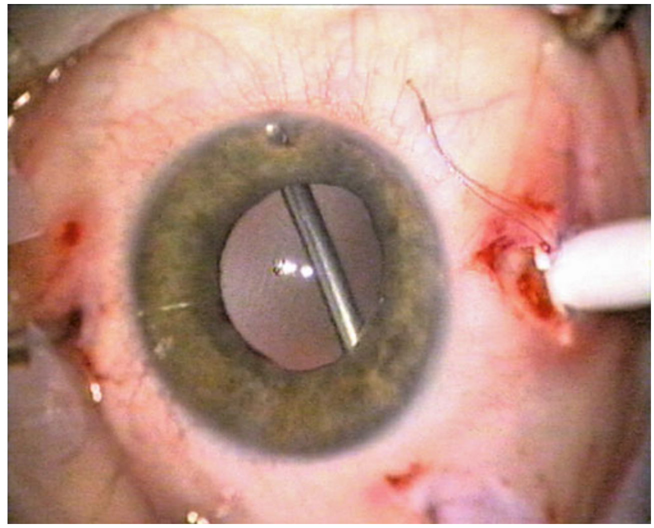


Fig. 3.24 To create an inferior peripheral iridectomy (*PI*) in an aphake with oil in situ, use the cutter on 'aspirate only' to engage the iris, then on low cut rate (200 cuts/min), remove a portion of the peripheral iris. Make sure there is no lens capsule or vitreous behind the PI

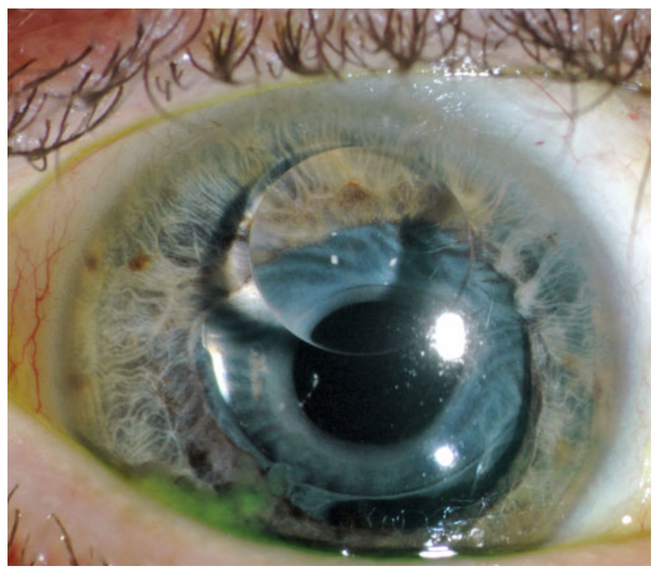


Fig. 3.25 Small bubbles of oil in the AC do not usually cause pupil block. The spherical shape of the bubble minimises the area of oil in contact with the corneal endothelium. Corneal decompensation is rare. The oil can have refractive effects on the vision

3.2.3.5 Cornea

- The oil is associated with the occurrence in some patients of band keratopathy. Some of these eyes are already extensively damaged. The keratopathy may be partly due to phthisis of the eye, which has been prevented by the oil, rather than by contact of the oil on the cornea itself.

3.2.3.6 Macular Toxicity

- Toxicity to the retina in its severest form may result in occasional patients suffering loss of central vision either with the oil in situ or around the time of oil removal (Herbert et al. 2005a, b, 2006; Newsom et al. 2005). For the latter, always avoid direct illumination of the macula during oil removal as the macula seems to be prone to light toxicity in oil-filled eyes. Unfortunately, the loss of vision is permanent often down to 20/200. There is associated relative central scotoma and reduction in colour sensation in the scotoma. OCT images have not shown a detectable abnormality in the retina so far, and electrophysiology has been inconclusive, showing defects in retinal and optic nerve function.
- Pathologically, the oil impregnates all the areas of the eye with characteristic foamy macrophages. Therefore, it has some mild effect on reducing visual acuity through effects on the retina.

3.2.3.7 Oil in the Wrong Place

- There are complications from oil in the wrong place such as subretinal, suprachoroidal or subconjunctival.
- Subretinal oil is very likely to be associated with a total retinal detachment. This may happen if the infusion cannula tip moves into the subretinal space during infusion of the oil. If the eye goes hypotonous during surgery, the tip may angle under the retina, especially if the anterior retina is elevated because of anterior contraction in proliferative vitreoretinopathy or because of retinal detachment into the ciliary body in preoperative hypotony. Once noticed, the oil should be evacuated, but this will usually require a retinectomy. The retinectomy should be large enough to allow the oil to pass through the hole (at least 2 clock hours) overcoming its

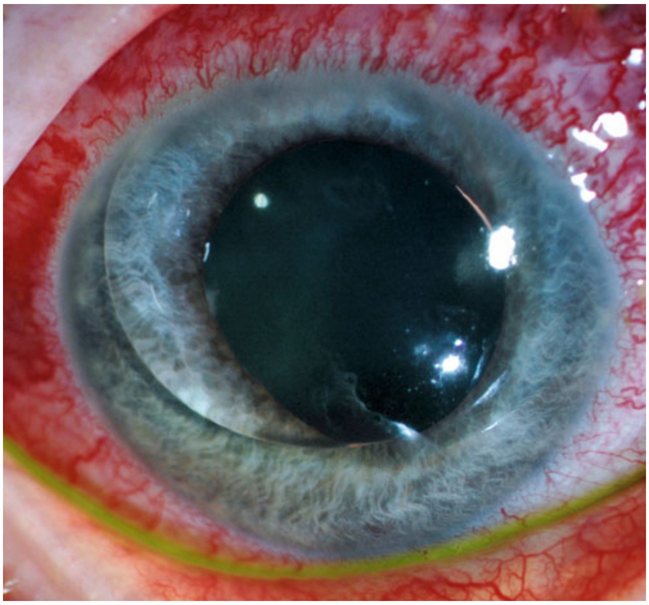


Fig. 3.26 A large bubble of oil in the AC may cause pupil block which is only temporarily relieved by peripheral iridectomy and usually requires oil removal from the AC and if possible from the posterior segment

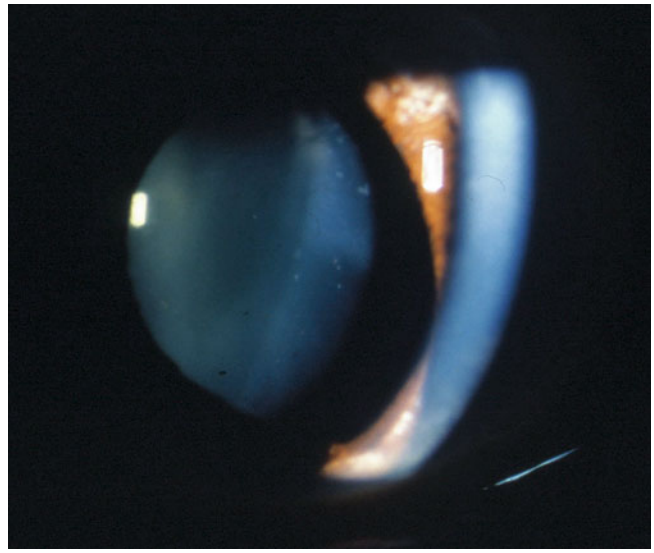


Fig. 3.28 Oil has entered the eye through the zonules of this phakic eye and has pushed the iris forwards and created pupil block glaucoma with a deep anterior chamber

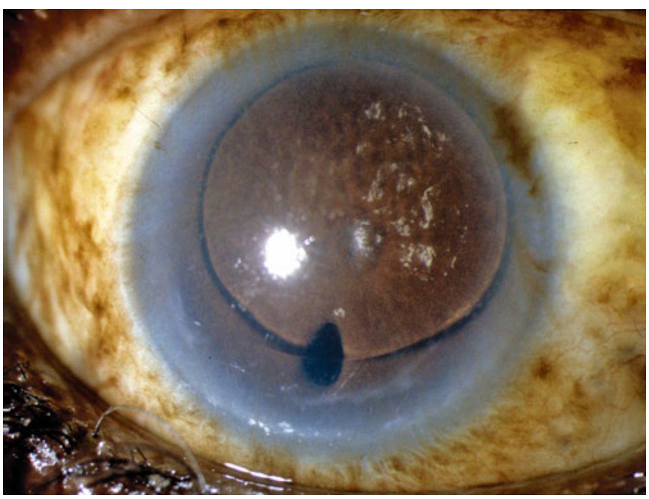


Fig. 3.27 Oil has entered the anterior chamber despite a patent peripheral iridectomy because this eye has become hypotonous and is no longer producing enough aqueous to keep the anterior chamber filled

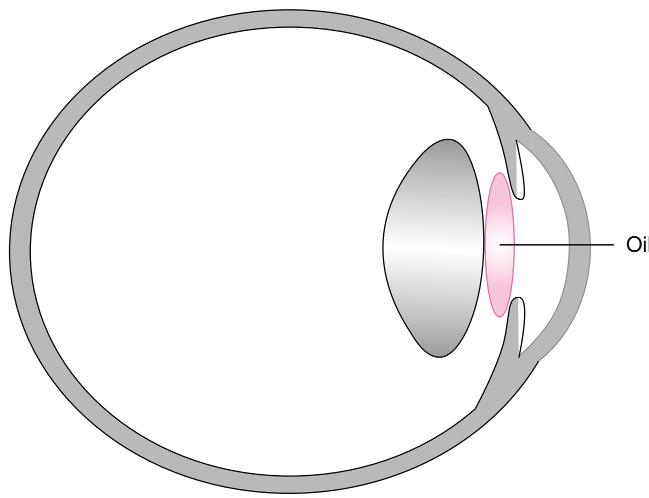


Fig. 3.29 Silicone oil trapped in the anterior chamber can cause forward projection of the pupil and iris and backprojection of the intraocular lens, causing pupil block glaucoma

surface tension. Postoperative movement of oil into the subretinal space is seen in the presence of large retinal breaks (or breaks that have become larger postoperatively because of traction) with continued contraction of epiretinal membranes usually PVR, for example, severe tractional and rhegmatogenous retinal detachment in diabetes.

- Suprachoroidal oil is a very rare occurrence and is again caused by problems with the infusion cannula moving as above but into the suprachoroidal space. A retinectomy and choroidectomy will be needed to evacuate the oil. The incisions should be anterior to allow the oil to float out. Alternatively cut down on the sclera to access the suprachoroidal space.
- Subconjunctival oil is extremely difficult to remove because it infiltrates the Tenon's layer with multiple small bubbles causing inflammation. It is caused by poor closure of a sclerotomy and possibly raised IOP. This should be seen very rarely.

Fig. 3.30 The inferior edge of a silicone oil bubble produces refractive changes, which if the bubble is under-filled can be problematic to the patient with changes in refraction on head movements

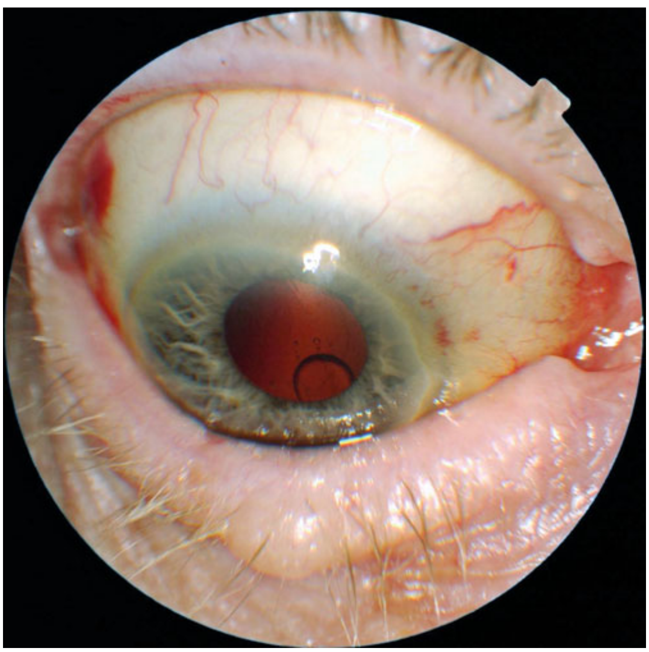


Fig. 3.31 In the first week postop, an oil droplet was noticed inferiorly between the IOL and the posterior capsule; at week two, this had risen into the visual axis. A YAG capsulotomy allowed the oil droplet to contact the oil in the posterior chamber into which it was absorbed see 3.32-33

Surgical Pearl of Wisdom

Post-Op Silicone Oil in AC After Closure of Inferior Iridotomy

An inferior iridotomy significantly reduces the chances of postoperative silicone oil pupillary block

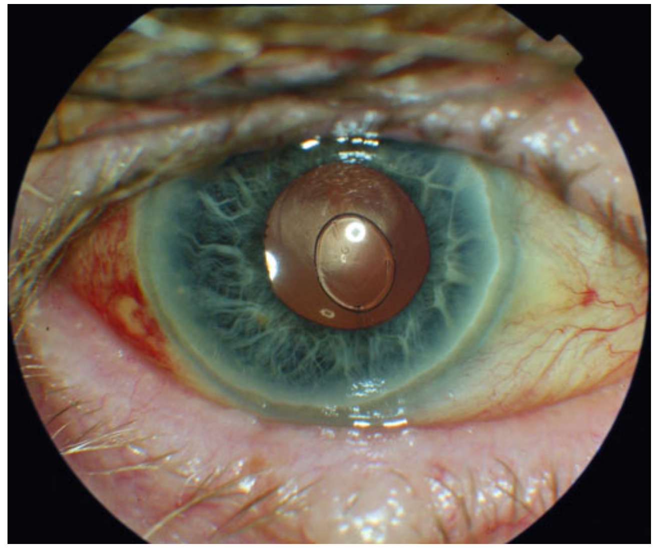


Fig. 3.32 See previous figure

in aphakic patients. However, iridotomies will occasionally fail, allowing silicone oil to enter the anterior chamber, resulting in severe elevation of intraocular pressure. Injection of tPA into the anterior chamber can dissolve fibrin occluding the iridotomy, but there is another technique that I have found effective. After appropriate topical anaesthesia and surgical prep, simply enter the anterior chamber with a 27-gauge needle, and mechanically reopen the iridotomy. Have the patient position in a face-down position, and examine the eye every 5 min or so. Aqueous will percolate into the anterior chamber from the reopened iridotomy, and the oil will return to the vitreous cavity.

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3.2.3.8 Emulsion

- Emulsified oil may reduce visual clarity and cause a white superior opacity in the anterior chamber with droplets producing a superior fluid level. Small residual droplets of oil are common even after oil removal and must not be confused with white cells and inflammation. The patient may experience floating objects in the vision seen especially on looking down at the ground when the oil droplets float up to the macula. In this position, the droplets are next to the retina and therefore are seen in focus as circles with a dark perimeter.

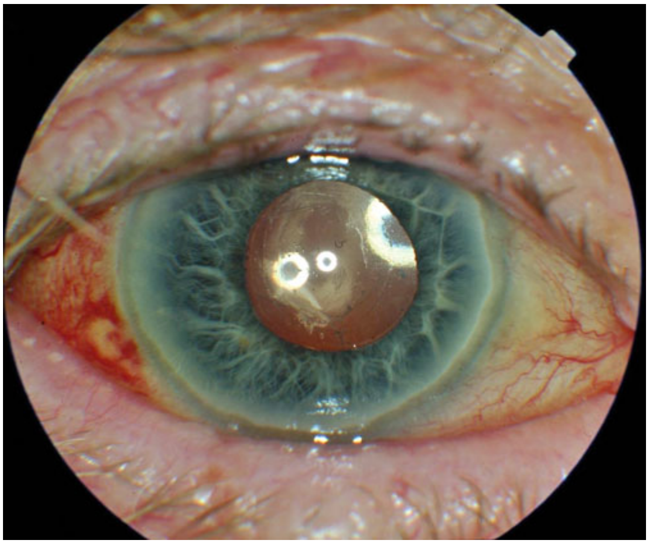

Fig. 3.33 See fig. 3.31

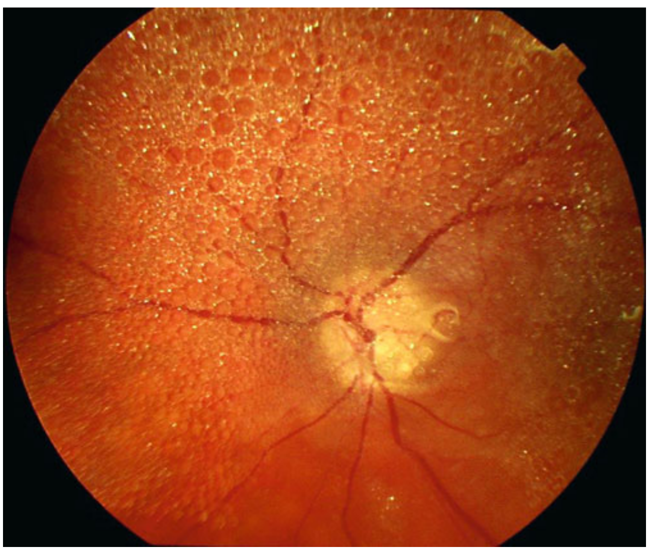

Fig. 3.34 Emulsified droplets of oil are seen on the retina

Surgical Pearl of Wisdom
Individual patient factors may contribute to silicone oil emulsification. These may be special immunologic conditions, individual protein configurations, medication taken by the patient, smoking habits or even environmental poisons like polybiphenyls and dichloro-diphenyl-trichloroethane, which are present in body fat (Dresp and Menz 2005; Valone and McCarthy 1994). These substances can be more or less dissolved in silicone oil but attack the surface of the silicone oil droplet. In addition, the presence of fibrin or serum may also facilitate the emulsification process (Heidenkummer et al. 1991). The decrease in surface tension may be due to the release of inflammatory agents and blood.

Despite routine cleaning and sterilisation of vitreoretinal instruments and accessories, remnants of silicone oil and detergents can remain and trigger emulsification of silicone oil that comes into contact with these contaminated devices during instillation of the endotamponade.

Other possible contaminants of silicone oil are substances that are used intraoperatively in cases of retinal detachments such as perfluorocarbons which have to be removed at the end of surgery. Removal is performed either by direct exchange to silicone oil or indirectly: indirect exchange means that in a first step, air/fluid exchange is performed.

A reduction of the risk of emulsification can be achieved by using a disposable device for silicone oil injection, thus reducing the content of impurities in the silicone oil to the lowest possible level. From a chemical point of view, a direct exchange should be avoided by removing heavy liquids from the vitreous cavity as completely as possible before silicone oil is injected. In contrast, many vitreoretinal surgeons are accustomed to the direct exchange technique, which can be performed easily with PFCL. If a direct exchange seems mandatory (e.g. where there is a risk of retinal slippage in surgery for giant retinal tear if an air exchange is used), the contact time between PFCL and silicone oil should be kept as short as possible and the contact area kept as small as possible.

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3.2.3.9 IOLs

- Oil may adhere to intraocular lenses especially those made of silicone. Wiping the lens with HPMC can help to remove the oil; occasionally, the lens has to be exchanged.

3.2.4 Silicone Oil Removal

Additional steps 20 G method 1:

1. Prepare for the vitrectomy as before.
2. Enlarge one superior sclerotomy (or in aphakes create a 2-mm clear corneal wound).
3. Hold the sclerotomy open whilst the infusion is on.
4. Allow the silicone oil to extrude (block the microscope light from entering through the pupil).

5. Sew up the sclerotomy (instruments can be inserted through the sewn up sclerotomy).
6. Perform an internal search.

Additional steps 20 G method 2 (preferred):

1. Prepare for the vitrectomy as before.
2. Use a 10-mm-long 18-gauge cannula attached to an oil injector pump set on extract.
3. Actively extrude the oil (block the microscope light from entering through the pupil).
4. Perform an internal search.

Additional steps 23 G:

1. Prepare for the vitrectomy as before.
2. Use a 4-mm-long 23-gauge cannula attached to an oil injector pump set on extract inserted through one of the trochars (if not available, create a 20 G sclerotomy as above).
3. Actively extrude the oil (block the microscope light from entering through the pupil).
4. Perform an internal search.

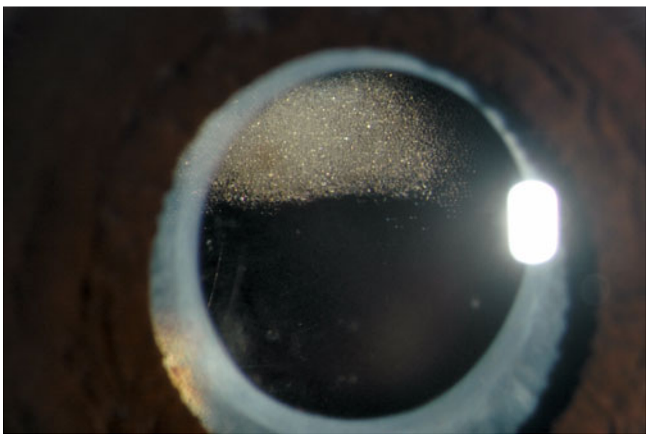

Fig. 3.35 Emulsion of oil between residual anterior vitreous and an IOL in Berger's space

Whenever silicone oil has been inserted, the aim must be to remove the oil at a later date to maximise vision and reduce the chance of complications. In the silicone oil study, oil was removed from 45 % of the eyes in which it was used (Hutton et al. 1994); however, it is better to aim for a much higher removal rate perhaps 80 %. Different methods are possible. The greatest risk is redetachment of the retina in the early postoperative period. For this reason, it is prudent to re-examine the retina at the time of oil removal and to deal with any redetachment there and then, ROSO plus operation (Herbert and Williamson 2007).

Insert an infusion line into the pars plana (take care that the infusion cannula can be more difficult to see because of the refractive properties of the edge of the silicone oil) and set up sclerotomies as for a PPV. Block the central illumination of the microscope light to avoid retinal light toxicity (the macula of the silicone-filled eye may be prone to damage). For 20 G, use a short (10 mm) cannula 18 G attached to a 10-ml syringe which is attached to the oil extraction system (the same one used for oil injection but on extract rather than inject). Insert the cannula into one of the sclerotomies. Aspirate the oil with vacuum of 300 psi and wait for the oil to enter the 10-ml syringe. For 23 G, use a 4–6-mm 23 G cannula inserted through a trochar with 500 psi.

Keep the tip of the cannula in the oil because if you enter the aqueous layer (which has much less viscosity), the high

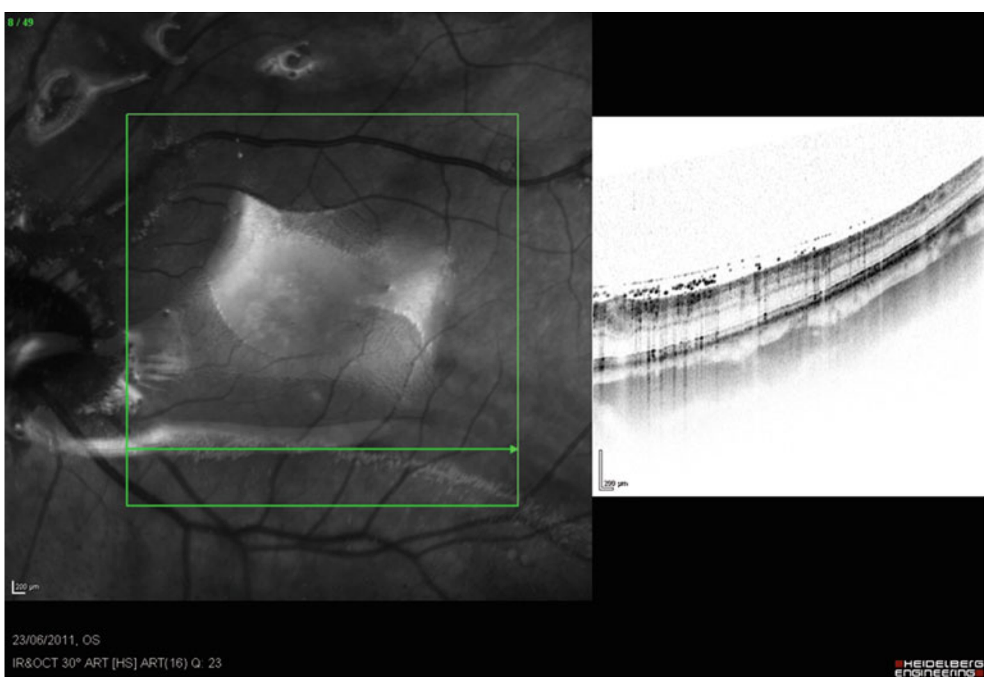

Fig. 3.36 Emulsified oil (*small black dots*) is seen just inferior to the line of contact of the main oil bubble with the retina (green arrow indicates line of scan)

vacuum can cause a sudden drop in IOP risking choroidal haemorrhage. Be especially careful when the bubble is small. Keep the tip in the oil with the cannula perpendicular to the oil surface. Try to stay in the bubble the whole time; this keeps the bubble on the cannula rather than allowing it to float away. When the bubble is small, it will be hidden behind the iris. Aspirate gradually drawing the tip of the cannula to the sclerotomy and slowly out of the eye; the oil bubble should be drawn to the sclerotomy, and start to exit through the sclerotomy (keep the sclerotomy at the highest point). Do not aspirate too vigorously just inside the sclerotomy in case you engage the remaining vitreous base and cause traction on the retina.

If a short cannula is not available and the eye is phakic or pseudophakic, the oil can be removed through an

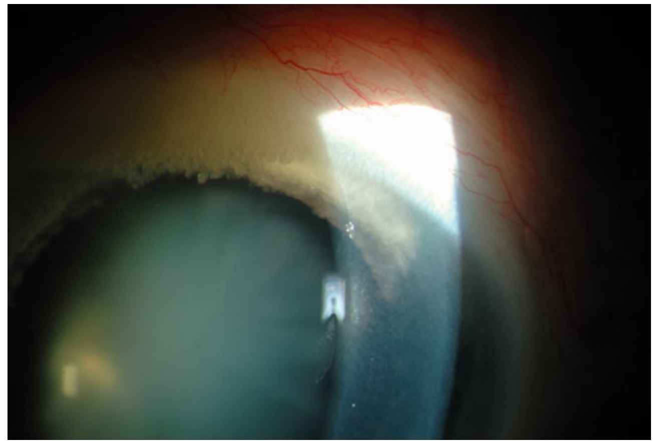

Fig. 3.38 Silicone oil can emulsify in the eye; the droplets float in the anterior chamber producing a 'fluid' level in the superior angle

Table 3.5 Silicone oil complications

Complications of silicone oil	
Cataract	Nuclear sclerotic
Glaucoma	Open angle Pupil block Oil overfill
Refraction	Reduced hypermetropia in aphakes Hypermetropic shift in phakic and pseudophakes
Emulsion	
Retinal toxicity	
Oil in the wrong place	Suprachoroidal Subretinal Subconjunctival
Band keratopathy	
Adherence to intraocular lens implant	

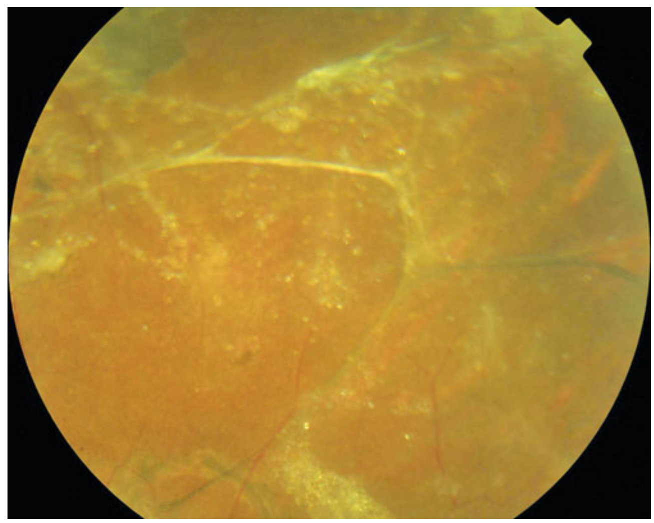

Fig. 3.39 Emulsified silicone oil gets everywhere including attached to epiretinal membranes

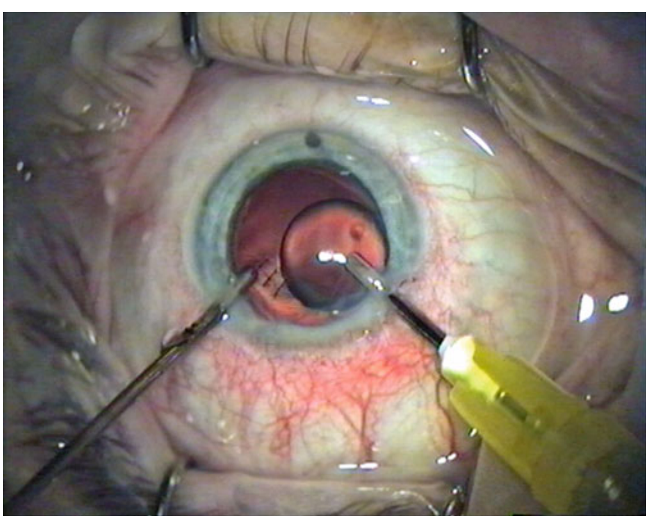

Fig. 3.37 Oil can be removed through the anterior chamber in an aphakic patient

Fig. 3.40 It is not easy for oil to leak through a sclerotomy because of its small size. If leakage occurs, multiple bubbles of oil appear in the Tenon's layer sometimes causing inflammation. Their multiplicity makes removal surgically difficult because the bubbles are loculated within the connective tissue

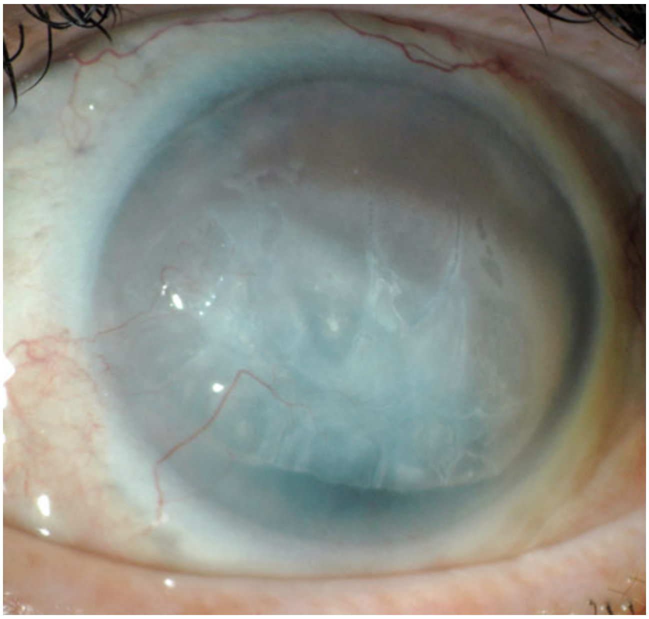

Fig. 3.41 A corneal scar from decompensation of the cornea in an eye with long-term silicone oil in situ

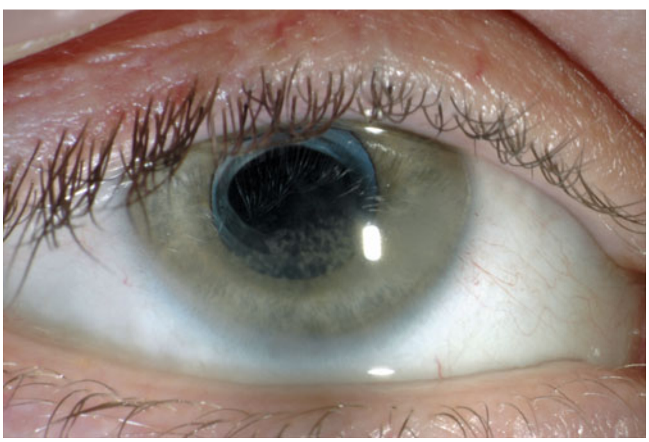

Fig. 3.42 Band keratopathy is a late complication of silicone oil tamponade

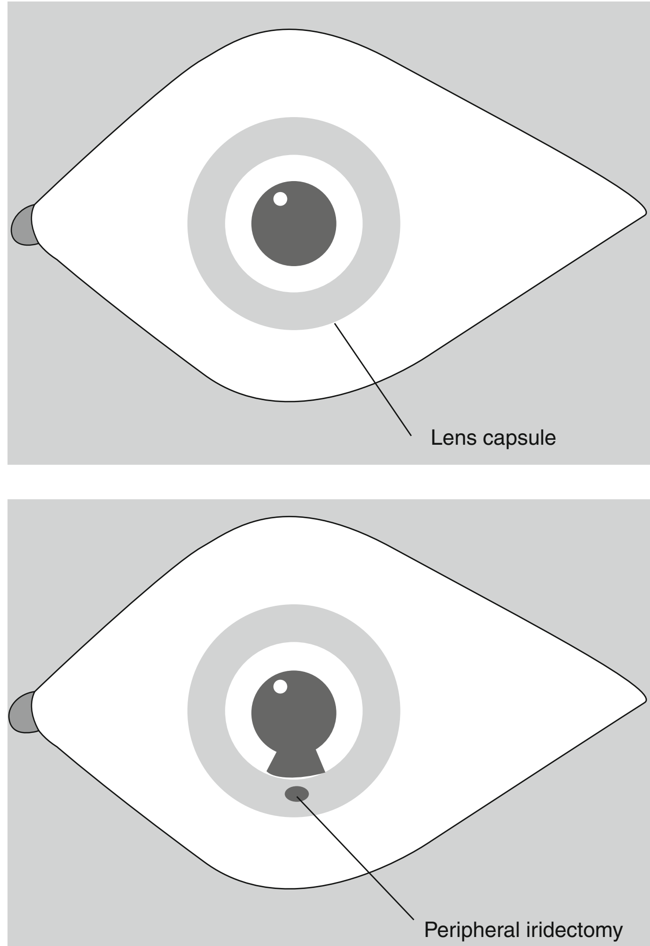

Fig. 3.43 Sometimes it is necessary to remove the lens of an eye which is about to receive silicone oil. Conventionally, the lens was removed in its entirety with capsule removed also, leaving no structure for subsequent lens implantation. It is possible to preserve some capsule, either anterior or posterior; however, leaving a ring of capsule will produce posterior synechiae and glaucoma. This can be avoided by excising a small wedge of capsule at the 6 o'clock position behind a peripheral iridectomy, thereby allowing aqueous to travel into the anterior chamber, avoiding pupil block glaucoma and maintaining capsule for later sulcus fixated lens implantation

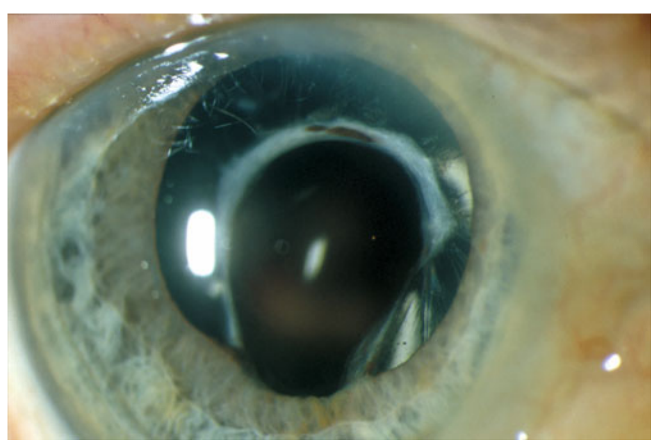

Fig. 3.44 An example of a keyhole capsulectomy postoperatively

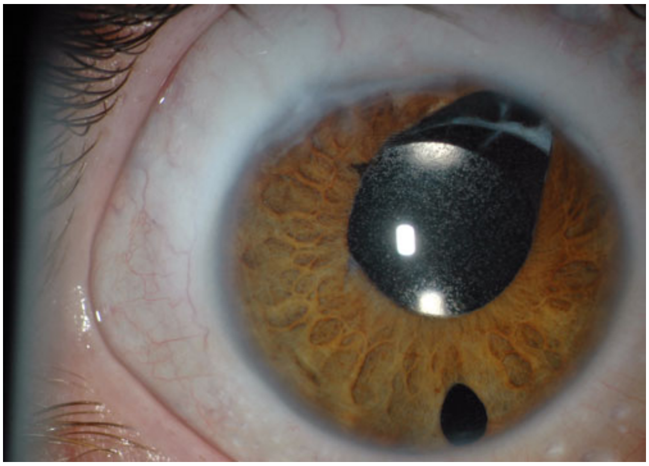

Fig. 3.45 This patient had a keyhole capsulotomy as part of the management of a traumatic retinal detachment with later sulcus fixated IOL. The IOL is stable as seen in this photograph 6 years later

Table 3.6 Difficulty rating of silicone oil removal

Difficulty rating	Low
Success rates	Moderate
Complication rates	Low
When to use in training	Early

enlarged 2-mm sclerotomy rather than by active suction. If using a 2-mm sclerotomy, the elasticity of the choroid often leads to a small hole in the choroid through which the oil will not pass; therefore, it is important to check this and enlarge the hole separately from the scleral incision. Sew up the sclerotomy hole after use and before the internal search; instrumentation will still pass into the eye despite the suture. Create the other sclerotomy and internally search the eye.

Perform the routine PPV approach, and internally search the retina for SRF, traction, open breaks or leaking retinectomy edges. The risk of retinal redetachment is extremely high if SRF is found in the inferior retina (six times more likely than if SRF is found superiorly) and reinsertion of the oil is recommended (Herbert and Williamson 2007). If breaks are found without SRF or SRF is found superiorly, these can be treated with retinopexy and gas tamponade.

3.2.4.1 Alternative Methods

If performing a cataract extraction at the same time, it is possible to perform a posterior capsulotomy to allow the oil to enter the anterior chamber and exit through the cataract excision in which case insert the IOL after the oil has been removed. If the eye is aphakic, a 2-mm corneal incision can be used to allow egress of the oil. These methods do not facilitate re-examination of the retina (ROSO plus).

3.2.4.2 Retinal Redetachment Rates After Oil Removal

These are high at 15–25 % because surgeons tend to use oil in patients with complex vitreoretinal pathologies such as severe trauma, failed tractional retinal detachment surgery or proliferative vitreoretinopathy (Lam et al. 2008; Falkner et al. 2001; Jonas et al. 2001). In addition, there is a risk of long-term hypotony approximately 16 % (Casswell and Gregor 1987). Some have tried to reduce retinal redetachment rates by applying 360° laser retinopexy to the peripheral retina before the ROSO operation claiming reduced posterior retinal detachment rates from 21 to 11 % (Laidlaw et al. 2002; Avitabile et al. 2008).

3.2.5 Heavy Silicone Oils

Silicone oil cannot be relied upon to provide inferior tamponade; therefore, oils which are denser than water have been developed.

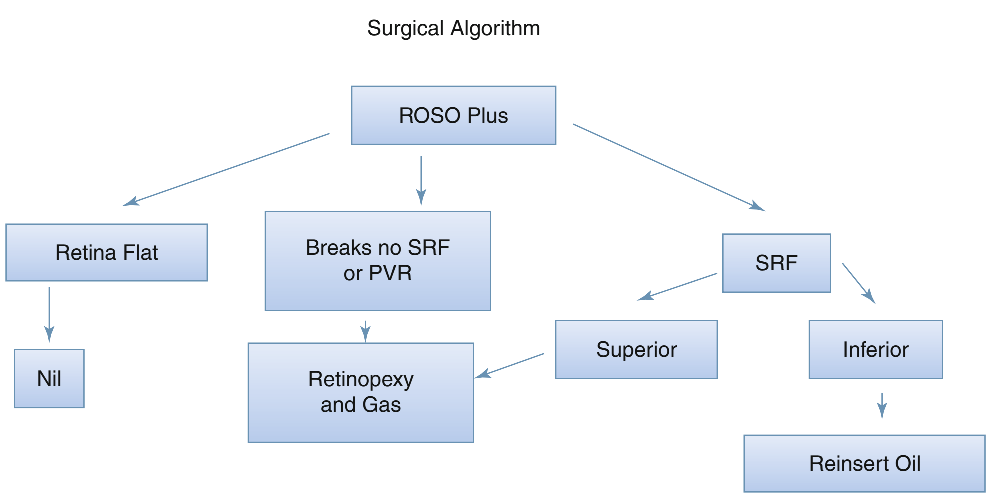

Fig. 3.46 During ROSO plus operation, use the algorithm as a guide to managing the retina to minimise postoperative redetachment and reoperation rates

Table 3.7 Properties of various liquids

	Molecular weight	Viscosity mPas	Refractive index	Density g/cm^3
Silicone oil	25,000 or 50,000	1,000–1,300 or 5,000–5,900	1.4	0.97
Densiron 68 (heavy oil)	NA	1,400	1.39	1.06
Oxane HD (heavy oil)	NA	3,300	1.4	1.02
Perfluorodecalin (heavy liquid)	462	2.7	1.3	1.8–2.0
Perfluorooctane (heavy liquid)	438	0.8	1.27	1.76

Densiron 68 (fluoron) is a heavy silicone oil made up of polydimethylsiloxane $(CH_3)_3SiO$-9($Si(CH_3)2O$)n-$Si(CH_3)_3$ and perfluorohexyloctane F_6H_8:

1. Density 1.06 g/cm^3.
2. Viscosity 1,400 mPas.
3. Refractive index 1.39.
4. Interfacial tension in water at 25 °C is 40.82 mN/m.

Oxane HD is a combination of silicone oil and partly fluorinated olefin:

1. Density 1.02 g/cm^3
2. Viscosity 3,300 mPa
3. Refractive index 1.40
4. Interfacial tension in water 40 mN/m

These can be inserted in the same way as silicone oil. Removal is more difficult than with silicone oil because the heavy oils do not float out of the eye; active suction is required with an 18-gauge cannula inserted through a sclerotomy. Metal tip cannulae are best to avoid sticking of the oil to the tip in the final stages of removal. The oils may adhere to the retina but can usually be separated off with care. Some of these oils will separate into their two components heavy and light which must be considered during removal.

Many surgeons have found uses for heavy oils, for example, inferior PVR or giant retinal tears, but results may not be improved over the use of conventional silicone oil (Wickham et al. 2010). My experience is that the heavy oils are not dense enough to reliably deal with inferior PVR and can produce postoperative PVR superiorly. Superior PVR is more difficult to deal with by retinectomy, so I prefer the predictability of conventional silicone oils.

Surgical Pearl of Wisdom

Veckeneer described a phenomenon occurring during SO oil removal: patches of SO-like material 'glued' to the retina which has particularly been seen with heavy oils (Veckeneer et al. 2008). Perfluoro-octane rather than perflurodecalin has been related to the phenomenon, and gas chromatography mass spectroscopy has revealed a significant presence of PFO in samples of sticky silicone oil. In order to elucidate the phenomenon of stickiness of silicone oil, Dresp analysed samples of heavy silicone oil that have been explanted either uneventfully or with reported 'stickiness', as well as the results of a laboratory experiment (Dresp and Menz 2007). Dresp's experiments showed that the cohesion of the silicone oil was lower than the adhesion between silicone oil and PFCL. Therefore, the aspiration of silicone oil from the vitreous cavity after a PFCL/silicone oil exchange could be extremely difficult. Winter et al. demonstrated that total removal of PFCL during surgery is almost impossible (Winter et al. 1999).

Despite the fact that PFO and PFD are very similar in their surface behaviours, the solubility of these two substances in silicone oil differs significantly. Indeed, the solubility of PFD in silicone oil (5.1 m%) is much higher than the solubility of PFO (3.2 m%). Residual PFCL can dissolve in the silicone oil over time reducing perhaps the chance of stickiness.

PFD must be used, endotamponade performed for longer, and all residual PFCL small droplets carefully removed. The transparent nature of the PFCLs makes complete removal difficult during exchange with silicone oil and especially with air. A coloured PFCL that facilitates visualisation of PFCL residues may prevent many of these problems.

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3.2.6 Heavy Liquids

Additional Surgical Steps (Chang 1992)

1. Use a heavy liquid filled syringe and a two-way cannula with the tip close to the fovea.
2. Expand the bubble of heavy liquid with the distal orifice within the bubble and the proximal orifice in the vitreous cavity fluid.
3. For removal, use a flute needle in the bubble, and try to remove in one smooth action to avoid losing the bubble when it is small.

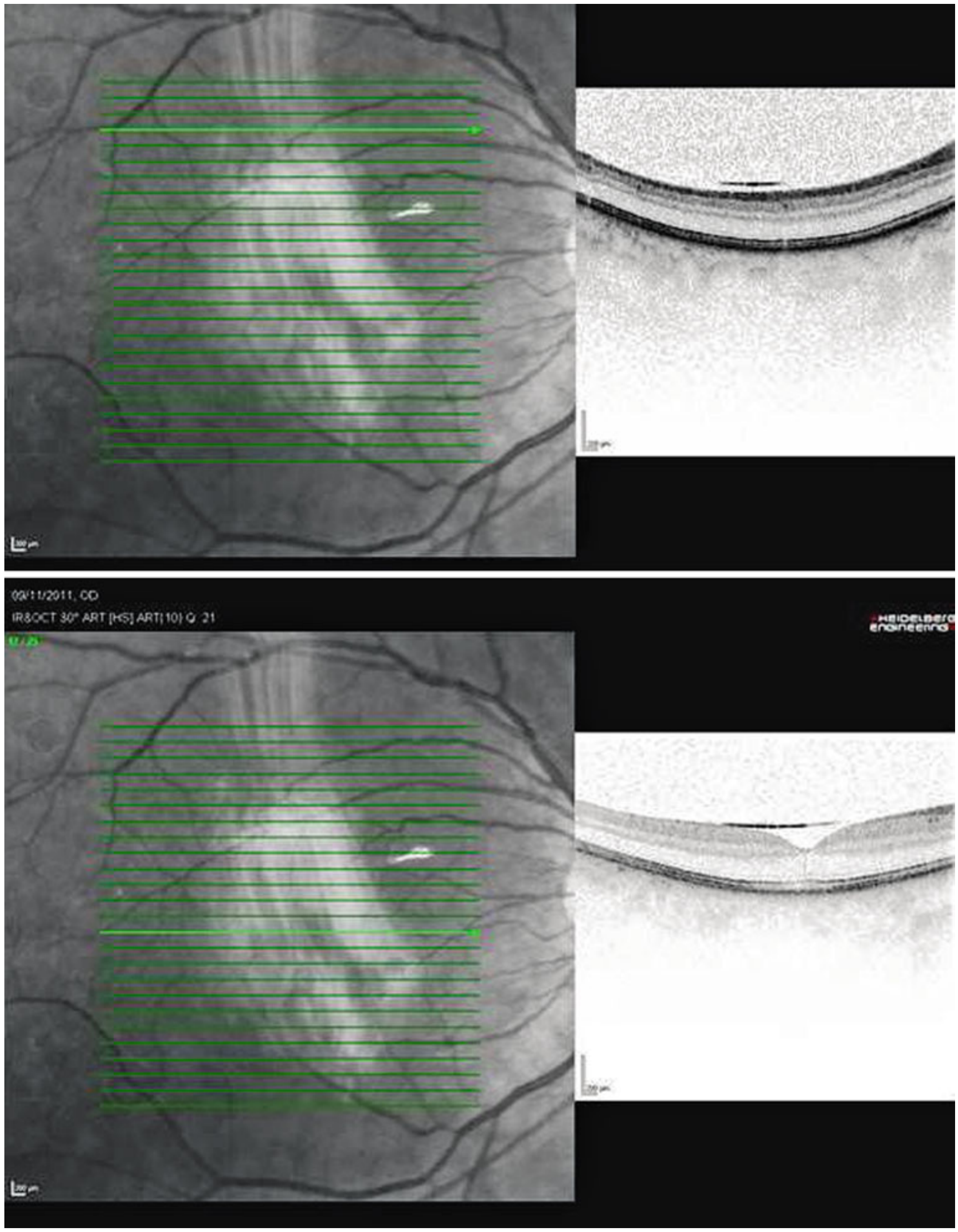

Fig. 3.47 Heavy oil is in contact with the retina at the fovea in this patient (*lower image*) but is not in contact superiorly (*upper image*)

Available heavy liquid agents include the perfluorocarbon liquids (PFCLs) such as decalin, octane or phenanthrene in which all carbon atoms of the carbon backbone are completely fluorinated. These agents may cause emulsification, vascular changes and structural alterations of the retina and are therefore usually removed at the end of surgery. They are biologically inert, with a specific gravity higher than water, immiscibility with water or blood and with a high gas binding capacity.

Perfluorodecalin, a fluorinated perfluorocarbon, has the following properties:

1. $C_{10}F_{18}$
2. Molecular weight 462
3. Densities of 1.8–2.0 g/cm^3
4. Refractive index 1.313
5. Boiling point 142 °C
6. Vapour pressure (37 °C) 12.5 mmHg
7. Surface tension (25 °C) 19 mN/m
8. Interface tension in water (20 °C) 57.8 mN/m
9. Viscosity (25 °C) 2.7 mPas

Perfluoro-n-octane has a high vapour pressure which theoretically allows small droplets at the end of surgery to vaporise into the air or gas bubble reducing the chance of retained droplets:

1. C_8F_{18}
2. Molecular weight 438

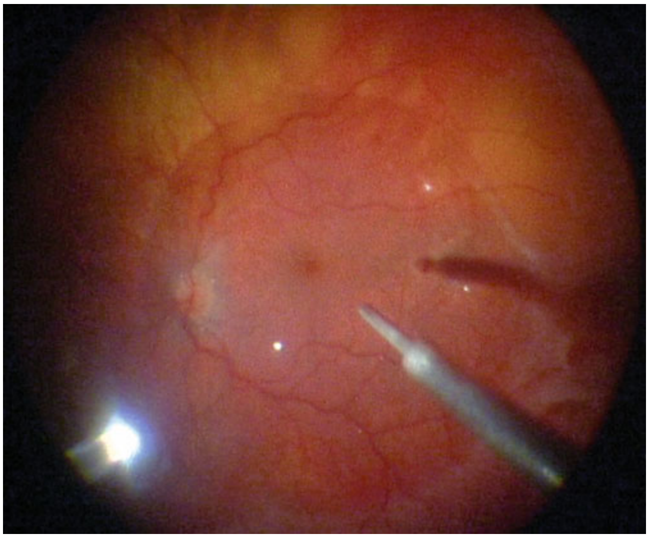

Fig. 3.48 A two-way cannula is used to insert heavy liquids into the eye; the heavies are infused through the distal orifice, whilst the vitreous cavity fluid exits through proximal hole on the shaft of the instrument

Fig. 3.50 Multiple droplets of subretinal heavy liquid are seen in this patient on fundus autofluorescence

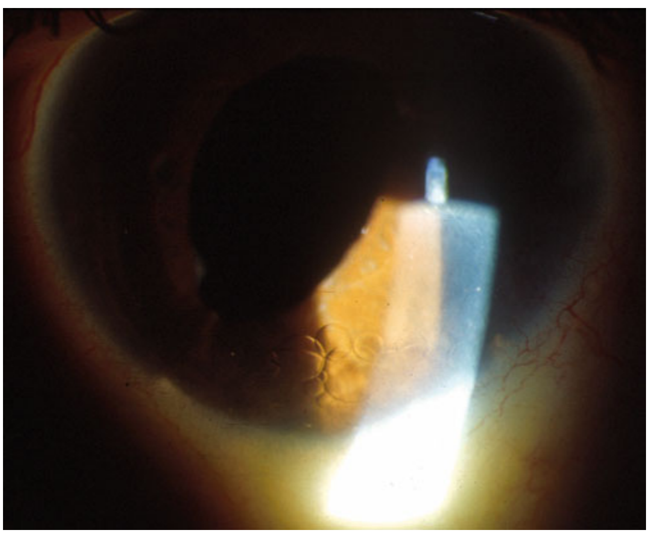

Fig. 3.49 Droplets of heavy liquid are present in the inferior angle of this patient. These can be easily aspirated by using a fine gauge needle and as a paracentesis

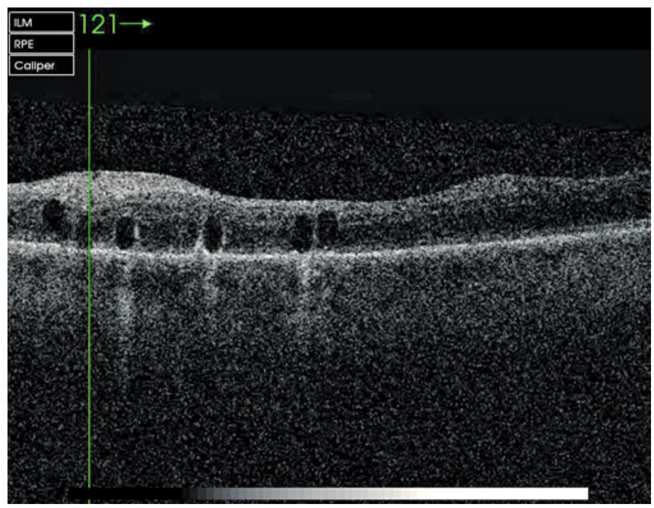

Fig. 3.51 An OCT of the same patient showing the droplets of heavy liquid

3. Densities of 1.8 g/cm^3
4. Refractive index 1.27
5. Boiling point 103 °C
6. Vapour pressure (37 °C) 52 mmHg
7. Surface tension (25 °C) 15 mN/m
8. Interface tension in water (20 °C) >40 mN/m
9. Viscosity (25 °C) 1.4 mPas

These agents are very useful peroperative tools for:

1. Retinal detachment
2. Giant tears
3. Ocular trauma
4. Assisting laser application
5. Lifting subluxated lenses
6. Peroperative stabilisation of the retina

Keep the heavy liquid away from breaks if these are on tension (e.g. in PVR) because the liquid easily separates into different bubbles and enters the subretinal space. With heavy liquid under the retina, occasional small bubbles become immobilised and cause no damage; larger bubbles are able to move in the subretinal space causing inferior RPE damage and persistent RD.

Subretinal heavy liquid can migrate to the fovea and use OCT to show an echolucent bubble.

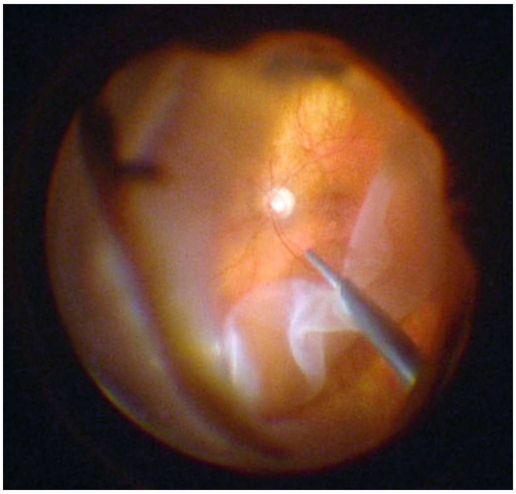

Fig. 3.52 The retina has incarcerated into the outflow channel of a heavy liquid cannula; this is a risk with mobile retina as in 360° macular translocation or giant retinal tear as in this eye. If you consider this likely to happen, use a single channel flute needle and allow the vitreous cavity fluid to egress through a sclerotomy

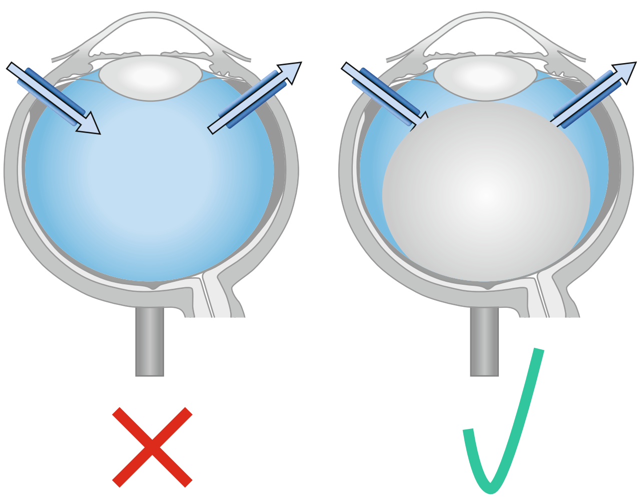

Fig. 3.53 Trying to remove emulsified oil by flushing the vitreous cavity with BSS is ineffective because the oil droplets can enter the BSS and only slowly become less concentrated in the vitreous cavity, with only a few emulsified droplets removed for unit of time (*left graphic*). Displacing the fluid containing the emulsion with a fluid (gas or F_6H_8) into which the emulsion cannot dissolve allows the emulsion containing liquid to be extracted rapidly (*right graphic*). F_6H_8 also has the advantage that the surface of the F_6H_8 will absorb some of the oil droplets which will be removed when the F_6H_8 is removed

Subfoveal liquid should be removed; you will need to detach the retina by infusing balanced salt fluid under the retina using a 40-gauge cannula attached to the oil injection pump. Once a bleb of subretinal fluid has been raised, insert air into the vitreous cavity to push the fluid towards the macula. This mobilises the heavy bubble away from the fovea, and it can be aspirated through a retinotomy.

3.2.7 'Light' Heavy Liquids

Semi-fluorinated alkanes, R(F)R(H), have a perfluorocarbon and a hydrocarbon segment in the molecule. They are physiologically inert, colourless, laser stable liquids with low densities of between 1.1 and 1.7 g/cm^3 and very low surface and interface tensions.

They are soluble in perfluorocarbon liquids (PFCL), hydrocarbons and silicone oils.

3.2.7.1 Removal of Emulsified Silicone Oil

F_6H_8 is a fluorocarbon liquid that has the density of 1.35 g/cm^3 and can be used for removal of emulsified silicone oil which it solubilises, easing removal of oil droplets. Fill the vitreous cavity with the light heavy liquid which advantageously displaces the emulsion, physically aiding its removal, in addition to solubilising residual oil.

3.3 Summary

There are a wide variety of surgical tools available to the vitreoretinal surgeon. Their use depends on personal experience, and each has its own set of additional complications.

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