AIOS ARC CME Series
'Transitioning to MIVS'

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‘Transitioning to MIVS’ an AIOS CME series takes us to the exciting world of vitreous surgery which has transformed over the last decade to yield exceptional results in Vitreo retinal pathologies like interface disorders, epiretinal membrane, vitreo-macular traction, etc which were mystic, inoperable, difficult to assess and intervene. The 4 key features – self-sealing sutureless sclerotomy wonderful viewing systems provided through wide angle vitrectomy lens systems, bioms, endo illuminators, newer vitrectomy machines with advanced fluidics and of course the high speed small gauge vitrectomy cutters have all contributed to this magnificent development. These key features are highlighted in the CME series written aptly by Dr. Lingam Gopal, Dr. Pukhraj Rishi and Dr. Mangat R Dogra.

This CME series will guide even the anterior segment surgeons to take a leap forwards and dwell in the nuances of vitreous management through the pars plana route in complicated scenarios. The fundamentals of the technology have been clearly decluttered for the understanding of every ophthalmologist. As technology eases towards more clear outcomes, many of us will enter the domain of vitreous surgeries and this CME series provides a perfect platform for the first stepping stone. As we move forward simplification will become the ultimate sophistication and performing vitreoretinal surgeries will be every ophthalmologist’s surgical skill. This CME series is an ode to this evolving future and opportunities that lie as we move on.

Yours in Ophthalmology,

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Preface

“Any sufficiently advanced technology is indistinguishable from magic” – Sir Arthur C Clarke

Vitreo-retina (VR) surgery is one of the most advanced and sought after sub specialities in Ophthalmology today. It has grown by leaps and bounds in the last two decades, so much so, that disease indications, prognosis, surgical techniques, approach and technology used has radically transformed in this period of time. However, even till a few years ago, VR surgeries remained time consuming for the surgeon and with long recovery times for the patient.

MIVS or micro incision vitrectomy surgery has brought about a paradigm shift in the field of VR surgery, making the procedures faster, safer and with swifter recovery time for the patient. From time to time, technology opens up new vistas in the medical field. Some of them are optional, some helpful, but there are some which are game changers. MIVS is one such technology. It is no longer a good to have, but a must have tool in the armamentarium of every VR surgeon.

Yes, the cost factor remains an issue, and there is a learning curve involved as with any new procedure. But the evidence based medicine reiterates the effectiveness, and it is imperative now that every VR surgeon, whether experienced or novice upgrade themselves with this technology.

The demand for minimally invasive surgeries has grown in every field since time immemorial, and just as laparasocopy and phacoemulsification have become the standard of care in their respective fields, it is expected that MIVS will become the gold standard in VR surgery in the days to come.

The indications, surgical technique and challenges of performing a MIVS has been elegantly described by some of the doyens in the field of VR surgery. I sincerely hope that this manual will be a useful tool for every ophthalmologist to understand the essentials of this technology.

Dr. Partha Biswas
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For the ophthalmologist, touching the vitreous was a taboo till Kasner in 1962 performed open sky vitrectomy and showed that vitreous could be removed without compromising on the integrity of the eye. It was Robert Machemer who opened the gates to controlled removal of the vitreous with the introduction of the VISC (vitreous infusion suction cutter). These instruments were bulky and needed large openings in the sclera for introduction. The problems were aplenty due to the size, irregular surface of the instrument with various steps caused by the infusion sleeve, sleeve for light pipe etc. Split function probes were introduced by Connor O’ Malley. 20 Gauge pars plana 3-port vitrectomy has remained the standard of care for a long time. Taking the analogy of conversion from extra capsular cataract surgery to phaco emulsification, vitreo retinal surgery has also undergone an upheaval with the introduction of 23 and 25-gauge vitrectomy. The initial teething troubles were quickly overcome with improved technology and materials. The thinner probes were made more stiff to withstand the rigors of moving the eye and the illumination has also been made more efficient. Most of the instruments such as scissors, forceps are available in these smaller diameters. However phaco fragmatome is not as yet miniaturized. Hence there is a need to enlarge the sclerotomy to accommodate this instrument, which remains of 20-gauge size. Several adoptions had to be done to accommodate smaller size of the instruments. The suction applied has to be correspondingly high.
when the size of the instrument is reduced. For example, 600-mm/hg suction with a 23-gauge instrument gives the same flow as 20 gauge with 150 mm/hg suction. Contrary to 20 gauge instruments, which are available both as reusable and disposable varieties, most small gauge instruments are disposable in view of the fact that they can be easily damaged during the surgical procedure, thus increasing the cost per surgery.

The concurrent development and universal adoption of wide angle viewing system has also helped the cause of small gauge vitrectomy. By giving a panoramic view of the fundus, the need to turn the eye to reach the periphery is minimized. Reaching the periphery is possible without turning the eye by differentially sliding the instruments within the sclerotomy and changing their direction.

This is a compilation of articles related to various aspects of MIVS, written by experienced vitreo retinal surgeons. In addition to covering the present day application of MIVS, the articles also cover the technical details, and complications related to the use of small gauge instruments. The articles have reasonable detail to be useful for both the novice and practicing vitreo retinal surgeons.
1. MICROSCOPES:
A good microscope is an absolute must for successful Micro incisional vitrectomy surgery (MIVS). It should have X-Y movement with respect to the patient’s eye. X refers to nasal temporal movement. Y refers to superior inferior movement. It should have foot switch controlled zoom, on off and fine focus. It should be fitted with laser filters and image inverting systems.

2. WIDE ANGLE VISUALIZATION SYSTEMS:
These systems have evolved over a period of time and have now become the preferred choice for most retina surgeons. They provide view up to retinal periphery, ease of operation and faster surgical time. They provide superior visualization in small pupil, hazy media, in eyes with keratoprosthesis and does not obviate change in lens during fluid air exchange. They are very useful in MIVS surgery because it is difficult to rotate the patient’s globe with flexible instruments. They are of two types: Contact and Non contact. Non contact systems have the advantage of no image distortion, ease of use, causes no corneal trauma and useful in fluid air exchange. However they have the disadvantage of a difficult learning curve and adaptability issues with different microscopes. Contact lens systems provide excellent panoramic vision with better depth perception however they have the drawback of being assistant dependent.

Brief descriptions of various lens system is given below:

a) **BIOM**: Binocular Indirect Ophthalmo Microscope (BIOM;
Oculus, Wetzlar, Germany) was introduced by Spitznas M in 1987.\(^1\) It works on the principle of Indirect Ophthalmoscope. The optical system of the BIOM® 5 consists of the reduction lens and the front lens. The reduction lens ensures that the distance between the patient’s eye and the surgical microscope remains more or less the same when the BIOM is swiveled in and out. Inverted real image of retina is formed 5.8mm above optical surface of ophthalmoscopy lens. It needs a SDI® (Stereoscopic Diagonal Inverter) to convert the image into an erect one. SDI has an internal prismatic system with near zero light escape. SDI inverts the indirect image. Earlier models of the BIOM required manual focus adjustment and an image inverter. BIOM 5, the latest version of BIOM, has an automatic inverter and focus adjustment with a footswitch. A variety of lenses are available as an attachment. 53603 Wide field high definition lens provides good resolution and a field of view up to 125°. 53606 Hi Res lens has a maximum field of view of approx. 60°. 53604 90D lens is the standard lens suitable for most cases. Maximum field of view is approximately 90°. 53601 Wide field lens is specifically suited for deep set eyes. It has a maximum field of view of approximately 70°. Recently disposable BIOM lenses have been introduced which are specially indicated for high risk cases like CMV related retinal detachment secondary to HIV.

b) **AUTOCLAVABLE LENSES**: Autoclavable lenses are coated with amorphous carbon which protects against damage due to aggressive cleaning and mechanical wear giving longer life. Two types are available. 53585 Widefield (E) lens with a field of view of 120° and 53586 Hi Res Macula lens with a field of view of 60°.

c) **PWL SYSTEM**: The Peyman-Wessels-Landers 132 D Upright Vitrectomy Lens (PWL; Ocular Instruments, Bellevue, WA) provides wide-field, upright images without an inverter because of an internal prismatic system\(^2\). It can be used with any microscope because no modification or attachment to the microscope is required.

d) **RESIGHT 700**: The Resight 700 (Carl Zeiss Meditec AG, Jena, Germany) is a wide-angle viewing system. It is incorporated in the Lumera 700 microscope. It has two aspheric lenses, a 128.00
D lens for wide-angle viewing and a 60.00 D lens for magnifying images of the posterior pole. The fundus image is automatically inverted by Resight’s Inverter tube. It has got the unique advantage that it does not need refocusing when the viewing system is moved in and out. The inbuilt varioscope optics ensures that the microscope always stays in same focal plane.

e) **OFFISS:** The Optical Fiber Free Intravitreal Surgery System (OFFISS; Topcon Medical Systems, Oakland, NJ), developed in 2003 by Masayuki Horiguchi, MD, is a wide-angle viewing system. It is specifically designed for the OMS-800 Operation Microscope (Topcon Medical). The specific advantage of this system is that the microscope is provided with its own illumination system which is condensed by the lens to illuminate the fundus without the need for a separate endoilluminator. Hence routine surgeries can be performed with 2 ports only. It also has an incorporated slit lamp which helps in focusing the light into tissues. Lenses currently available are 40D and 80D giving 60° and 120° field of view respectively.

f) **EIBOS:** EIBOS 2 is a wide angle viewing system. It has an integrated inverter which keeps the microscope short and flips away if not needed. The viewing angle inside the eye is 90° for the 90 D lens and 124° for the wide-angle SPXL lens with 132 D. It provides the advantage of simultaneous observation of the fundus and the incision area.

g) **VOLK ROLS:** Reinverting Operating Lens System is a contact lens system manufactured by Zeiss. This provides excellent transparency and stereopsis. It needs a microscope mounted image inverter. A diode laser safety filter is built in. They provide wide angle view up to the ora. New self stabilizing lenses of power 58D, 85D and 156D has been introduced recently.

3 **INFUSION CANULAS:**

Infusion line forms the pivot of vitreous surgery. Separation of the infusion function from the vitreous cutter decreases its size and enhances flexibility. The wide separation of the infusion and egress ports decreases turbulence and operating time. The infusion system
is placed first and taken out last. 23 G infusion cannula has 0.56 mm diameter. 23G infusion cannulas area available with 4 mm and 6 mm tip. 25-gauge Entry Site Alignment system (ESA) or microcannula system includes a cannula-based infusion line with a female Luer-lock connector. In this system infusion cannula has a precise sliding fit within the microcannula. The 27-gauge infusion line has a beveled sharp-tipped metallic tube 4 mm long. It is designed for 1-step perpendicular insertion through the pars plana.

4. VITREOUS CUTTERS:

Vitreous cutters are available for 23, 25 and 27 G systems. Specifications of the cutters are enumerated in Table 2. Both the 23 and 25 G systems have the same lightweight probe, weighing four grams without tubing. Vitreous cutters consist of a hollow inner tube surrounded by a hollow outer tube. Both the tubes are arranged coaxially. During vitrectomy vitreous is drawn into a port near the distal end of the outer tube. There after the inner tube slides forward, closes the port and shears off the vitreous. Finally the cut material is aspirated out through the inner tube. The cutting mechanism of these probes may be guillotine-style or rotational. In guillotine-style, the inner tube moves along the longitudinal axis whereas in the rotational type the inner tube moves around the longitudinal axis. The cutters can be driven either pneumatically or electrically. Pneumatic guillotine vitrectomy cutters are powered by a pneumatic drive pulse that acts upon a rubber diaphragm. When the surgical system provides an air pulse, the diaphragm is extended and the cutter tip closes, completing a cut. When air is released, a spring returns the tip to the open position. As cut rate is increased, the duration of open time per cut decreases, while the closed time remains constant. Thus as the cut rate increases the total time the port is open decreases. (decreasing duty-cycle) The second type of pneumatic drive mechanism utilizes a dual drive line system. This is used in the Ultravit® probe used with the Constellation Vision System. The guillotine cutter of the Ultravit® probe is driven with a pneumatic drive pulse that acts upon a diaphragm. However, instead of a return spring, a second pneumatic drive pulse acts against the diaphragm in the opposite direction to reopen the cutter. Because of this unique design, the ULTRAVIT® probe can operate up to 7500 cpm. Electrically operated vitrectomy cutters are another
option. They come in two varieties: rotational electric motor and solenoid drive. Cutter motion is generated via mechanical coupling in rotating electrical motor cutters. The duty cycle is not adjustable in these cutters. The Stellaris PC provides a cut rate of 5000 cpm, Oertli 6000 cpm, Constellation 7500 cpm and midlab vit enhancer ultimate 8000 cpm. There are two setting options, proportional and 3D(Dual, Dynamic, Drive). In proportional setting, suction is variable depending on position of foot switch but cutting rate is fixed. In 3D setting, both cutting and suction can be independently controlled with foot switch. 3D setting further enhances the safety while working closer to the retina.

5. VITRECTOMY MACHINE:

The primary aim of vitreous microsurgery is to remove vitreous without causing undue vitreous traction and collateral retinal damage. This is achieved by inflow and outflow matching. This balance is achieved by the vitrectomy machines. It comprises of an inflow system and an outflow system.7

a) **Inflow system:** This regulates the entry of fluid into the system. These are of two types: Gravity fed system and Pressurized system. In gravity fed system the inflow pressure is controlled by changing the bottle height with respect to the eye. It is assistant dependent, cumbersome and provides imprecise intraocular pressure control.

Vented gas forced infusion (VGFI) is a pressurized system of controlling the infusion pressure used in Alcon Accurus machine. Here filtered pressurized gas is delivered into the infusion bottle through tubing. Rapid pressure elevation or reduction can be achieved with this system e.g. in cases of bleeding the pressure can be rapidly raised without assistant help. Alcon Constellation system offers further modification into this system. Here infusion solution is pressurized within the cassette. Constellation system has inbuilt real time IOP monitoring which tracks infusion canula and tubing resistance. It also has dual infusion chambers instead of one where in the moment one bottle empties the other takes over minimizing iop fluctuations.

b) **Outflow system:** Though a variety of factors control the egress of
fluid out of the system. Vitrectomy machine pumps are one of the main factors controlling it. Two types of pumps are available—peristaltic and venturi. In venturi systems flow is induced by vacuum changes within the cassette. Flow hence occurs as a result of vacuum, and in homogeneous low viscosity substances, flow is directly proportional to the vacuum applied. Venturi system is controlled by surgeons foot pedal however they do not incorporate flow rate limiting. Peristaltic pumps are positive displacement machines. The fluid contained within a tube is forced to move within the system by rollers that compress it. Here the vacuum rise occurs only after occlusion. So flow rates can be maintained very low with peristaltic systems and can still achieve high vacuum at occlusion. This adds to the safety and causes minimal iatrogenic complication. Vitrectomy machines like Oertli OS3, Alcon Constellation, Dorc Associate and Geuder Megatron S4 have both the pumps. Surgeons can choose between either of the pumps while using these machines. On the other hand there are machines with only a peristaltic pump, e.g. the Oertli Faros or with venture pump only like Alcon Accurus.

Apart from the aspiration pumps there are other factors which control the outflow rate.

They are as follows:

i) **Gauge size**: Narrow gauge vitrectomy has higher resistance to aspiration as compared to wider gauge for the same set vacuum.

ii) **Port size**: It is also a limiting factor reducing the outflow. Newer 25 G probes are designed with a larger port area to compensate for this deficiency.

iii) **Duty cycle**: Cutter duty cycle, i.e. the amount of time the port stays open for each cut cycle. In electric cutters, the duty cycle is set at 50%, i.e. the cutter is 50% closed and 50% open for each cut cycle. The duty cycle is fixed and flow remains near constant up to the maximum set cut speed of the cutter. Newer machines give the option of altering the duty cycles. Constellation system offers three separate duty cycle options. Core is the maximum port-open duty cycle control. It is best suited for core vitrectomy, in which
higher flow rates are more efficient and desirable, and the risk of traction is not as great. Shave is the minimum port-open duty cycle. It is best suited for delicately removing tissue in situations where lower flow rates are desirable, such as near mobile retina or shaving in the periphery. 50/50 is the setting between core and shave, for those users who prefer that the cutter be open and closed for the same amount of time. This is a similar setting to older electric cutters.8

6. ENDOILLUMINATION:

Endoillumination systems have undergone tremendous advancements to match the cutting edge changes in the MIVS. Peyman is credited with the development of first endoillumination systems in 1976, involving an optical fibre going inside the vitreous cavity. Endoillumination system comprises of power supply, illumination source, optical system consisting of lenses and filters, coupling system to convert energy in free space into optical fibre and an optical fibre based delivery system.

**Light sources:** Light sources could be endoilluminator types or exoilluminator.

**Endoillumination:** Incandescent, fluorescent, high intensity discharge lamps and semiconductor based lighting are the illumination sources available. Exoillumination is provided by a slit lamp attached to the microscope. Table 3 enumerates various endoillumination sources.

Brief description of various light sources are mentioned below –

a) **Halogen lamps:** It contains an incandescent lamp with tungsten filament which is enclosed with inert gas and small amount of halogen compounds like bromine or iodine. Halogen lamps were standard installation in Accurus of Alcon Laboratories, Inc (Fort Worth, TX, USA). When used in MIVS system they provide less than 50% of brightness as compared to 20 G probes. Spectral radiance and hazard efficacy of halogen lamps are 650nm and 1,920 lumens/hazard watt respectively.

b) **Metal halide lamps:** These are high intensity discharge lamps. They use mercury, argon and various metal halides in their arc tubes. They have the disadvantage of lower life span. They are
part of the Millenium vitrectomy system of Bausch and Laumb Inc (St. Louis, MO, USA). They have spectral output at two peaks of 550nm and 580nm and a hazard ratio of 1343 lumens/hazard watt.

c) **Xenon lamps**: These are high intensity discharge lamps. These are high pressure sodium lamps with short arcs filled with gases such as mercury and xenon. They are fitted with 420nm/435nm filters and 650nm/700 nm filters to reduce phototoxicity due to ultraviolet, blue and infrared light respectively. They provide excellent illumination and are part of next generation vitrectomy machines like Stellaris and Constellation. The DORC Bright Star (DORC) is capable of providing different fundus viewing environments by changing filters (~420 nm, ~435 nm, ~475 nm and ~515 nm) to produce different lighting within the eye. The Stellaris PC also features a xenon light source with three types of built-in filters (green-tin, yellow-tin and amber filters). The only disadvantages of these lamps are that they require cooling systems which increases cost and storage space. They have a hazard efficacy of 1,913 lumens/hazard watt.

d) **Mercury vapor lamps**: These are high intensity discharge lamps. They provide extremely bright illumination even more than Xenon lamps. They have a 435-nm cut-off filter to reduce exposure to ultraviolet and blue light. They produce green-yellow illumination which is soothing to the surgeon’s eye. They have spectral output peaks at 550 and 580 nm and hazard efficacy of 2,200 lumens/hazard watt. These are available from Photon II; Synergetics and Stellaris.

e) **Light – emitting diode lamps**: They are the latest endoilluminators available. They produce brightest light and generate least heat. They have a spectral peak of 455 nm and 565nm.

**Chandelier system**

Chandelier illumination system provides fixed wide angle illumination for bimanual surgery. They also provide the advantage of working away from the retinal surface thus minimizing the chances of phototoxicity.
Because of reduced risk of photo toxicity this system is preferred for longer duration surgeries. 9,10

**Types:** Single Optical fibre type and Dual optical fibre type (Eckhart’s)

**Gauges:** Available in 25G, 27G, and 29/30G

**Fixation:** Self retaining transconjunctival insertion with or without trocar canula system

**Pearls:** Dual optical fibre system eliminates the problem of shadowing.

Glare while using the chandelier systems can be minimized by reducing the brightness, tilting the probe or by using amber filter.

### 7. INSTRUMENTS:

In the early years of MIVS surgery advances were stunted by the lack of entire array of surgical instruments for the smaller gauge system. But recently these deficiencies have been overcome and almost full ranges of instruments are available in 23 and 25 G systems.

a) **Cutters:** Newer generation 25 G cutters have 57% more shaft rigidity than predecessors.

b) **Endoilluminators:** Major breakthrough has been the advent of xenon lighting for the endoilluminators, whose brightness at times supercedes 20G endoilluminators. Newer endoilluminators by Alcon have more illumination, more divergence angle (74%) and markedly reduced glare. Chandelier lighting is available in 29/30 G sizes and Chandelier infusion has also been introduced.

c) **Endolaser:** Both straight and curved and lighted endolaser probes are now available in both 23 and 25 G systems.

d) **Forceps:** ILM peeling, End grasping and Asymmetric forceps are available in both 23 and 25 G systems. For thicker membranes 23 G serrated forceps are available. Illuminated picks has also been introduced recently.

e) **Scissors:** Curved scissors are available

f) **Silicone oil injector:** Both 23 and 25 G viscous fluid injector is available for silicone oil injection and similar extractor is also present.
f) Miscellaneous: Dual bore 23-g infusion cannula - One bore enables PFCL to be injected, while the other simultaneously allows passive aspiration of intraocular fluid. The cannula prevents high pressure and the need to vent either the port or the infusion line. DORC has recently released the 23-gauge Rayes Fragmentation Needle.

References:


1. INTRODUCTION
Ophthalmic surgeons have embraced minimally invasive techniques for a range of procedures from cataract extraction to vitreoretinal surgery. This trend has been fuelled by a desire to reduce surgical times and hasten postoperative recovery, and supported by superior instrumentation for ever expanding indications.

2. MICROINCISION WOUNDS
Self-sealing wounds that cause minimal disturbance of the ocular coats are the essence of minimally invasive vitreous surgery (MIVS). Proper wound construction is, therefore, vital to the success of MIVS. An ideal incision should be simple to construct, provide adequate intraocular access and facilitate maneuvers during surgery. MIVS wounds must additionally maintain integrity in the postoperative period- prevent egress of intraocular contents (fluid, gas) and ingress of extraocular material (contaminants).

3. ATTRIBUTES OF THE MIVS INCISION
An important principle in wound construction for microincision vitrectomy is misalignment of the conjunctival and scleral wounds. This ensures coverage of the sclerotomies by intact conjunctiva and provides additional safety.

For the purpose of description, a microincision wound can be said to have two parts- the surface entry incision and the intrascleral path. The entry incision represents the slit created in the sclera. MIVS
wounds may either have this entry incision parallel to the limbus (circumferential) or perpendicular to the same (radial). The intrascleral path may be oriented anteroposterior (radial) or parallel to the limbus (circumferential). An entry incision at right angles to the scleral path represents a valvular tunnel that can provide for appositional collapse and watertight closure. A wound with the entry incision oriented parallel to the intrascleral path represents a stab incision with minimal forces acting to effect closure (Figure 1). Stab incisions are known to leak and are associated with a higher incidence of postoperative hypotony and endophthalmitis. Tunneled incisions are therefore preferred for MIVS.

**Figure 1:** MIVS wound anatomy. A- Stab incision, B-Tunneled incision (45°), C- Tunneled incision (15°). Given the scleral thickness of 0.5 mm at the pars plana, the intrascleral length of incision would be 0.5 mm, 0.71 mm and 1.93 mm in A, B and C respectively.
Another important feature of tunnel incisions is the obliqueness of the tunnel through the sclera, i.e., the angle that the tunnel makes with the external or internal scleral surface. Simple trigonometry shows us that increasingly oblique tunnels are longer (Figure 1) and hence, more securely air/water tight. The tunnel can be uniplanar or multiplanar.

Figure 2: Commonly employed MIVS wounds. Bold line - scleral entry incision; shaded area- intrascleral tunnel; dotted ellipse – internal entry; R – radial tunnel; C - circumferential tunnel. Reproduced with permission Kothari AR, Narendran V. Principles and Practice of Vitreoretinal Surgery. Jaypee Medical Publishers. New Delhi. 2013 pp 99-105

Tunneled wounds are of two types (Figure 2). They may have entry incision parallel to the limbus with the intrascleral tunnel running anteroposterior (radial tunnel). The other type has the scleral entry perpendicular to limbus and the intrascleral tunnel parallel to it (circumferential tunnel). Scleral collagen fibres are arranged in bundles running in a random manner- hence the opacity of sclera compared to the transparency of the cornea. Consequently, both these incisions can provide equally acceptable sealing provided the tunnel is oblique enough. However, with the radial tunnel configuration, the internal opening of the tunnel is significantly posterior to the external wound – placing it close to the ora serrata and risking inadvertent damage. The risk is especially higher in the one-step technique of incision with the trocar-cannula assembly. Here, the trocar blade extends well beyond the microcannula and has to be inserted to its full length to place the microcannula in the wound. This type of wound also carries a risk of injury to the lens in phakic patients and is, as expected, employed infrequently. The circumferential tunnel wound is generally preferred.
4. MIVS WOUND VARIANTS

Several variations of microincision vitrectomy wounds have been proffered.\textsuperscript{3-7} Initial reports of 25-gauge surgery described straight (stab) incisions. Here, the trocar was introduced straight into the vitreous cavity. These incisions were more likely to have leakage related problems.\textsuperscript{4} Hagemann and Lopez-Guajardo et al proposed inserting trocars with a 30° inclination to the sclera, leading to a radial scleral entry and tunnel parallel to limbus with 30° oblique path. Rizzo et al subsequently reported their technique of making scleral incisions with circumferential entry wound and anteroposterior tunnel. The external entry wound was made at 3 mm from the limbus, with the tunnel 30° oblique to the sclera and vitreous entry at 4 mm. Ultrasound biomicroscopy studies have confirmed the superiority of both the oblique techniques compared to the straight incision.

For 23-gauge vitrectomy incisions, oblique incisions with an angle of 45° to the sclera have been given up for those with an inclination of 30°. This is because of the substantially longer length of tunnel with increased obliqueness. The earlier practice of straightening the trocar during the final entry into the vitreous has also been found unnecessary. It is preferable to insert the trocar-cannula system in a single direction obliquely without straightening. Decreasing the inclination angle to 10-15° and entering without straightening has been demonstrated to produce safe and airtight wounds (the so called ‘Zorro’ incision). Pollack et al suggested a biplanar incision with initial tunnel at 5° to the sclera and entry into vitreous at 30°. Similar to that described for 25-gauge wounds, Rizzo et al have reported their technique of making scleral incisions with circumferential entry wound and anteroposterior tunnel for 23-gauge.

5. MIVS WOUND CONSTRUCTION

Two techniques have been described for wound construction in small gauge vitrectomy. The one-step technique utilizes a trocar-cannula set. This is an assembly of a sharp trocar over which the microcannula is mounted. The trocar is introduced obliquely through the sclera to create the incision and the microcannula is left behind in place as the trocar is withdrawn. Several systems have a caliper at the end opposite to the trocar, which helps in measuring the distance from limbus for
the sclerotomy without the need to change instruments. The first generation trocars were beveled. Introduction of these required some force and sclerotomies produced could be irregular, ‘Chevron’ shaped and often patulous. The newer trocar design is similar to conventional MVR blades. These blades encounter less resistance during incision and result in better slit like wounds.

The two-step technique was originally described by Eckardt for 23-gauge surgery. The first step involves using a stiletto blade to create the initial sclerotomy. This is followed by the placement of a microcannula into the sclerotomy over a blunt inserter. This method produces stable self-sealing wounds. However, it has certain disadvantages-need for two instruments, difficulty in finding the conjunctival opening during microcannula insertion and double conjunctival punctures.

Good fixation of the globe is essential to ensure precise wound construction. The conjunctiva is held by a forceps and displaced laterally for about 2-3 mm over the proposed sclerotomy. It is best to pick up the conjunctiva (preferably with Tenon’s tissue) just posterior to the proposed incision site and bring it up and hold it just ahead of this site. Holding anterior to the site of incision helps in exerting counter-pressure while introducing the trocar and prevents torsion of the globe. Holding the conjunctiva at the opposite limbus or behind the incision site leads to excessive torsion and conjunctival tearing while incisions are made. Alternatively, a pressure plate can be used. These fixation plates have serrated undersurfaces to hold the globe and calibration marks for distance from limbus and even the angle of entry. Care is needed in elderly patients and those with thin conjunctiva as there is propensity for the conjunctiva to tear while performing the incision. Cotton tipped applicators may be used to stabilize the globe in these cases. A sharp trocar prevents undue pressure and rotation of the globe while making the incision.

A description of the standard oblique incision follows. The incision is made with the blade of the trocar perpendicular to the limbus. The trocar is held at an angle of 30° (or even less) tangential to the sclera in a direction parallel to the limbus and introduced in that direction to create an oblique tunnel in the sclera. After introducing the trocar fully, the external hub of the microcannula is held in place as the
trocar is withdrawn, leaving it in place in the sclerotomy. Creation of a biplanar tunnel requires tilting up the trocar midway during insertion to the desired angle, prior to entry into the vitreous cavity. The practice of oblique initial entry followed by tilting up of the trocar handle 90° to enter the vitreous cavity perpendicular to the sclera serves no additional purpose and may result in leaky sclerotomies. Hence a fully oblique pass is recommended.

For anteroposterior tunnels (Rizzo et al), the blade is positioned parallel to the corneal limbus to create circumferential scleral wound 3 mm from the limbus. It is then introduced posteriorly towards the posterior pole to create radial tunnel in the sclera.

**Figure 3:** Direction of Insertion of the trocar for creating MIVS wounds Reproduced with permission Kothari AR, Narendran V. Principles and Practice of Vitreoretinal Surgery. Jaypee Medical Publishers. New Delhi. 2013 pp 99-105

During incision making, the trocars are directed towards either the inferior pole of the eye (6 o’clock) or the superior pole (12 o’clock) (**Figure 3**). We prefer to direct the trocars towards the 6 o’clock position for the superior sclerotomies. Most of the vitreous surgery would happen with instruments (cutter, endoilluminator, etc.) entering the superior ports directed towards the inferior or posterior pole. Tunnels with a similar orientation would, therefore, tend to get distorted less
during surgery. Tunnels pointing towards 12 o’clock would be subject to more twisting and distortion during surgery, and more likely to leak without sutures.

The infusion cannula is secured first through a sclerotomy made preferably in the inferotemporal quadrant. A tactile click of the infusion tip in the 23-gauge microcannula indicates firm connection. This is essential to prevent the infusion cannula coming loose during globe manipulation during surgery. The tip of the infusion cannula is visualized in the vitreous cavity with a fibreoptic light source held inside the limbus with one hand and the microcannula depressed with the other. Once correct placement is confirmed, the infusion can be turned on. Doing this prior to the other sclerotomies is especially helpful in eyes with hypotony, low scleral rigidity or those that are previously vitrectomised.

Active sclerotomies are made in the superotemporal and the superonasal quadrants. These sclerotomies are preferably placed one clock hour above the horizontal. The superonasal sclerotomy site is chosen depending on the available approach in patients that have a prominent brow or nasal bridge or sunken orbits- the usual site may have to be moved more superiorly. Distance from the limbus depends on the phakic status of the patient (phakic eyes: 3.5 mm to 4 mm; aphakic or pseudophakic eyes: 3 mm).

6. INCISION CLOSURE

Adequate attention at the end of surgery ensures that the case concludes with achievement of the aims of MIVS- enhanced safety, optimal outcomes and fast recovery. Secure wound closure prevents the most common complications encountered with MIVS, namely hypotony and endophthalmitis.

Though vitreous plugging of the MIVS sclerotomy is common and effects a seal, it is undesirable as it can emulate a wick. It is preferable to have a MIVS wound close from ‘tunnel collapse’ or approximation of tunnel walls. Vitreous from the inner end of the microcannula is removed to the extent possible during surgery. The infusion is clamped transiently or infusion pressure is lowered sufficiently (15 mm Hg) during microcannula removal to minimize chances of vitreous
prolapse through the wound. The light probe is introduced through the microcannula into the vitreous cavity and the microcannula pulled out slowly over the same. The light probe is then slowly withdrawn and gentle pressure and massage is done over the sclera. This should be done for a couple of minutes preferably with a blunt firm instrument, e.g. scleral depressor or reverse end of a forceps. After both superior microcannulas are removed in this fashion, the pressure is elevated to 20-25 mm Hg to check the wound integrity. 23-gauge wounds are larger than 25-gauge ones and at a higher risk for wound leaks. A conjunctival bleb over a sclerotomy is suggestive of its leaking nature. Such sclerotomies may need to be sutured. A single transconjunctival 7-0 or 8-0 absorbable suture through the scleral wound lips gives good closure with patient comfort. The infusion cannula is removed the last. If there is leakage from this sclerotomy and subsequently hypotony, a suture is placed and globe reformed with BSS or gas, as applicable. Factors associated with wound leaks include eyes undergoing resurgery, multiple instrument exchanges, extensive vitrectomy with base dissection, low scleral rigidity and young age.\textsuperscript{15,16}

There are two mechanisms active in preventing wound leaks. The mechanical collapse of the tunnel with good apposition of its roof and floor is an important mechanism. Such closure occurs more frequently with the radial tunnel incisions. Though complete apposition is desirable in every case, this does not always occur. The other mechanism preventing leaks is the surface tension of the intraocular vitreous replacement. If the surface tension of the vitreous substitute exceeds the intraocular pressure acting across the sclerotomy, it will remain as a single bubble and withstand leaking. Gas has a substantially high surface tension and sclerotomies in gas filled eyes rarely leak. In BSS filled eyes, this factor is negligible and tunnel collapse is the only factor preventing egress. These eyes are, therefore, more prone to have wound leaks with microincision wounds. Several surgeons perform a partial air-fluid exchange at the end of surgery to enhance wound closure and prevent post-operative hypotony in BSS filled eyes. Silicone oil has a lower surface tension compared to gas, and eyes with this substitute are also at a higher risk of wound leaks, causing ineffective tamponade and subconjunctival silicone oil (especially with 1000-1300 centistokes). A large study found sclerotomy leakage requiring suturing to be most common in eyes with silicone oil (20%),
followed by fluid (4.9%) and the least common with gas tamponade (1.9%). Hence, a careful check is needed at the end of surgery for any leakage in these eyes. The desire for sutureless surgery should not supersede the need for safer surgery, and a low threshold for the suture option is better when any doubt exists as to the wound integrity.

7. CONCLUSION

The development of microincision vitrectomy has enabled vitreoretinal procedures with minimal morbidity and an early rehabilitation for patients. The keystone of this type of surgery is the ‘minimally invasive’ wound. Understanding wound architecture and proper wound construction goes a long way to ensure the success and safety of microincision surgery.

References:


INTRODUCTION

Dr. Steve Charles, one of the pioneers of minimally invasive vitreous surgery (MIVS), recently opined that sutureless vitrectomy systems had improved to the extent that the conventional 20-gauge (20G) vitrectomy, the erstwhile “gold standard” for 30 years, could be consigned to history.\(^1\) MIVS is indeed a great innovation, a continuum of enterprise of ophthalmic surgeons, similar to their non-ophthalmic brethren, to make surgery - ocular or systemic - less invasive.\(^2-4\) However, there is more to MIVS than mere size: the cannulated entry system, the versatile vitreous cutters, the chandelier illumination and bimanual maneuverability, all have made life easier for the vitreoretinal surgeon as well as for the patient (see below).\(^5-9\)

ADVANTAGES OF MIVS

Vitreoretinal surgery has come a long way from the days when postoperative care of patients was primarily assigned to the Low Vision Aid clinic. Today, while vitreoretinal surgeons confidently operate a wide spectrum of cases like vitreous floaters, macular holes and optic pit maculopathy with preoperative Snellen acuity of 6/9-6/12;\(^10-12\) they are able to achieve similar outcomes in giant retinal tears and endophthalmitis, at least in the best-case scenarios.\(^13,14\) If we think of surgery as an art, we have to consider the surgeon as an artist, who wishes to sign off a clean surgery with an esthetic finish. MIVS probably evolved as surgeons ventured into mild-moderate pathologies so far stoically tolerated (e.g., epiretinal membrane), started operating early, grew more assured of the clinical outcomes…
and therefore started to look at hitherto peripheral aspects like a quiet and comfortable eye, early rehabilitation, daycare surgery and astigmatism-neutrality promised by the smaller gauge.\textsuperscript{15}

Labeling MIVS as a mere cosmetic innovation would however be unjust. A major positive with MIVS is the cannulated entry system. Fluent passage of surgical instruments, esp. scissors and forceps, through a pre-placed smooth metallic cannula in contrast to the repeated trauma to vitreous and uvea, appears intuitively safer, as has been borne out by reports of reduced incidence of breaks and dialysis,\textsuperscript{7-9} as well as lesser postoperative inflammation and macular edema.\textsuperscript{6} The fact that these small, cannulated opening are transconjunctival entails that the conjunctival dissection and scarring are avoided: a major advantage in complicated situations like preexisting or planned trabeculectomy bleb or when multiple intraocular surgeries have been performed or are anticipated.\textsuperscript{2-4}

Another advantage of MIVS is the “portability” of the transconjunctival ports. In presence of any obstruction to visualization of the infusion port (e.g., an inferotemporal choroidal detachment), the surgeon can shift the infusion superiorly, and can complete the vitrectomy with/ without changing his position on the table.\textsuperscript{1,16} This flexibility is also a great help when unusual port positions are mandated by repeated vitrectomies and thinned-out, ectatic sclera.\textsuperscript{1}

The vitreous cutter in MIVS hasn’t just become smaller; it is more efficient in four seminal parameters: modifiable duty cycles and reflux settings, cutting port closer to the tip, and ultra-high speed cutting. While reduction in duty cycle (percentage of time during a cutting cycle that the port remains open) facilitates safe shaving of the vitreous base, increasing the duty cycle makes the cutter more efficient for core vitrectomy.\textsuperscript{17,18} The ultra-high speed cutters (5000 cps) reduce vitreous surge and make cutting close to mobile retina safer.\textsuperscript{1,17-19} The position of the opening closer to the tip also gives greater control during fine tissue manipulations close to retina.\textsuperscript{1} Momentary vitrectomy and proportional reflux are other helpful modifications in close encounters with epiretinal tissue.\textsuperscript{20} Together, these refinements allow membrane peeling without forceps and scissors in many complex cases.\textsuperscript{1,17,20}

Small-gauge instruments are particularly advantageous in pediatric
vitreoretinal disorders where small gauge is a natural fit for the small eye. The entry ports can be further miniaturized by innovative use of belt-buckle bits. One should however not hesitate to suture the ports if needed (see below).

**LIMITATIONS: PAST & PRESENT**

When evaluating new procedures, we always need a devil’s advocate, and MIVS found one in Dr. Hilel Levis, who in a 2007 editorial, lambasted the “unclear benefit and uncertain safety” of small gauge vitrectomy for being thrice as expensive with minimal, and unimportant benefits; and increased risks of complications. Several of these initial limitations have fallen by the wayside over the last decade with refinement in instruments, equipment, technique and experience.

Some of the most talked about and still lingering issues are incision-related: wound leak, hypotony and endophthalmitis. While incisions have become easier and cleaner with improved trocar tip designing, use of beveled surgical wounds for both 23- and 25-G incisions and simple additions like partial air-fill after vitrectomy have nearly eliminated the wound leaks. Endophthalmitis also became rare with these improvements, along with misalignment of conjunctival and scleral openings and removal of vitreous wick rom the sclerotomy, which was initially thought to help in sealing the wound.

25G incisions are less likely to leak, but 25G surgeons were initially hampered by hyper-flexibility of instruments, low light levels and reduced flow rates. Also, there was a lack of complete range of instruments in both and 25G. To begin with, some authorities consider reduced flow and advantage rather than a limitation, citing greater control. Greater lumen-caliber ratio has now compensated for the reduced flow to some extent, and adjustable duty cycles provide customized surgical speed, the best of both worlds. With stiffened 2nd and 3rd generation 25G instruments, peripheral vitrectomy is less of a hassle; and 23G instruments are no different from 20G in this respect. The xenon-based endo-illuminators are similar or superior to halogen-light based 20G instruments. Today we have a nearly complete range of 23G and 25G instruments, with the exception of fragmatome and dual-function 20G instruments like aspirating...
diathermy.\textsuperscript{1,17,23} The angled instruments like scissors and picks are available, but less efficient than their 20G counterparts. This relative inefficiency is counterbalanced by more versatile cutters which have replaced scissors and forceps substantially.\textsuperscript{1,2,20} The oblique entries, combined with angled instruments, were also implicated to cause more retinal breaks and retinal detachments.\textsuperscript{30,31} More recent studies however contradict and in fact reverse these claims, reporting reduced retinal break formation with MIVS.\textsuperscript{7-9}

There are usage-related situations where small gauge doesn’t appear to make sense, e.g., concomitant use of band buckle and high-viscosity silicone oil. Several controlled trials however have shown no advantage of an additional belt-buckle over a standalone primary vitrectomy.\textsuperscript{32-34} In fact, the band buckle doesn’t allow silicone oil to snugly drape the retina over the vertical slope of the buckle, and is more commonly associated with epimacular membrane formation; a large recent study reports actually inferior outcomes with the addition of belt buckle to vitrectomy for complex retinal detachments.\textsuperscript{33} Silicone oil, both regular (1000 cs.) and high-viscosity (5000 cs.), can now be comfortably injected through 23G ports, and with additional effort, through 25G ports as well. Finally, there are surgeries not considered feasible through small gauge: removal of crystalline lens and intraocular foreign body.\textsuperscript{2,3} For lensectomy, 23G cutter, at a low cut rate and high suction, is quite efficient for all juvenile and some adult lenses. For the harder lenses and foreign bodies, enlargement of a single port suffices in a hybrid 25-20G technique.\textsuperscript{1}

Some of the original objections to MIVS that remain valid to date are the transient nature of benefits, in face of the reported 3-times higher surgical cost.\textsuperscript{24} Over the past decade, as is universally true for technology in general, the costs have come down even as instruments have improved. Still, small gauge vitrectomy remains more expensive than 20G surgery,\textsuperscript{2} a factor that must be balanced against the patient’s perceived or factual need for early rehabilitation, a modern-day necessity which has permeated all surgical fields.

Whatever be the current compulsions, there are situations where one must tread with caution. Though pediatric surgeries are supposedly more suited for small gauge, the wound needs often needs to be sutured in small children, either in anticipation of rubbing of eyes or
due to greater scleral elasticity. The latter is also problematic when making ports: the stab entry distorts the globe substantially more than in adults, esp. during re-surgeries. These can be minimized to some extent by increasing intraocular pressure, and avoiding re-use of trocar and cannula. The potential trauma to lens and retina by the infusion port in an infant eye (e.g. during surgery for retinopathy of prematurity) can be addressed by entry through a cut-piece of silicone rubber (#42 or 240 band), reducing the intravitreal length of the infusion cannula. Small, oblique and un-sutured (and therefore relatively mobile) infusion cannula can end up under the retina or choroid in presence of a bullous retinal detachment or a large choroidal detachment. In all the above situations, entry should be straighter, more anterior (3mm), rechecked repeatedly during surgery; and 20G infusion port kept ready in back-up.

A potentially lethal complication of un-sutured cannula slipping under the choroid – specifically during fluid-air exchange - is PAVE syndrome (Presumed Air by Vitrectomy Embolization), a recent christening of fatal or near-fatal venous air embolization reported in both anesthesia and ophthalmology literature, but largely unknown to vitreoretinal surgeons. In spite of initial skepticism and denial, recent reports confirm this grim possibility; more relevant now in the era of obliquely placed un-sutured cannulas. The best way to prevent PAVE is to check infusion cannula status before starting fluid-air exchange, to start infusing air at low pressure (approx. 30mmHg), and to immediately replace air with saline infusion if a choroidal detachment is noted. The attending anesthetist should also be made aware of this possibility and should monitor systemic oxygen saturation closely when air infusion starts.

LOOKING BACK; LOOKING FORWARD

How does a young, newly trained vitreoretinal surgeon choose his/her armamentarium to launch into clinical practice? Should one jump-start with a no-holds-barred, no-suture mostly-gas MIVS, encouraged by the western literature which has almost cast away scleral buckling both as a standalone procedure and as adjunct to vitrectomy? Or should one approach the transition to small gauge with caution, keeping options of silicone oil, scleral buckle and 20G open? While there are
no easy answers, it is wise to remember that at least some of the current innovations in vitreoretinal surgery are subjective assertions by the manufacturers, peddled by vitreoretinal surgeons on their payroll. No controlled trial has yet demonstrated the superiority of MIVS over conventional vitrectomy in final visual and anatomical outcomes, the litmus test of a true surgical advancement, and the reason the author prefers to label MIVS as an innovation rather than a revolution. One must also remember that MIVS originated in the West where macular hole and epimacular membrane are very common posterior segment procedures; where most retinal detachments and endophthalmitis generally present early; and where surgical candidates of proliferative vitreoretinal disease usually present with scatter photocoagulation in place. In this scenario, where results are more or less assured, the surgeon’s focus naturally has shifted to external aspects like patient comfort and early rehabilitation. Even though these aspects – borrowed from cataract surgery where visual recovery to 6/6 is the norm – have transient benefits, they guide a significant part of surgical research by western surgeons. Finally, MIVS, by faster surgery, lack of sutures and early rehabilitation actually reduces surgical costs in West as “70 percent of the cost of surgery is labor.”

In the developing countries, we are still stuck with delayed (and therefore complicated) presentations of poor patients, with inadequate initial management and suspect postoperative compliance. Increased surgical time or sutures do not add up costs significantly in India at least at present; rather it’s the use of MIVS that adds up surgical expenses. There is therefore no shame in staying close to basics, taking time to adapt to progressively smaller gauge, and focusing on final anatomical and visual outcomes; rather than fussing over patient comfort and speed of recovery, at least in complex surgical cases.

MIVS is a work in progress: once the issue of practically operable smallest gauge is resolved, the advances in instrumentation, illumination and accessories, as well as more creative use of the existing technology shall help us improve visual and anatomical outcomes across the entire spectrum of surgical complexity. However, one must also address the higher issue of what the direction of vitreoretinal research should be: concrete improvement in surgical techniques and outcomes, or cosmetic enhancements like minimizing
transient astigmatism after simple vitrectomy. Even the latter would be relevant only when immediate visual rehabilitation is close to 6/6 (as in cataract extraction), a horizon still elusive for MIVS. Finally, the vitreoretinal surgeons should introspect whether they are fitting their surgical field around MIVS, or looking at better surgical solutions where MIVS is means to an end, rather than the end itself. The quest for minimally invasive procedures may ultimately usher us out of the realm of surgical intervention: from the currently available alternatives like pneumoretinopexy to the newer pharmacotherapeutic options like ocriplasmin,\textsuperscript{17,42-45} however deflating that scenario may be for our conventional pride in surgical skills.

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1. INTRODUCTION
With the continuing trend towards minimally invasive interventions, 27-gauge instrumentation has now emerged at the horizon of microincision vitreoretinal surgery (MIVS). Smaller gauges offer the advantages of reduced inflammation and pain and hence better patient comfort, and improved safety from better wound closure and instrumentation.

The 27-gauge chapter in the MIVS saga was initiated by Oshima et al in 2010. They introduced vitreous surgery with an array of 27-gauge instrumentation for predominantly macular indications. Several manufacturers now offer 27-gauge instrumentation and compatibility with existing vitrectomy platforms. Refinements and expansion of the 27-gauge repertoire is ongoing, to match the needs in an ever expanding array of indications where such instruments may be applied.

2. INDICATIONS
27-gauge vitreous surgery was initially employed for macular indications (epiretinal membranes, macular holes, vitreomacular traction) alone. With a wider range of instruments and growing experience, it is now also employed for vitreous hemorrhage, simple diabetic vitrectomies and simple rhegmatogenous retinal detachments. 27-gauge is considered the platform of choice for surgery for floaters (‘floaters only vitrectomy’ or FOV). It is also ideally suited for vitreous biopsy. Retinal detachments with proliferative vitreoretinopathy, complicated diabetic vitrectomies, trauma especially with intraocular
foreign body, and surgery in high myopes (long axial length) are examples where current 27-gauge instrumentation may prove inadequate for the surgical tasks at hand.

3. EQUIPMENT

27-gauge instruments go through 0.4 mm incisions. This is about 20% less than 25-gauge (0.52 mm) incisions. This incision size lends itself to better self-sealing than larger wounds, and does not require beveled entry. This is an advantage in eyes with thin sclera or low scleral rigidity (younger patients).

With slender instrumentation, tool flexion becomes increasingly apparent. To reduce this problem, 27-gauge cutters have a shaft length of 25 mm (compared to the standard 32 mm on other gauges). 32 mm 27-gauge cutters are also available.

A 20% reduction in the lumen diameter leads to about 65% reduction in the flow (Poiseuille’s law- flow proportional to fourth power of radius). Practically, with a shorter shaft length, 27-gauge cutters allow approximately 55% less flow rate than 25-gauge cutters. This is the most noticeable disadvantage with this system. Vitreous removal can be partially hastened by employing higher aspiration/infusion rates, staying in the vitreous and always using a vented gas-forced infusion set to about 30 mm Hg. DORC (Zuidland, Netherlands) also offers a high-flow infusion line with cannula. Though 27-gauge cutters require more time for vitreous removal than existing systems, their cutter port is larger (0.079 mm²) and closer to the cutter tip (0.211 mm) than the 25-gauge cutter port (0.066 mm², 0.330 mm respectively). This is a distinct advantage while performing membrane surgery close to the retina. The duty cycle of 27-gauge cutters has also been found to be better than that with 25-gauge cutters at 2500 cpm. The new TDC cutters from DORC (Zuidland, Netherlands) go up to 8000 cuts per minute while maintaining a duty cycle of 92% and a high relatively constant aspiration rate. This is better than the current 25-gauge instruments available with other vendors. DORC (Zuidland, Netherlands) and Synergetics, Inc. (St. Charles, MO) currently have commercially available 27-gauge packs that include 2,500-cpm pneumatic vitreous cutter, a wide-angle endoilluminator, a trocar-cannula system with infusion line and membrane forceps. Medical
Instrument Development Laboratories, Inc. (San Leandro, CA) also market 27-gauge cutters.

Endoillumination efficiency reduces by about 35% when the diameter of the light pipe falls by 20%. Older light sources do not produce enough illumination in conjunction with the 27-gauge endoilluminator. Xenon and mercury vapor lamps are powerful enough to provide excellent illumination with 27- and even 29-gauge fibres (>20 lumens). 27-gauge endoilluminators are available with both wide-field and focal illumination patterns. For bimanual surgery, DORC provides 27-gauge twin fiber chandelier with stabilization footplate. 29-gauge self retaining chandeliers (Synergetics, Inc., O’Fallon, MO) are also available.

Laser probes, membrane spatula, diamond-dusted membrane scraper, microforceps, angled scissors, brush needle, back-flush needle and diathermy probe are all available in 27-gauge, considerably expanding the range of indications for which surgery with this platform may be considered. Recently, 27-gauge oil injection cannula has also been introduced.

4. TECHNIQUE

The experience with 27-gauge surgery is close to that with the initial 25-gauge platform. Surgeons well versed with 25-gauge surgery will find surgery with 27-gauge instruments equally challenging but slightly more tedious. 27-gauge sclerotomies are made perpendicular to the sclera in a single step direct entry manner. They need not be angled or biplanar to attain subsequent self-sealing closure. The sclerotomies are made in the routine locations and where required, a chandelier may be placed according to the surgeon’s preference.

The infusion line is connected to a vented-gas forced infusion system set at 30-35 mmHg. Gravity-fed infusions may prove inadequate. Vitreous removal is performed in the standard fashion. The 27-gauge cutter is particularly advantageous for working close to the retina (membrane work or vitreous shaving) due to its small size and port close to the tip.

Closure is affected by simple withdrawal of instruments and cannula and the incisions self-seal even in eyes with thin sclera. There is
practically no leakage from the sclerotomies. The author does not perform cryopexy posterior to the sclerotomies as a routine.

5. RESULTS

There is very little literature available on the results of surgery with the 27-gauge platform. Anatomical success rates of 100% and significant visual gain in 65% have been reported\(^1\) with 27-gauge surgeries for the indications mentioned above. In this series, there was no wound leak related complication. The author’s experience with 27-gauge vitrectomy is limited to selected cases of macular pathology. Early results have been excellent- both anatomical and functional. Of special mention is the minimal, if any, patient discomfort experienced post-operatively.

6. THE FUTURE

Currently, about 5% retinal surgeons in the USA and 10% surgeons worldwide employ 27-gauge surgery in their practice.\(^4\) As availability of this system and experience increases and the range of instrumentation expands, we feel that a large proportion of MIVS surgeries in the future could be done using this platform. Better outcomes with faster recovery will no doubt drive the adoption of this system by vitreoretinal surgeons worldwide.

References:


Gases, liquids and Silicone oil in MIVS

Prasan Rao

PERFLUOROCARBON LIQUIDS

INTRODUCTION

Perfluorocarbon liquids (PFCLs) were first developed for use as blood substitutes (substitutes to erythrocytes) because of their high oxygen carrying capacity and being chemically inert.\(^1\,^2\) These agents were first used in dispersed form in the intravascular compartment as an oxygen transporter in a mouse model by Clark and Gollan.\(^3\) Later, in humans, they were used in coronary angioplasty to deliver oxygen to the ischemic myocardium. Based on their properties, they were then introduced as vitreous substitutes by Haidt and associates.\(^4\) In 1987, Chang and associates first utilized these low viscosity liquid fluorocarbons as intraoperative tools in four patients with complicated retinal detachments.\(^5\) However it was found that long-term tamponade with PFCL produces retinal atrophy and retinal necrosis at the perfluorocarbon aqueous interface at 4 weeks. The introduction of PFCL has been associated with improved retinal reattachment rates, especially in eyes with complicated retinal detachment. Currently, its role is limited to intraoperative use and occasionally as a short-term postoperative tamponade agent.

Properties of perfluorocarbon liquids

PFCL is a synthetic fluorinated hydrocarbon compound made up of carbon-fluorine bonds with a chemical structure which are either straight chains or cyclical. Straight chain compounds contain carbon chains from C\(_5\) to C\(_9\), whereas cyclic compounds contain higher carbon
chains ranging from C\textsubscript{5} to C\textsubscript{17}. Compounds with carbon chains shorter than C\textsubscript{5} exist in gaseous state at room temperature e.g. perfluoroethane (C\textsubscript{2}F\textsubscript{6}) and perfluoropropane (C\textsubscript{3}F\textsubscript{8}). Some may also contain hydrogen, bromide, and nitrogen elements.

All PFCLs are colourless, odourless, have low viscosity (2 – 3 centistokes) due to low intermolecular forces. They have higher specific gravity and higher density than water due to their high molecular weight (specific gravity of 1.3-2.1), which is twice that of water and six times that of silicone oil. They have a low surface tension, a refractive index close to BSS and are stable under room temperatures. Various PFCLs have been tried out for ophthalmic purpose and these include perfluoro-n-octane (C\textsubscript{8}F\textsubscript{18})\textsuperscript{7}, perfluoroperhydrophenanthrene (C\textsubscript{14}F\textsubscript{24})\textsuperscript{8}, perfluorodecalin (C\textsubscript{10}F\textsubscript{18})\textsuperscript{9}, perfluoroethylcyclohexane (C\textsubscript{8}F\textsubscript{18})\textsuperscript{10}, perfluorotributylamine (C12F27N)\textsuperscript{11} and perfluorotri-n-propylamine (C\textsubscript{19}F\textsubscript{21}N)\textsuperscript{12}. Of these, Perfluoro-n-octane has been approved by the US Food and Drug Administration for intraocular use.

**Table 1**: Characteristics of perfluorocarbon liquids for intraocular use

<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical formula</th>
<th>Specific gravity</th>
<th>Molecular weight (g/mol)</th>
<th>Refractive Index</th>
<th>Surface tension (dyn/cm at 250C)</th>
<th>Viscosity (cSt at 250C)</th>
<th>Vapour pressure (mmHg at 370C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfluoro-n-octane</td>
<td>C\textsubscript{8}F\textsubscript{18}</td>
<td>1.76</td>
<td>438</td>
<td>1.27</td>
<td>14</td>
<td>0.8</td>
<td>50</td>
</tr>
<tr>
<td>Perfluorodecalin</td>
<td>C\textsubscript{10}F\textsubscript{18}</td>
<td>1.94</td>
<td>462</td>
<td>1.31</td>
<td>16</td>
<td>2.7</td>
<td>13.5</td>
</tr>
<tr>
<td>Perfluoroperhydrophenanthrene</td>
<td>C\textsubscript{14}F\textsubscript{24}</td>
<td>2.03</td>
<td>624</td>
<td>1.33</td>
<td>16</td>
<td>8.03</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Perfluorotributylamine</td>
<td>C\textsubscript{12}F\textsubscript{27}N</td>
<td>1.89</td>
<td>671</td>
<td>1.29</td>
<td>16</td>
<td>2.6</td>
<td>1.14</td>
</tr>
</tbody>
</table>

**Table 2**: Physical properties and its intraoperative clinical application

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical clarity and colourless</td>
<td>Easy manipulations under PFCL and easy visualization of underlying structures</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Use</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>High specific gravity and high density</td>
<td>Unrolling of retinal folds, flattening of retina, avoids need for posterior retinotomies, floatation of lens matter</td>
</tr>
<tr>
<td>Refractive index (not similar to saline)</td>
<td>Allows visible PFCL-fluid interface, aids in intraocular maneuvers and easy removal</td>
</tr>
<tr>
<td>Refractive index (close to saline)</td>
<td>No optical aberrations and good visibility with conventional visualization systems</td>
</tr>
<tr>
<td>Immiscibility</td>
<td>Does not mix with blood, silicone oil or BSS</td>
</tr>
<tr>
<td>Boiling point higher than water</td>
<td>No vaporization during endolaser treatment</td>
</tr>
<tr>
<td>Low surface tension, high interfacial tension</td>
<td>Ability to stay as a single bubble, less risk of subretinal migration through a break</td>
</tr>
<tr>
<td>Low viscosity</td>
<td>Easy injection, aspiration with micro-incisional vitrectomy systems</td>
</tr>
<tr>
<td>Does not absorb the laser wavelength</td>
<td>Endolaser delivery through the PFCL bubble is safe and predictable.</td>
</tr>
</tbody>
</table>

**PFCL injection technique**

**20-gauge vitrectomy system:**

During a standard 3 port pars plana vitrectomy, all the ports will be occupied by – infusion cannula, light pipe and PFCL cannula. When a single bore cannula is used to inject PFCL, the IOP increases since there is no outlet available for egress of the BSS from the vitreous cavity. This would also increase the resistance to injection of PFCL. Hence it is advisable to use a dual-bore cannula for injection of PFCL. This cannula would provide an alternative passage for egress of intraocular BSS and reduce the resistance.

**23-gauge vitrectomy system:**

23-gauge dual-bore cannula is small in caliber; hence a high force is necessary to inject the PFCL. Consequently, the PFCL comes out as a jet and can cause damage to macula with risk of subretinal migration. Hence when performing 23-gauge vitrectomy, it is advisable to use either a chandelier system or an illuminated infusion. PFCL can then
be injected with a single bore cannula, while fluid is aspirated using a vitreous cutter or flute needle. It is always advisable to use a luer-lock syringe for PFCL injection as sometimes a forceful injection can dislodge the cannula from the syringe and damage the retina and choroid.

Before the PFCL, it is important to induce a posterior vitreous detachment, if it is not present. Also meticulous removal of the peripheral vitreous around the tip of the infusion cannula and the active sclerotomies should be done. This would prevent clogging of the infusion cannula by the vitreous, which may lead to hypotony and intraocular hemorrhage. Traction on the peripheral vitreous by the injection cannula may cause peripheral retinal breaks. It is preferable to remove all traction on the retina, as a forceful injection may cause the PFCL to go through the break into the subretinal space.

During the injection process, the cannula should never be directed towards the macula, as iatrogenic macular holes can be produced due to forceful jet of PFCL. Also, avoid directing the cannula towards a retinal break, as this may lead to subretinal migration of PFCL. It is preferable to direct the cannula towards the optic disc during the injection process. The injection should be sustained and gradual. This allows the PFCL to gradually flatten the retina or unfold the retina while displacing the subretinal fluid (SRF) anteriorly. This would also prevent breaking of PFCL into small bubbles. Placing the tip of the cannula within the PFCL bubble during the entire process of injection can prevent bubble formation. Some surgeons place few drops of PFCL over the posterior pole, these drops will coalesce to form a single bubble. Once the bubble is formed, the tip of the cannula can be submerged into this formed bubble. Bubble formation should be avoided as these bubbles may migrate subretinally through the retinal breaks. The BSS-PFCL interface should also be observed and injection should be stopped once the desired level has been achieved.

Turbulence within the vitreous cavity can also produce multiple small bubbles of PFCL. This commonly occurs in 20-gauge vitrectomy, when instruments (such as vitreous cutter, intravitreal scissors, forceps or light-pipe) are removed from the eye. With an open sclerotomy port, irrigating BSS escapes out of the eye in large quantities. This in turn leads to increase in the inflow of the infusion fluid, which
leads to turbulence within the vitreous cavity. This can be avoided by placing scleral plugs to close the sclerotomies as the instruments are removed. With the current generation of valved cannulas during micro-incisional vitrectomy, turbulence is less likely while removing the instruments. Even in valved cannulas, turbulence can occur while performing the scleral depression during peripheral vitrectomy. When the scleral depression is suddenly realized, it causes the IOP to drop suddenly, which in turn, causes an increase in the infusion flow and turbulence within the vitreous cavity. Hence instead of releasing the scleral depression, the indentor / muscle hook /cotton tip applicator should be moved to an adjacent location to maintain the near same amount of indentation. When the peripheral vitrectomy is complete, the scleral depression should be reduced gradually allowing the slow expansion of the globe.

Subretinal migration of PFCL can be avoided by injecting PFCL once all major retinal traction has been relieved. However in eyes with funnel shaped retinal detachment, PFCL can be injected over the posterior pole and further PFCL can be added, as peripheral membrane dissection frees the traction. The level of the PFCL bubble should be well posterior to the posterior edge of the retinal break as rotation of the globe while performing maneuvers in the periphery can cause the PFCL to roll over the posterior edge of the break. The other option is to place a larger bubble of PFCL in a manner that the anterior edge of the retinal break is submerged in the PFCL bubble.

Removal of PFCL

PFCL should be completely removed from the vitreous cavity once it has reattached the retina and endolaser photocoagulation of the breaks or retinotomies has been performed. This can be accomplished with a PFCL-fluid, PFCL-air or PFCL-silicone oil exchange. PFCL can be removed using passive suction with a flute needle or soft-tip needle or using active suction of the vitreous cutter.

For PFCL-fluid exchange, the flute needle or vitreous cutter is placed close to the disc to allow aspiration of the bubble. The small bubble of PFCL is then aspirated over the optic disc.

During PFCL-air exchange, it is important to place the tip of the flute
needle at the fluid meniscus at the edge of the PFCL bubble to allow aspiration of the BSS. This technique helps in near complete removal of BSS. This can either be recognized by the gurgling sound as the air passes through the flute needle or by the sudden change in the light reflex (from convex to concave) from the PFCL bubble during the final stage of BSS removal. To achieve removal of all PFCL bubbles, few drops of BSS can be placed over the posterior pole (saline rinse). This saline rinse helps to collect the microscopic layer of PFCL that can remain over the posterior pole. The saline is then aspirated using the flute needle as is done in routine fluid-air exchange.

There are various ways of performing PFCL-silicone oil exchange. The first option is to inject the silicone oil (SO) through the infusion port. This would allow placement of the flute needle through one of the superior active ports. The second option is to inject the SO using an automated infusion pump through one of the superior active sclerotomies with a chandelier light source or an illuminated infusion cannula. In both techniques, the SO injection cannula is first positioned for injection followed by placement of the flute needle within the PFCL bubble. Once the SO injection commences, this causes the IOP to increase allowing passive aspiration of the PFCL. As the specific gravity of SO is lesser than that of PFCL, it floats over the PFCL. Silicone oil fills the vitreous cavity from anterior aspect to posterior aspect, as the PFCL is drained out of the eye.

One of the major issues is slippage of the retina, which can occur as the PFCL bubble is being removed from the vitreous cavity. Slippage is caused by posterior displacement of the vitreous fluid in the subretinal space towards the posterior pole by the incoming SO or air bubble. Two techniques of PFCL-SO exchange have been described to avoid slippage. Both PFCL and SO are hydrophobic in nature, and have a tendency to stay in contact with each other and form a single bubble. This would eliminate any aqueous between the interface. In the technique, the flute needle is passed through the SO bubble as it is being injected and then into the PFCL bubble. The residual aqueous then gets pushed laterally or superiorly. As the SO injection progresses, the aqueous at the junction of the fluid meniscus of the edge of the PFCL is aspirated followed by the PFCL. This reduces the chance of slippage.13
In the second technique, the PFCL is injected to overfill the eye all the way back to the three-way stopcock, before initiation of the SO injection through the infusion cannula. With this technique, all the aqueous is removed from the eye and the infusion cannula. Since there is no aqueous available in the system, the risk of slippage is reduced.

Clinical applications of PFCL

Retinal detachment

In eyes with simple rhegmatogenous retinal detachment, PFCL can be used to flatten the retina, allowing drainage of the SRF through the primary break located in the anterior retina. This avoids the need of a posterior drainage retinotomy, which causes more nerve fibre damage and subsequently visual field defects. It stabilizes the retina and reduces the movement of the retina. This helps to reduce the chances of iatrogenic retinal breaks while shaving the vitreous base. In eyes with more posterior retinal breaks, it is not possible to drain the SRF completely. Once the retinal break is submerged under the PFCL bubble, the SRF gets displaced under the anterior retina. In these cases, the posterior edge of the break can be treated with endolaser. This is followed by PFCL-air exchange during which the residual SRF under the anterior retina is drained through the retina break. The posterior edge of the retinal break is then treated with endolaser photocoagulation under air or can be treated with cryotherapy before the PFCL-air exchange. Any residual minimal SRF would be pumped out by the retinal pigment epithelium (RPE) in the next few days.

Retinal detachment complicated by proliferative vitreoretinopathy (PVR)

In the era when PFCL was not available, membrane peeling and vitrectomy in eyes with extensive PVR was a challenging task. The surgery was performed in the anterior to posterior direction. Chang and associates first described the successful use of PFCL in the management of retinal detachments complicated by PVR. With the use of PFCL, dissection of membranes can now be done in a more safe manner starting from the posterior pole and progressing anteriorly towards the vitreous base. This reduces the risk of iatrogenic retinal tears, allows easy and more thorough removal of epiretinal membranes and obviates the
need for a posterior drainage retinotomy.\textsuperscript{17} It also shortens the surgical time and improves the success rate of complex retinal detachment with PVR.\textsuperscript{18,19} In eyes with funnel-shaped retinal detachment, PFCL can be injected to open the funnel. In these eyes, PVD is usually present, if not present, this helps to dissect the posterior hyaloid from the disc and retina. Membranes over the macula can then be peeled under the PFCL bubble. PFCL stabilizes the retina and provides counter traction during the peeling procedure. PFCL helps to identify area of residual traction, as this portion of the retina does not flatten under PFCL. As the peeling progresses peripherally, more PFCL can be injected.\textsuperscript{20} This technique of alternate peeling and PFCL injection is continued till the entire retina is flat under the PFCL with no residual traction till the vitreous base. Using scleral depression, vitreous base shaving is done to reduce the risk of reproliferation of PVR membranes.\textsuperscript{17} In eyes with severe anterior PVR, PFCL would help to minimize the extent of the relaxing retinotomy.\textsuperscript{21} PFCL prevents the subretinal migration of blood in these eyes. Endolaser is then performed to the retinal breaks, edge of the retinotomies and 360 degrees posterior to the vitreous base. This is followed by PFCL-air or PFCL-SO exchange depending on the extent and duration of internal tamponade required. Thus PFCL provides the best intraoperative retinal tamponade during membrane dissection and acts as a “third hand” during management of complex retinal detachment.

In eyes with severe inferior PVR requiring retinectomies and/or eyes with large inferior retinal breaks, a combination of PFCL and SO can be used as a “double tamponade”. The vitreous cavity is filled with a mixture of two-thirds PFCL and one-third silicone oil. The principle of this double tamponade is to provide tamponade to both the superior (with SO) and inferior (with PFCL) quadrants of the retina. PFCL is removed after 2-3 weeks and the vitreous cavity is filled either with SO or gas as required.\textsuperscript{22,23}

**Vitreous base shaving**

Meticulous dissection of the vitreous base and close shaving of the vitreous base is important to achieve a more complete SO fill. The residual gel after vitrectomy will be compressed and dehydrated by the silicone oil bubble. This increases the capacity of the eyes, which
leads to underfill of the SO. Vitreous base shaving also prevents reproliferation of the PVR membrane and reduces the risk of retinal detachment. When PFCL in injected, it displaces the vitreous anteriorly and a clear interface between the PFCL and vitreous fluid can be identified. In areas with residual vitreous, the contour of the PFCL bubble is indented, indicating the presence of vitreous. It is difficult to visualize the vitreous during shaving. The visualization of vitreous can be facilitated by injection of triamcinolone and visualization with trans-scleral illumination. When light is shone perpendicular to the line of sight, triamcinolone crystals trapped in the peripheral gel can be easily seen.24

**Giant retinal tears**

In the past, giant retinal tears (GRT) were managed by intraoperatively rolling the patient into a prone position, and reattaching the retina with fluid-air exchange.25 This was technically difficult and was associated with low success rates.26 The use of PFCL has eased the surgery and allowed surgeons to operate the patient in a supine position. In eyes with GRT and no PVR, the folded flap can be repositioned by injection of PFCL. The edges of the GRT can then be treated with 2-3 rows of endolaser once the PFCL bubble has attached the retina to the underlying RPE. For eyes with immobile rolled flaps and PVR, thorough membrane dissection is critical to reattaching the retina. As described previously, PFCL can aid in membrane dissection, and reattaching the retina. Some surgeons prefer the use of encircling buckle in these eyes. There is a high chance of slippage during PFCL removal. The technique of prevention of slippage has been discussed previously in this chapter.

Some surgeons in Australia prefer to treat GRTs with short-term PFCL tamponade (for 1-2 weeks). During the subsequent surgery, PFCL is removed and the retinal status is assessed. If the retina is found to be stable, vitreous cavity is filled with long-term intraocular gas. Otherwise, further maneuvers are performed such as membrane peeling, endolaser photocoagulation, followed by SO endotamponade. ref
Ocular trauma

Traumatic retinal detachment may be associated with lack of proper PVD, intraocular haemorrhage, retinal incarceration, vitreous incarceration, dislocated lens, dislocated IOLs and retained intraocular foreign body (IOFB). PFCL plays an important role by stabilizing the retina during vitrectomy. It helps in separating the posterior cortical vitreous from the retina, and also provides a clear media for visualization.\textsuperscript{27} It facilitates removal of incarcerated vitreous and retina, and removal of dislocated lens, IOLs or foreign bodies. It is also useful in displacing preretinal, subretinal and suprachoroidal haemorrhage.\textsuperscript{28}

PFCL is useful in the management of intraocular foreign bodies. It can be used to float organic or nonmetallic foreign bodies, which allows removal of IOFB through an anterior approach or sclerotomy. It helps to stabilize and makes grasping of metallic IOFBs easier. PFCL prevents migration of blood into the subretinal space, prevents migration of pre-existing blood into the submacular region and provides counter traction for extraction of impacted IOFBs.

Traumatic retinal incarceration is usually associated with entry site proliferation, retinal detachment and PVR. After removal of incarcerated vitreous, PFCL can be injected over the posterior pole to provide a tamponade effect. In this process, the incarcerated retina may get pulled back without damage.\textsuperscript{29} However if the retina cannot be retrieved in this manner, it is advisable to perform a limited retinotomy to circumscribe the incarcerated site.

Proliferative diabetic retinopathy

PFCL is a useful in the management of tractional and combined retinal detachment due to proliferative diabetic retinopathy or vein occlusions. In eyes with tractional retinal detachment, during removal of the fibrovascular membrane, there is high likelihood of occurrence of iatrogenic retinal breaks due to the atrophic nature of the retina. During subsequent fibrovascular membrane removal, any possible traction on the retina can cause fluid to enter the subretinal space and convert a tractional detachment into a bullous combined detachment. PFCL helps to stabilize the retina and provides counter traction...
in such cases. Similarly, during management of combined retinal detachment, PFCL helps in fibrovascular membrane removal. It also helps to prevent any blood from encroaching on the macular area, thus avoiding problems of removal of blood clots over the macula. Some surgeons use a continuous PFCL infusion during vitrectomy without BSS, however this technique has limited success.\(^{30,31}\)

**Dislocated lens, dropped lens fragment and IOL**

The management of posterior dislocation of crystalline lens, nuclear fragments or intraocular lens has become simpler with the use of PFCL.\(^{32,33}\) A thorough vitrectomy with removal of the posterior cortical vitreous, vitreous base shaving and removing adhesions to the lens matter is done. PFCL can be injected to float the lens fragments, avoiding damage to the retina during ultrasonic removal of fragments and from posterior falling particles. It prevents lens matter from entering into the subretinal space through a retinal break, if there is an associated retinal detachment.\(^{34,35}\) PFCL levitates the crystalline lens to allow removal through a corneal incision or with the use of a phacofragmatome.\(^{36}\) Dislocated IOLs may be removed in the similar manner by floating them to the pupillary plane or these can be repositioned in the sulcus over the residual capsular remnants or by scleral fixation using prolene sutures.\(^{37,38}\) Since the PFCL bubble has a convex meniscus, there is tendency for the lens or IOL to slide off to the periphery and often becomes entangled with any residual vitreous (if thorough shaving of vitreous base has not been performed). A modified technique using viscoelastic agents and PFCL for removal of dislocated lens has been described. Injecting an ophthalmic viscosurgical device around and on the top of the PFCL bubble tends to keep the lens centered and reduces its mobility during phacofragmentation. This allows easy removal of the dislocated lens and reduces complications due to sliding of the lens towards the retinal periphery.\(^{39}\)

**Suprachoroidal hemorrhage**

Small suprachoroidal haemorrhage that do not involve the posterior pole or the macula do not require drainage. Larger suprachoroidal haemorrhage is easier to drain after 7 to 14 days because the clotted blood has a greater chance of liquefaction. Ocular B-scan ultrasonography is useful to assess the degree of liquefaction of
the haemorrhage. This is based on the reflectivity of the A-scan (reduced with liquefaction) and pattern on B-scan (echolucency with liquefaction). The optimal drainage site is the highest point of choroidal elevation using a sclerotomy, which should be radial and created with a cut-down incision. Since the liquefied blood is lighter than PFCL, following vitrectomy, PFCL injection displaces the blood towards the sclerotomy ports and helps to evacuate the blood. Otherwise specially fashioned drainage sclerotomies can be used – 3mm circumferential sclerotomies created 4 mm from the limbus in the superior, nasal and temporal quadrant.

Other clinical applications

PFCL has been used in retinal detachment associated with disc coloboma, detachment from retinopathy of prematurity, displacement of submacular hemorrhage, vitrectomy for endophthalmitis, and excision of subretinal membranes.

Complications

PFCL is used as an intraoperative tool and removed completely at the conclusion of the surgery. It has a good safety profile, however retinal toxicity from unintended retention of PFCL in the eye has been reported. The retention rate depends on the steam pressure, refractive indices, and viscosity. The rates of intraocular retention are lower with perfluoro-n-octane than perfluoroperhydrophenanthrene (7.8% versus 38.3%). Retained PFCL is known to produce an inflammatory response in the form of white flake-like deposits. Hence, complete removal of PFCL from the eye is advisable, after it has served its intraocular purpose.

Subretinal PFCL

Subretinal migration of PFCL can occur either during surgery or may be diagnosed in the postoperative period. The predisposing factors include – formation of PFCL bubbles, persistent traction on the retina, giant retinal tears, large retinotomies and incomplete saline rinse. To avoid PFCL bubble formation, the PFCL injection should be gradual, sustained and directed towards the optic disc, keeping the tip of the injection cannula within the PFCL bubble at all times. Avoid
turbulence within the vitreous cavity and monitor the level of PFCL bubble such that it is always much lower than the posterior edge of the retinal break. Despite all these measures, if PFCL accidentally enters the subretinal space, all efforts should be made to remove it, as PFCL bubble has a tendency to land in the subfoveal location. It can reduce retinal function, cause central scotomas and even retinal holes. The subretinal PFCL can be removed through a small drainage retinotomy created adjacent to it. A small 39-50 gauge cannula inserted through the retina, is used to directly aspirate the PFCL bubble.49,50 PFCL bubble can also be removed by flute needle passed directly under the retina through a peripheral retinotomy. The PFCL can be directly aspirated after injecting BSS around the PFCL bubble to create a partial detachment around the bubble. Injecting a gas bubble into the eye can pneumatically displace subfoveal PFCL bubbles. This causes the PFCL to migrate to an extramacular location and prevent damage to the overlying retina.

**Toxic effects of PFCL**

Retention of PFCL after surgery can give rise to retinal toxicity, which can be either mechanical or chemical in nature. Mechanical effects are due to extended compression of the inferior retina due to its higher specific gravity. It has been postulated that these mechanical changes may be due to altered potassium transport by the Muller’s cells due to the lack of aqueous on the overlying retinal surface. The changes noted in the inferior retina include loss of the outer plexiform layer, atrophy of the retinal pigment epithelium and displacement of photoreceptor nuclei into the outer segments.11 PFCL has very high oxygen carrying capacity, which can cause damage to the retina and the blood vessels.53 Due to the high partial pressure of oxygen in the residual PFCL, it can cause direct oxygen toxicity to the blood vessels in the form of loss of pericytes and endothelial cells.54 It can also lead to vasoconstriction of the retinal blood vessels.55

**Corneal toxicity, glaucoma and inflammation**

PFCL in the anterior chamber can cause corneal endothelial damage, which can lead to visual disturbance.56 If a large amount of PFCL is present in the anterior chamber, it can lead to reduction of vision by blocking the visual axis (usually while reading). Foster and associates
described the occurrence of secondary open angle glaucoma with retained PFCL secondary to inflammation and trabecular damage.\textsuperscript{57} PFCL in the anterior chamber is also known to cause pupillary block glaucoma. These PFCL bubbles can be removed at the slit-lamp by passing a 23-gauge needle attached to syringe in the anterior chamber through the inferior cornea. Otherwise it can combine with revision vitrectomy.

**Conclusion**

Perfluorocarbon liquids are colourless, odourless, with low viscosity, high density and high specific gravity. PFCL in retinal surgery can be considered synonymous to ophthalmic viscosurgical devices in cataract surgery. The introduction of PFCL in vitreoretinal surgery has revolutionized the intraoperative management of complex retinal detachments and other vitreoretinal pathologies such as dislocated lenses, trauma and suprachoroidal haemorrhages. Ocular toxicity associated with PFCL is primarily due to unintended retention of PFCL. This can be overcome by use of coloured PFCL, which allows easy visualization of even small PFCL droplets and can help in complete removal of PFCL from the eye.\textsuperscript{58} With continued use of PFCL, new techniques would be developed, thus increasing the indications of PFCL in vitreoretinal surgery.

**References**

7. Bourke RD, Simpson RN, Cooling RJ, et al. The stability of perfluro-n-


INTRAOCULAR GASES

Historical Background

In 1911, Ohm\(^1\) treated two patients by injecting air into the vitreous cavity after drainage of subretinal fluid, although the importance of retinal breaks in the pathogenesis of retinal detachment was not recognized then. Rosengren described his technique of internal tamponade with air after subretinal fluid drainage, in conjunction to external diathermy to create adhesion, and demonstrated an increase in success rate in retinal detachment repair.\(^2\) Norton used air to manipulate the flap of giant retinal tears in 1960\(^3\) and while performing vitreous surgeries, Machemer realized the value of expansile gases and their longer persistence than air.\(^4\) In 1980, pneumatic retinopexy was first introduced by Lincoff\(^5\), and later popularized by Hilton and Gizzard.\(^6\)

With the development of expansile gases for pneumatic retinopexy, treatment of retinal detachment was transformed from an inpatient procedure with scleral buckling to an office-based procedure with comparable high retinal reattachment rates. In the present era, primary vitrectomy for retinal detachment has gained popularity. The use of intraocular gases in primary vitrectomy has become indispensable. Also, gas tamponade has improved success rates in more complicated situations such as proliferative vitreoretinopathy and giant retinal tears. Indications for intraocular gases extend to macular hole repair and pneumatic displacement of submacular haemorrhage. Intraocular gas injection is also useful as salvage procedure for recurrent detachments following scleral buckling and vitrectomy, and for postoperative vitreous cavity haemorrhage following vitrectomy for proliferative diabetic retinopathy.

Physical properties of intraocular gases

Gases can be used either in the pure form (expansile) or as a mixture with air (non-expansile). To achieve non-expansile concentration, pure form of the gas is mixed with air in different proportions. For a clinician to make rational choices of the gases, one should have an understanding of expansion ratio of the pure form, non-expansile concentration, and the longevity inside the eye. In daily practice, air, sulfur hexafluoride (\(\text{SF}_6\)) and perfluoropropane (\(\text{C}_3\text{F}_8\)) are most
commonly used (Table 1).

**Table 1 – Physical properties of commonly used intraocular gases**

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Molecular weight (g/mol)</th>
<th>Expansion (times original size)</th>
<th>Time to maximum expansion (hours)</th>
<th>Non-expansile concentration</th>
<th>Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>29</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5-7 days</td>
</tr>
<tr>
<td>Sulfur hexafluoride</td>
<td>SF₆</td>
<td>147</td>
<td>2.0</td>
<td>18</td>
<td>1 - 2 weeks</td>
</tr>
<tr>
<td>Perfluoropropane</td>
<td>C₃F₈</td>
<td>188</td>
<td>4.0</td>
<td>14</td>
<td>6 - 8 weeks</td>
</tr>
</tbody>
</table>

Air is a non-expansile gas, which is often used in conventional scleral buckling surgery (D-A-C-E technique). Subretinal fluid is drained first, followed by air injection. This allows the retina to become re-apposed to the underlying retinal pigment epithelium. Limited and precise cryotherapy is then applied to the apposed retinal break. Finally, low profile scleral buckle can be placed at the appropriate location. If the entire vitreous cavity is filled with air, then the bubble usually lasts for 5-7 days.

Sulfur hexafluoride is a colourless, odourless, nontoxic gas approximately five times heavier than air. It is chemically inert because the sulfur atom is protected by six closely packed peripheral fluorine atoms. Commercially, it is used as an electrical insulating medium. The first medical application of the gas was to facilitate pneumothorax in the treatment of tuberculosis during the pre-antibiotic era. The non-expansile concentration of SF₆ is 20%. As a rule of thumb, if the vitreous cavity is totally filled with a bubble of 20% SF₆, it would last for about 2 weeks.

Perfluorocarbon gases are inert, colourless, odourless and inflammable and about six times heavier than air. They have the generic chemical
formula \((\text{C}_x\text{F}_{2x+2})\), where \(x\) can be \(1-4\). They are manufactured by direct vapour phase fluorination of hydrocarbon or cobalt trifluoride process. The longer the carbon chain, the lower the solubility in water, hence the longer is the intraocular longevity. For instance as a rough guide, 1ml of \(\text{C}_2\text{F}_6\) expands 3.3 times when injected into the eye, and stays in the eye for 4-5 weeks, but for 1ml of \(\text{C}_3\text{F}_8\), the same volume expands four times, and stays for 6-8 weeks.

**Functional role of intraocular gas bubble.**

The important physical properties of gases that help its role in internal tamponade are buoyancy and surface tension.

**Buoyancy:**

It is the phenomenon (discovered by Archimedes) that an object less dense than fluid will float in the fluid. More generally, Archimedes’ principles states that a fluid will exert an upward force (thrust) on an object immersed in it, and the force is equal to the weight of the fluid displaced by the object.

There are two forces, which act on a gas bubble, which is injected into the eye. The downward force is the gravity and the upward force is the buoyancy. Gravity is equal to the weight of the intraocular gas. Thus upward force exerted by an intraocular gas bubble is equal to the buoyant force (upwards) minus its weight (downwards). The SI unit of buoyancy is newton (N).

The buoyant force of gas is approximately ten times that exerted by an equivalent volume of silicone oil and almost same in magnitude as the downward force associated with perfluorocarbon liquids, with a specific gravity close to 2g/ml. Perfluorocarbon liquids are not used as long term tamponade agents, as these are heavy and cause mechanical damage to the inferior retina. On similar grounds, Wong et al questioned the safety of gas bubbles pressing too hard and causing toxic changes to the upper retina. As a rule, the buoyant force exerted by the gas bubble is maximum at the apex of the arc of contact of the gas bubble with the retinal surface, and reduces to almost zero at the inferior edge of the lower meniscus. This buoyant force achieves mechanical displacement of the subretinal fluid and subretinal haemorrhage away
from the contact area between the bubble and the retinal surface. Thus, it is useful in flattening the retina in pneumatic retinopexy, helpful to iron out retinal folds on the buckle and displacement of haemorrhage from under the fovea in cases of submacular haemorrhage. This property of gas bubble to express the subretinal fluid out through the retinal break and to protect the macula being affected by retinal folds is described as “stream-rolling technique”. 10

**Surface tension:**

The surface tension of a substance is determined by the internal cohesive attraction of its own surface molecules and also by the surface molecules’ attraction to the substance it is forming an interface with. Substances that have a very high internal attraction by virtue of polar attraction (i.e. water), will have a very high surface tension measured against air, as compared to silicone oil. Thus, the gas/water interface surface tension is the greatest and therefore is the most effective in closing retinal breaks (70 erg/cm²). This is followed by silicone oil / water interface surface tension (50 erg/cm²). 11

When a gas bubble, which is larger than the retinal break, comes in contact with the edges of the retinal break, it effectively seals the break. This occurs primarily due to the high surface tension of the gas at the gas/ water (subretinal fluid) interface, which prevents surface deformation of the bubble and prevents its passage through the break. Once an effective seal has been created, there is no trans-retinal flow of fluid from the vitreous cavity to the subretinal space. Also this allows absorption of the subretinal fluid by the retinal pigment epithelium, which achieves flattening of the retina. It also prevents migration of retinal pigment epithelial cells into the vitreous cavity through the retinal break and due to a smooth and inert gas fluid interface, deters the attachment of proliferating cells, thus preventing proliferative vitreoretinopathy (PVR).

The combination of fluid displacement (due to buoyancy) and an effective seal at the retinal break (due to the surface tension) ensures subretinal fluid resorption and approximation of the neurosensory retina and retinal pigment epithelium.
Gas bubble geometry

Shape of the gas bubble
Lincoff made the observation that the shape of the gas bubble varies with its volume. If the volume of the gas bubble is small as in pneumatic retinopexy, it assumes a spherical / rounded shape due to its high surface tension. As the bubble expands, buoyancy becomes more important. Every molecule within bubble tends to float upwards, thus causing the lower meniscus of the bubble to become flattened. This shape is referred as a spherical cap.12

Arc of bubble contact (tamponade)
To calculate the arc of contact, the surgeon needs to measure the vertical meniscus height of the bubble in the eye. The arc of contact can be calculated as

Arc of contact $\theta = 2 \cos^{-1} (1-h/R)$, where $h$ is height of the bubble in the eye, $R =$ radius of the eye (Figure 1)

Figure 1 – Geometry of a spherical cap

Parver and Lincoff have measured the arc of contact subtended by the gas bubbles of varying sizes and also varying diameters of the vitreous cavity (Table 2).
### Table 2 – Geometry of intraocular gas bubble.

<table>
<thead>
<tr>
<th>Arc of bubble contact (degrees)</th>
<th>Vitreous diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21mm</td>
</tr>
<tr>
<td></td>
<td>24mm</td>
</tr>
<tr>
<td>90</td>
<td>0.28ml</td>
</tr>
<tr>
<td></td>
<td>0.42ml</td>
</tr>
<tr>
<td>120</td>
<td>0.75ml</td>
</tr>
<tr>
<td></td>
<td>1.13ml</td>
</tr>
<tr>
<td>150</td>
<td>1.49ml</td>
</tr>
<tr>
<td></td>
<td>2.24ml</td>
</tr>
<tr>
<td>180</td>
<td>2.40ml</td>
</tr>
<tr>
<td></td>
<td>3.62ml</td>
</tr>
</tbody>
</table>

Two important aspects needed to be remembered. The spherical cap is the most effective shape for an intraocular bubble to achieve a tamponade effect. It is difficult, if not impossible to achieve a total tamponade effect. Even a slight gas tamponade unfill leaves a large area of the inferior retina unsupported.

**Gas dynamics inside the eye**

Once the gas bubble is injected inside the eye, it undergoes three phases before complete resorption into the bloodstream. These phases are gas bubble expansion, nitrogen equilibration and gas dissolution. The changes in volume of the gas inside the eye are governed by Fick’s diffusion equation, which states that when a semipermeable membrane separates two gases, these gases move across the membrane till their concentrations are equal on both sides. Also, if the rate of diffusion of the gases across the membrane are not similar, then one gas travels faster across the membrane than the other, and this causes a difference in the size of the bubbles on either side of the membrane.

**Gas bubble expansion:**

For gases such as SF$_6$ that are less soluble in water than nitrogen, there is enlargement of gas bubble volume. This occurs as gases (nitrogen, oxygen, carbon dioxide, water vapour) from the surrounding tissue fluid diffuse into the expanding gas bubble until their partial pressures equilibrate between the two compartments. Nitrogen diffuses more slowly as compared to oxygen and carbon dioxide that diffuse more rapidly into the bubble. The most rapid rate of increase of the volume of the gas bubble occurs within the first 6 -8 hours. The bubble achieves its maximal expansion when the rate of diffusion of nitrogen
into the bubble equals the rate of diffusion of expanding gas into the surrounding fluid. For sulfur hexafluoride, maximal volume is attained by 24-48 hours\textsuperscript{13} and for perfluoropropane, maximal expansion is attained between 72 to 96 hours. \textsuperscript{5,14}

Hence, intraocular pressure should be measured using applanation tonometry in eyes injected with expansile concentration of the gas bubble at about 6-8 hours following the procedure. Also, in eyes with narrow angles, occluded angles from neovascularization or peripheral anterior synechiae, injection of expansile gases should be avoided as this may result in marked elevations of intraocular pressure (IOP).

**Nitrogen equilibration:**

This phase begins when the partial pressure of the nitrogen in the bubble is equal to that in the surrounding fluid compartment. Also, diffusion rate of the expansile gas out of the gas bubble may exceed the nitrogen diffusion into the gas bubble. Nitrogen equilibration is reached at a faster rate than other gases due to the higher solubility of nitrogen. This can result in small diminution of gas volume during this phase until the partial pressures in the two compartments equilibrate. For perfluoropropane, C\textsubscript{3}F\textsubscript{8}, this phase lasts 2-3 days.\textsuperscript{14}

**Gas bubble dissolution:**

This phase begins, as the partial pressure of all gases within the bubble equals that in the fluid compartment. The volume of the gas bubble gradually decreases in size as gases dissolve into the surrounding fluid compartment. Bubble volume diminishes in first order exponential decay pattern.\textsuperscript{15} Among all the three phases, this phase is longest. A bubble of at least 50% volume of the vitreous cavity is essential for adequate internal tamponade of inferior breaks with the patient in prone position. In other words, gas has a therapeutic tamponade effect for less than 25% of its total life within the eye. The factors which influence the time taken for complete gas dissolution are lens status, aqueous turnover, presence of vitreous, presence of preretinal membranes, ocular blood flow and ocular elasticity.\textsuperscript{15} The lifespan of SF\textsubscript{6} and C\textsubscript{3}F\textsubscript{8} may be less than half as long in aphakic vitrectomized eyes than in phakic nonvitrectomized eyes.\textsuperscript{16}
Effect of nitrous oxide used during general anaesthesia on gas kinetics:

When nitrous oxide is used during general anaesthesia during vitrectomy, intraocular gas bubble volume may increase significantly during the surgery. Nitrous oxide is 34 times more water-soluble than nitrogen and 117 times more water-soluble than SF$_6$. Nitrous oxide rapidly diffuses from the surrounding fluid compartment in the gas bubble in the eye, causing an increase in the bubble volume. The volume of the gas bubble may increase almost three times its original size if the gas is sulfur hexafluoride. This increase of gas volume causes increase in the intraocular pressure, which maximizes after 15-20 minutes of nitrous oxide usage during general anaesthesia. Once the nitrous oxide is discontinued, it diffuses out of the body through ventilation causing the bubble to shrink with lowering of the intraocular pressure in the postoperative period, and failure of the desired tamponade effect. The concentration of nitrous oxide in the lung alveolars is reduced by 90% after 10 minutes of stoppage of this inhalational gas. To avoid this intraoperative rise in intraocular pressure and smaller than expected gas bubble volume in the postoperative period, it is essential to inform the anaesthetist to preferably avoid the usage of nitrous oxide before the patient is induced under general anaesthesia. If the nitrous oxide is being used, and the surgeon decides to inject an intraocular gas into the vitreous cavity, the nitrous oxide should be discontinued at least 15-20 minutes prior to the intraocular gas injection. Severe visual loss resulting from central retinal vein occlusion and choroidal ischaemia has been reported in patients undergoing general anaesthesia for nonocular surgeries while they still have intraocular gas in the vitreous cavity. It is imperative that the patient with intraocular gas should be forewarned adequately regarding the risks of general anaesthesia with nitrous oxide. A wristband with type of gas and time of gas injection can be worn by the patient throughout the life span of the bubble.

Alteration of gas dynamic due to atmospheric pressure changes.

Ambient atmospheric pressure has an influence on the partial pressure of gases dissolved in the body fluids, which in turn affects the rate of diffusion of gases into the intraocular gas, thus altering the size and
volume of the intraocular gas. Lower ambient atmospheric pressure causes gas bubble expansion accompanied by rise of the intraocular pressure. During air travel, the airplane cabin pressure is only equal to the atmospheric pressure at an altitude of 8000 feet. With a rapid airplane ascent of 2000-3000 feet per minute, there is a rapid fall in the atmospheric pressure. This fall causes rapid expansion of gas bubble, which may translate into IOP rise\(^{19}\), causing severe pain and visual loss due to central retinal artery occlusion.\(^{20}\) Patients with intraocular gas bubble are advised to avoid air travel, unless the gas volume is less than 0.5ml or 10% of the eye volume. For the same reason, IOP rise may occur in patients with intraocular gas, when they ascend or transit to high altitude location or high rise buildings. Such patients are advised to ascend for few 100meters, then allow the eye to acclimatize before proceeding to ascend again. Similar rise in IOP can be observed during scuba diving.\(^{21}\) Inhalation of compressed oxygen from the air tanks causes the bubble expansion and IOP rise during resurfacing from underwater.

**Preparation for injection.**

Intraocular gases are usually marketed either in disposable or reusable cylinders. These cylinders have two-stage regulator valve, which prevents gas leakage from the cylinder and contamination entering the cylinder. Gas pressure within the cylinder should be checked to ensure no gas leakage has occurred before withdrawing the gas from the cylinder. A 50mL syringe is then connected to the outer end of the regulator valve with two 0.22 \(\mu\)m Millipore filters. The outlet flow valve is opened gradually to dispense the gas. The pressure of the gas causes a spontaneous backward displacement of the plunger of the syringe allowing the gas to enter into the syringe. The syringe is then flushed two or three times to remove the gas mixed with air from the “dead space” of the tubing and connections. Pure gas of desired volume is then withdrawn into the syringe. In case of pure gas injection, the syringe is connected either to 30-gauge needle for direct intraocular injection or connected to the infusion for use. For achieving a non-expansile concentration of gas, the syringe with the desired volume of pure gas is disconnected from the regulator valve along with the distal filter. Atmospheric air is then withdrawn through the distal filter into the syringe to obtain the desired concentration of
gas-air mixture. Once the distal filter is disconnected from the syringe, the syringe opening is occluded with tip of the finger and then syringe is either connected to a 30-gauge needle or to the infusion line. This gas-air mixture should be prepared just before the step of gas injection, and used immediately to avoid changes in the gas concentration within the syringe as a result of diffusion of gas out of the syringe. To achieve non-expansile concentration of 20% SF$_6$, 10cc of pure SF$_6$ is withdrawn into the syringe and 40cc of filtered atmospheric air is added. Similarly, to achieve a non-expansile concentration of 14% C$_3$F$_8$, 7cc of pure C$_3$F$_8$ is withdrawn into the syringe and 43cc of filtered atmospheric air is added to it.

To avoid errors in preparation of gas-air mixture, one can perform the following steps – use 100mL syringe instead of 50mL syringe, ensure the correct type of gas, appropriate gas cylinder, appropriate concentration. The surgeon should supervise the assisting nurse during preparation of the mixture, and lastly surgeon can double check if the correct gas volume has been withdrawn by observing the telltale condensation line on the syringe. A condensation line is formed where the syringe stopper was drawn up to with the pure gas, for example, a line at 10mL in case of SF$_6$ and at 7mL in case of C$_3$F$_8$. This condensation line can be identified by holding the syringe against the light.

Clinical applications of intraocular gases in retinal disorders:

The most common indications for intraocular gas injection is in

1. Pneumatic retinopexy for retinal detachment (pre-requisites)
   a. RD in the superior half of the retina
   b. Single break or group of breaks within 1 to 2 clock-hours in the superior 8 o’clock to 4 o’clock position (clockwise)
   c. No inferior breaks or retinal thinning
   d. Preferably presence of posterior vitreous detachment (PVD)

2. In scleral buckling for retinal detachments
a. Restoration of intraocular volume after subretinal fluid drainage
b. For management of fishmouthing of the break on a circumferential buckle
c. Insufficient apposition of the break by the buckle
d. As a salvage procedure in post-scleral buckle eyes with persistent subretinal fluid underneath the break or meridional folds, or fishmouthing of breaks.

3. Vitrectomy for retinal detachment
   a. Superior retinal breaks
   b. Giant retinal tears
   c. Posterior retinal breaks, RD associated with macular holes
   d. Proliferative vitreoretinopathy.

4. Macular hole surgery

5. Pneumatic displacement of submacular haemorrhage
   a. Intravitreal injection of expansile gas
   b. Vitrectomy with subretinal bevacizumab and t-PA injection followed by gas injection
   c. Subretinal air injection for pneumatic displacement of subretinal haemorrhage.

6. For postoperative recurrent retinal detachments or postoperative vitreous cavity haemorrhage.

Selection of appropriate gas

Principle: the duration for which the gas tamponade is required should be long enough for the chorioretinal adhesion to develop. Air is preferred in situations where a small volume of gas would be adequate to tamponade the break, whereas expansile $SF_6$ and $C_3F_8$ is preferred in situations where multiple breaks or multiple retinal folds require a large bubble.
1. In pneumatic retinopexy
   a. \( \text{SF}_6 \) or \( \text{C}_3\text{F}_8 \) may be used.

2. In scleral buckling, gas may be injected to smoothen out the retinal folds or fishmouthing of retinal breaks, in eyes with insufficient apposition of break by the buckle. Hence the gas tamponade is necessary for a short period
   a. Air or \( \text{SF}_6 \) can suffice and are commonly used.\(^3,25,26\)

3. For fishmouth tears or meridional folds in eyes with recent scleral buckle, air or expansile gases can be injected.\(^3\) The head of the patient is positioned to allow the gas bubble to tamponade the break or flatten the fold, this helps to avoid a revision surgery or vitrectomy.
   a. For single superior retinal break above the horizontal meridian – air can be used
   b. For multiple retinal breaks (grouped together) above the horizontal meridian – \( \text{SF}_6 \) is the choice of tamponade
   c. For inferior retinal breaks, larger bubble obtained with \( \text{C}_3\text{F}_8 \) is employed.

4. In giant retinal tears or highly myopic eyes with retinal detachment from macular holes - \( \text{C}_3\text{F}_8 \) is the gas of choice.\(^26,27,28\)

5. Eyes with proliferative vitreoretinopathy
   a. Severe PVR (Retina Society Stages C3 and D) - \( \text{C}_3\text{F}_8 \) is more effective than \( \text{SF}_6 \) for intraocular tamponade.\(^29,30\)
   b. Mild form of PVR can be managed by \( \text{SF}_6 \)

6. For internal tamponade of iatrogenic posterior retinal breaks or retinal tears associated with tractional retinal detachment and proliferative diabetic retinopathy, \( \text{C}_3\text{F}_8 \) is preferred

7. For retinal detachment with penetrating ocular trauma, the choice of the gas is based on severity and location of the injury.
Technique of gas injection

There are various techniques by which gas injection is performed and it is influenced by various factors such as whether the procedure is performed in the operation theatre or in the outpatient clinic, lens status – aphakic, pseudophakic, phakic, and whether the eye is vitrectomized or not.

Fluid-air exchange in eyes with attached retina.

In eyes with attached retina, with the infusion line in place, infusion into the vitreous cavity is switched from balanced salt solution to air. The atmospheric air is introduced through a 0.22 μm Millipore filters connected to the air-insufflation pump of the vitrectomy machine. Before the introduction of the air, view of the retina has to be adjusted depending on the visualizing system such as with BIOM. When performing fluid-air exchange in aphakic and pseudophakic eyes, only slight adjustments need to be made to the knurled knob of the BIOM. In phakic eyes, due to the posterior curvature of the lens, the knurled knob must be rotated counter clockwise to lift the objective lens towards the microscope. Simultaneously, the objective lens of the BIOM should be brought closer to the cornea using the vertical motor of the microscope. To avoid bothersome glare, it is preferable to use conventional light pipes (do not use chandelier system), and place the tip of the light pipe within the fluid as the fluid goes down and is replaced with the gas. Once the level of fluid over the retinal surface is minimal, to avoid damage to the retina, raise the light pipe till it is just inside the sclerotomy cannula. This method provides maximum illumination of the optic disc, posterior pole and decreases the amount of glare.

Fluid-air exchange in eyes with detached retina.

After a thorough vitrectomy and relieving of tractions, fluid-air exchange is used to flatten the retina by removing the subretinal fluid. This allows larger gas bubble to be placed in the eye for longer tamponade effect as well as allows intraoperative laser retinopexy of the retinal break. Drainage of the subretinal fluid is done by keeping the tip of the flute needle, soft tip cannula, active extrusion needle or even by using 23 or 25-gauge vitrectomy probes over the retinal break.
or drainage retinotomy until the break is completely flattened or dry of any fluid. Once the retina is flattened, the residual fluid over the optic disc is aspirated. In pseudophakic eyes with open posterior capsule, condensation occurs over the posterior surface of the intraocular lens. This fogging of the lens can be avoided by injection of small amount of viscoelastic to coat the posterior surface of the intraocular lens. Partial fluid-air exchange can be performed to achieve airtight closure of the sclerotomies after the removal of the 23 or 25-gauge cannulas.

**Air-gas exchange**

In eyes with retinal detachment, intravitreal air is exchanged with either 20% sulfur hexafluoride or 14% perfluoropropane before closing the sclerotomies. Once the fluid-air exchange is complete, specific concentration of gas-air mixture is prepared as described above. The infusion line is clamped with a hemostat and disconnected from the air pump, the 50mL syringe is quickly connected to the infusion line. The hemostat is removed. A 27-gauge needle connected to an empty TB syringe without the plunger, is introduced through the valved 23 or 25-gauge cannula and placed in the vitreous cavity. This allows the air from the vitreous cavity to escape. The non-expansile gas mixture in the 50mL syringe is injected to flush the vitreous cavity as air escapes through the 27-gauge needle. Undue IOP rise can be prevented by injecting the gas slow enough to match the rate of air exit. When the last 10mL of gas is left in the syringe, the 27-gauge needle is withdrawn. The valved cannulas are removed by sliding them over the light pipes placed through them. The light pipe is then removed in the similar direction as the cannula was introduced, pressure over the sclerotomy is applied with a cotton-tipped applicator. If there is some gas leakage from the sclerotomy, the sclerotomy is sutured using a single, radial, trans-conjunctival 8-0 vicryl suture. If the gas leakage has caused the IOP to drop, then further gas injection is done. IOP is assessed either digitally or using the Barraquer tonometer. The cannula with the infusion line is then removed and the pressure over the sclerotomy is applied in a similar manner. The 50mL syringe is disconnected from the infusion line and a 30-gauge needle is attached to it. If hypotony is noted at the end, additional gas in the syringe
is injected to make up for lost volume of the gas. Another approach is to remove both the superior valved cannulas. A 27-gauge needle connected to an empty TB syringe is introduced through the sclera at the 3.5 -4.0mm from the limbus to allow the air to escape. Another method is to inject the gas-air mixture directly into the eye through the sclera with 30-gauge needle or sclerotomy, and allow the air to exit via the infusion line, which is open to the atmosphere at the other end. Air-gas exchange can also be performed using a two - chimney technique. In this technique, a 30-gauge needle is used to inject the non-expansile gas and a 27-gauge needle attached to a TB syringe without plunger, is inserted in the opposite side of the globe to function as a chimney.

**Gas injection in non-vitrectomized eyes in the operating room.**

This technique is useful during scleral buckling or for pneumatic retinopexy and generally performed with pure gas. Gas in a 2-3mL syringe attached to a 30-gauge needle is injected in a swift and constant manner after the needle is inserted into the vitreous cavity at a distance of 3.0-3.5mm from the limbus in aphakic and pseudophakic eyes or 3.5-4.0mm from the limbus in phakic eyes. Once the needle tip is visualized in the vitreous cavity, the needle is withdrawn so that the needle is just deep enough to penetrate all the layers. The globe is rotated such that the site of injection is uppermost. These maneuvers help to avoid fish egg formation. Once the injection is complete, the injection site is rotated laterally before pulling out the needle from the eye. This allows the bubble to move away from the site of injection and prevents leakage. If fish-eggs have formed, the sclera can be gently tapped with a cotton-tipped applicator to promote fusion of the small bubbles. The patency of the central retinal artery is assessed. If the IOP is found to be high, then AC paracentesis can be done to reduce the IOP.

**Outpatient gas injection in non-vitrectomised eyes.**

This is a technique similar to the previous injection technique, useful for pneumatic retinopexy or failed scleral buckling. The eye is anaesthetized using either topical or local anaesthesia and it is prepped with 5% betadine solution. The injection can be performed with the
patient seated at the slit-lamp or lying supine with the head tilted so that the site of injection is superior. Eyelids are kept open by placing a lid speculum. Once the gas is injected, IOP can be lowered by AC paracentesis. Eye is padded with topical antibiotics.

**Outpatient fluid-gas exchange in vitrectomized eyes.**

The patient is prepared in the similar manner as mentioned in the above procedure. This technique is performed with air / non-expansile gas / mimimally expansile gas. The 30-gauge needle is introduced via the dependent pars plana 3-4mm behind the limbus and the barrel of the syringe is kept dependent. The horizontal meridian is avoided to prevent damage to the long posterior ciliary structures. In eyes with aphakia, the needle can be introduced through the inferior limbus. Using a push-pull technique, the fluid from the vitreous cavity is aspirated in small amounts, allowed to collect at the lower end of the barrel, and then replaced with the same amount of gas. Further fluid aspiration is done by directing the needle into the fluid compartment of the vitreous by withdrawing the needle into the dependent part of the vitreous and gas injection is done by redirecting the needle up into the gas bubble till the entire vitreous cavity is replaced by the gas. It is important to visualize the tip of the needle before aspiration of the fluid to avoid inadvertent entry into the suprachoroidal space and also to avoid accidental aspiration of the residual peripheral vitreous. The second method involves the use of a three-way stopcock with two syringes attached to it, one with gas and the other empty to allow aspiration of the fluid from the vitreous cavity. However, it requires an assistant to switch the stopcock between the two syringes during the repeated cycle of aspiration – injection.

**Outpatient gas-gas exchange**

This technique is sometimes required in patients with secure retina with long acting gas and are required to perform air travel, prior to absorption of the gas bubble or eyes with inadvertently higher than desired concentration of non expansile gas. The exchange is performed with the patient lying supine using two syringes attached to a three-way stopcock. Little volume of intravitreal gas is aspirated in one syringe, the three-way stopcock is turned, and similar volume of gas in the syringe is injected into the globe.
Postoperative care in patient with intraocular gas

Postoperative posturing

Postoperative positioning is important to allow proper apposition of the break by the gas bubble. Maximum contact between the gas and break occurs when the head is positioned such that the break is located at the uppermost part of the eye – facedown positioning for posterior breaks, lying on the left for right-sided breaks. Facedown positioning is useful to prevent pupillary block glaucoma, optic capture in pseudophakic eyes and to prevent cataract. This should be done by assuming a facedown or prone position immediately after surgery. Eyes in patients with good compliance exhibit precipitates on the central corneal endothelium due to gravitational deposition of inflammatory elements. This sign is known as “good positioning spot”. Prone posturing should be maintained till the bubble decreases to 20% of vitreous cavity. Bending the head forwards, and resting the forehead on a pillow placed over the table is also a good alternative to prone positioning.

Change in vision after surgery.

It is essential to inform the patient that vision will drop after injecting gas especially in eyes with macula-on retinal detachments and eyes with good pre-operative visual acuity. Intraocular gas bubble renders the phakic and pseudophakic eyes myopic and often the patient can see clearly, objects close to his eyes and looking down. Aphakic eyes are rendered more hypermetropic. Postoperative blurred vision is due to these refractive changes. As the bubble becomes smaller, a dark horizontal line (inferior edge of the bubble) is noticeable to the patient and gradually moves downwards in the patient’s visual field defect. The patient first appreciates initial clarity of vision in the superior visual field. Multiple bubbles may start appearing before complete absorption of the bubble. Once the bubble edge recedes below the horizontal visual axis, the patients will start to see more clearly.

Intraocular pressure and tonometry

As mentioned earlier, bubble expansion occurs maximally in the first postoperative day. IOP should be measured using applanation tonometry at 6-8 hours after surgery. IOP measurements with
applanation tonometry are more accurate than Tonopen or Schiotz tonometer, as the latter underestimate the IOP in gas filled eyes because of altered scleral rigidity. Tonometry is extremely important to detect raised intraocular pressure, as an overfilled expansile bubble may cause irreversible visual loss due to central retinal artery occlusion. Prophylactic treatment with oral acetazolamide and topical timolol should be administered in cases with pre-existing glaucoma, and when spike in IOP is anticipated.

Retinal examination

Gas filled eyes can be difficult to examine with indirect ophthalmoscopy due to the reflections from the gas-fluid interface. In eyes with near complete gas fill, examination through the gas is fairly easy. In eyes with intermediate volume of gas, the patient should be examined while sitting upright by leveling of the patient’s chin. Percentage of vitreous cavity fill can be estimated. The portion of the fundus under the gas bubble tamponade can be examined by asking the patient to look downwards. With small gas bubbles, the patient is made to lie supine to allow the bubble to fill the pupillary area; this reduces the reflections from the gas bubble interface making visualization of the retina easier.

Air travel, scuba diving, transit to high altitudes

It is imperative preoperatively to emphasize to the patient to refrain from air travel, scuba diving and transit to higher altitudes. Intraocular gas injection is best avoided in patients who need to travel by air in the immediate postoperative period. If there is gradual change in altitude, the bubble expansion occurs at a relatively slower rate, this allows IOP compensation by the aqueous outflow facility. However, rapid change in altitude causes sudden bubble expansion and IOP rise. This can lead to central retinal artery occlusion as the aqueous outflow facility may not be sufficient to compensate for this rise.

Complications

Intraoperative complications:
Subretinal gas

Infusion of air in subretinal space can occur in eyes with anterior contraction of vitreous base (in anterior PVR) or with detachment of the pars plana. This can occur due to inadvertent movement of the infusion cannula. Rarely the infusion cannula may be dragged downwards, by the weight of the plastic eye drape filled with the irrigating solution and when the infusion cannula is stuck to the drape with an adhesive. Visualization of the tip of the infusion cannula before initiating fluid-air exchange can help avoid this complication. The bubble can be displaced with the help of the external scleral depression. Subretinal gas can also occur in eyes with residual traction of the retina. If this happens, further fluid-air exchange should be stopped and the infusion fluid should be re-introduced into the vitreous cavity. Subretinal air is then aspirated either through the pre-existing break or retinotomy. Relief of traction is achieved with further membranectomy and other retinal maneuvers before fluid-air exchange is commenced.

Gas in the suprachoroidal space

This rare complication can occur again commonly in eyes with anterior PVR or detached pars plana. If the bubble is large, inserting a needle across the sclera to allow the air to egress while visualizing the retina internally can drain air.

Gas in the anterior chamber.

Gas may present in the anterior chamber in eyes with weak zonules or pseudophakes with open posterior capsule. The infusion cannula may become unstable and tilts anteriorly causing air infusion into the anterior chamber through the lens zonules. This can make visualization of the retina difficult. Gas can be displaced by injecting viscoelastic agents in the anterior chamber. Air may reappear in the anterior chamber when the removal of viscoelastic agent is attempted. In pseudophakic eyes which require postoperative silicone oil tamponade, when air repeatedly enters the anterior chamber, it is sometimes necessary to explant the IOL and make the eye aphakic, as there is high likelihood of postoperative silicone oil in anterior chamber.
Air embolism
During vitrectomy for open globe injury or when performing choroidectomy for malignant melanoma, slow fluid-air exchange with low infusion pressure is advisable. Also ensure that the patient does not have low arterial blood pressure. Ensure the infusion line is in the vitreous cavity to avoid inadvertent suprachoroidal air infusion. Air in the suprachoroidal space increases the risk of presumed air embolization. In the event of air embolism, there is a notable reduction of end-tidal CO₂, oxygen saturation and arterial blood pressure and a distinct “mill-wheel” murmur can be observed. If the patient develops any of these signs, immediately stop the air infusion and revert to fluid infusion. This requires administration of high-inspired oxygen saturation and vasopressors. Although rare, venous and pulmonary air embolisms have been observed during fluid-air exchange.32,33,34

Postoperative complications:

Elevated intraocular pressure
Incidence of elevated intraocular pressure (IOP) following gas injection is 26-59%.35 It is more commonly seen with expansile gases or improper concentration of gas-air mixture. It is usually due to overfill or expansion of the bubble or pupillary block especially in aphakic eyes. IOP increases in eyes when the aqueous outflow facility cannot compensate for an overfill of the gas or expansion of the gas bubble. In most eyes, rise in IOP is transient and can be treated with oral and topical anti-glaucoma medications. Eyes with preoperative narrow-angles should be prophylactically treated with laser iridotomy as these eyes are prone to develop anterior movement of the iris-lens diaphragm due to the gas bubble, leading to angle closure glaucoma, especially in patients who are not compliant to maintaining prone position. Eyes with aphakia may benefit from an inferior peripheral iridotomy during surgery. Postoperatively, when secondary angle closure glaucoma with pupillary block occurs in these eyes, it is treated with anterior reformation with saline or viscoelastic agent. When the IOP is persistently high despite maximum medical management with open angle, release of some portion of intraocular gas must be considered.
**Hypotony, subconjunctival gas, inadequate gas bubble size**

Leak from sclerotomies either at the end of the operation during removal of cannulas, or postoperatively, through a poorly constructed leaky wound can present as subconjunctival gas with hypotony. Mild cases can be observed, however eyes with persistent hypotony with either air or non-expansile gas, there is a risk of choroidal effusion or haemorrhage. In these eyes, reinjection of gas is recommended.

**Subretinal gas**

Gas in the subretinal space affects proper reattachment of the break leading to recurrent retinal detachment. Management of subretinal gas is based on the amount & type of gas, location of the air bubble with respect to the break, whether there is compromise in internal tamponade of breaks. If volume of the subretinal gas (air or non expansile gas) is minimal, and not communicating with the edges of the break, it can be left alone and will usually get absorbed within a few days. If either the subretinal gas is expansile, or communicating with the edges of the break or large in size indicating presence of retinal traction, reoperation is required.

**Gas in the anterior chamber.**

Eyes with aphakia, pseudophakia and phakic eyes with zonular dialysis are prone to get gas entering into the anterior chamber. Maintaining a prone position helps to prevent corneal decompensation due to contact of gas with the corneal endothelium. Since the bubble has flat lower meniscus, the risk of pupillary block is negligible. However gas in the anterior chamber may lead to anterior capsular opacity.

**Cataract**

Intraocular gas itself may cause a feathery posterior subcapsular cataract or “gas cataract” which is temporary and clears once the gas absorbs. Maintaining a prone position as well as leaving a thin layer of anterior hyaloid help to prevent this form of cataract. Gas injection is associated with increased risk of nuclear sclerosis. In eyes with persistent cataract associated with long acting gases, surgical removal of cataract may be required especially if view of the fundus is
compromised. During cataract surgery in eyes with gas bubble in situ, aspirating of the gas is done before cataract extraction.

**Temporal visual field loss**

Incidence of permanent temporal visual field loss after macular hole surgery was reported to be 20% in the past.\(^{36,37,38,39,40}\) The probable cause of the visual field loss is mechanical injury or dehydration damage to the retina from air streaming from temporally placed infusion cannula. During fluid-air exchange, if the air infusion pressure is high and the sclerotomies are open, the stream of air entering the globe can cause mechanical injury or dehydration damage to the nasal retina.\(^{41}\) This complication can be avoided by secure closure of the sclerotomies to reduce the air flow through the sclerotomies during fluid-air exchange, leaving a large puddle of fluid posteriorly until the final aspiration,\(^{42}\) by humidifying air \(^{43}\) and using low air pressure during fluid-air exchange.\(^{44,45}\) With the currently available valved cannulas for 23 and 25-gauge vitrectomy system, the occurrence of this complication has reduced.

**Conclusion**

Intraocular gases form an important and indispensable tool in vitreoretinal surgery. High surface tension and buoyancy, expansile or non-expansile nature of gases with availability of various types and concentration provide the surgeon with an array of options to choose from depending on clinical scenario. Possessing knowledge of physical and chemical properties of the gases allows the surgeon to make appropriate use of these agents in vitreoretinal surgery to enhance the final visual and anatomic success rates.

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SILICONE OIL

Introduction
Silicone oil (SO) was first introduced by Cibis\textsuperscript{1,2} to treat retinal detachment in humans in the 1960s prior to the introduction of pars plana vitrectomy.\textsuperscript{3} In the initial days, SO was injected into nonvitrectomized eyes to overcome tractional forces and to aid dissection of preretinal membranes.\textsuperscript{4} There were some initial concerns with possible silicone toxicity and its associated complications such as cataract formation, glaucoma and poor visual outcome\textsuperscript{5}, but the main concern had been retinal toxicity.\textsuperscript{6,7,8} This led to the discontinuation of SO usage especially in the USA. However few surgeons such as Scott\textsuperscript{9} in Europe continued to use SO as an intraoperative tool. This continued usage of SO was met with higher rate of successful retinal reattachment especially in cases of PVR, which were previously thought untreatable. With the advent of pars plana vitrectomy\textsuperscript{4} in the 1970s and continued surgical refinements by Scott,\textsuperscript{9} Zivojnovic,\textsuperscript{10,11} and other surgeons, SO eventually became an internal tamponade agent of choice in many European countries in 1980s. Further refinement of micro vitreoretinal surgical instrumentation and techniques\textsuperscript{12,13} greatly increased the success rate of retinal reattachment.

While long-acting intraocular gas was used as a primary intraocular tamponade in the USA, the use of SO gained popularity in Europe.\textsuperscript{14,15} This varied choice in tamponade agent eventually led to a head to head comparison, the Silicone Study.

The Silicone Study was a series of randomized controls trials comparing the efficacy and safety between silicone oil and long-acting gases, sulfur hexafluoride (SF\textsubscript{6}) and perfluoropropane (C\textsubscript{3}F\textsubscript{8}) in the treatment of rhegmatogenous retinal detachment (RRD) with proliferative vitreoretinopathy (PVR).\textsuperscript{16-23} This study showed that SO was as effective as C\textsubscript{3}F\textsubscript{8} and the difference between these two agents was not as significant as expected.

PROPERTIES OF SILICONE OIL

Chemical Properties
Silicone is made up of repeating units of siloxane. Siloxane consists
of a silicone and an oxygen molecule, with the chemical formula \((-\text{Si-O-})\). Silicone oil is polymer where silicone is capable of forming two additional bonds on its sides, thus when different organic or inorganic side chains get attached to the silicone molecules, these form polymers with different properties. The more general term silicone can be used to describe all organo-siloxane materials, including silicone fluids (“silicone oil”) and silicone elastomers (“silicone rubber”). Chemically, it is relatively inert. Silicone oil is a polymer with a backbone of \((R_2\text{-Si-O})\), where \(R_2\) is 2 methyl groups, having common siloxane \((-\text{Si-O-})\) repeating units as their backbone. Thus one should use the correct name polydimethylsiloxane (PDMS). In ophthalmology, we often use the term silicone oil. Polydimethylsiloxane certainly has some of the properties of being hydrophobic, liquid and clear. It is however, not technically “oil” as it is not a hydrocarbon.

Depending on the length and molecular weight of the polymer the viscosity differs and can be adjusted. In addition, different side groups on the Si-atom of \(-\text{Si-O-}\) repeating units and different end terminal of the polymer chain can be synthesized, yielding SOs with various chemical and physical properties. For example, two methyl (-CH\(_2\)) side groups can be attached to the Si atom, giving the dimethylsiloxane repeating units, which is the most common SO with lighter-than-water property. Different side groups can be attached to the same Si atom for example, methyl and trifluopropyl methyl siloxane polymer, giving rise to fluorosilicone oils with the heavier-than-water property. Moreover, different monomers can be used in various ratios, yielding copolymers.

Polydimethylsiloxane has a specific gravity of about 0.97. It is immiscible with water and forms an interface with it. The specific gravity remains the same irrespective of the shear viscosity.

During the synthesis of SOs, a number of undesirable impurities may be present. These include unpolymerized residual monomers, low molecular weight oligomeric chains, polymerization by-products or catalytic impurities that may be toxic. In general, it is the low molecular weight component that is important in emulsification.
Physical properties

The effectiveness of an endotamponade depends on its ability to displace aqueous from the surface of the retina. This ability is influenced by its specific gravity, buoyancy, interfacial surface tension and viscosity.

Specific Gravity

The specific gravity of aqueous is around 1.01; hence we can assume that it is almost same as water (1.00). Specific gravity (SG) of a vitreous substitute will determine if it will sink or float in aqueous and will also determine the shape of an intraocular bubble. As the specific gravity of PDMS (0.97) is slightly lower than that of aqueous (1.01), it floats in the vitreous cavity. Also higher the specific gravity of the vitreous substitute, the better it will contact with the retina.

Buoyancy

Buoyancy is an upward acting force exerted by a fluid that opposes an object’s weight. In a static fluid, the net upward buoyancy is equal to the magnitude of the weight of the fluid, displaced by the body. Buoyancy (upward force) of an intraocular tamponade in a vitrectomized eye depends on the difference in specific gravity between the tamponade agent and aqueous. Specific gravity and buoyancy are two directly opposite forces acting on an intraocular bubble tamponade. Gas (SC of 0.001) in water (SG of 1.00) exerts a far greater upward force than SO (SG of 0.97) in water.

When the buoyancy is large, the shape of the bubble of the tamponade agent is a spherical cap (sphere with a flat bottom) such as in intraocular gases. When the buoyancy is small, the bubble assumes a relative spherical shape as in SO. Hence the arc of contact with the intraocular gases is larger than with SO. Also, in eyes with scleral buckle, SO retains its spherical shape and does not conform the shape of the eyeball in the inferior quadrant. Hence when SO injection is contemplated, in order to achieve an effective tamponade effect, it is essential to achieve a near 100% fill.
**Interfacial tension or Surface tension**

Surface tension or interfacial tension is a force that tends to keep the bubble as a whole.\(^{26}\) It also refers to the Van der Waal forces between the molecules within the bubble.

A bubble with a high interfacial tension has fewer tendencies to deform into small bubbles and makes it an effective tamponade. These agents are less likely to pass through small openings such as retinal hole because in order to do so, its surface would need to be deformed. Intraocular gases have the highest interfacial tension among tamponade agents especially when compared with silicone oil.

**Viscosity**

There are two types of viscosity, namely shear and extensional viscosities. Shear viscosity is the measure of the resistance of a fluid towards being deformed when under shear stress or tangential force e.g. flow of SO through infusion cannula. This is due to the attractive forces between molecules in close contact, and the friction between molecular chains. Highly viscous liquid require higher energy, while lower energy is needed for deformation of less viscous fluid. Extensional viscosity is the measure of the resistance of SO to break up, when a globule is drawn into a strand or perpendicular force. When a strand of SO is pulled perpendicularly, it breaks into satellite droplets. A higher energy is needed to disperse a large and highly viscous (extensional viscosity) fluid bubble into small droplets (emulsification). Viscosity is expressed in centistokes (\(1\text{cs} = 10^6 \text{m}^2/\text{s}\)) or more often these days as milliPascals (mPas). Viscosity of SO has practical implications – ease of injection and removal of SO is directly proportional to viscosity, while rate of emulsification is inversely proportional to the viscosity. Emulsification of SO occurs when the surface energy is reduced by the presence of surfactants, these droplets are stabilized and tend not to reform into a single bubble. These droplets can block the trabecular meshwork and induce inflammation by attracting neutrophils.\(^{27}\)

**Clinical indications**

Silicone oil was used by Cibis without vitrectomy in 1960s for the treatment of retinal detachment considered not treatable at that time.\(^1\) Several complications associated with SO usage led to its unpopularity
among retinal surgeons. After the development and refinement of pars plana vitrectomy in 1980s, the use of SO as an intraocular tamponade has now become critical in the management of certain cases of retinal diseases.

**General**

Silicone oil is the tamponade of choice (as compared to intraocular gases) in patients with need to travel by air, anticipated difficulty in postoperative positioning (children, mentally challenged persons or those with physical disabilities) and the need for early visual rehabilitation due to poor vision in the fellow eye. The benefit of SO in providing navigational vision in the immediate postoperative period makes it a more practical surgical option in one-eyed patients. The main disadvantage of SO is that a second surgery is needed to remove it.

**Retinal detachment complicated by proliferative vitreoretinopathy (PVR)**

The Silicone Study was a multicenter, prospective randomized clinical trial, which defined the role of SO in the management of retinal detachments treated with pars plana vitrectomy. This study compared the efficacy of silicone oil with long-acting intraocular gases (SF₆ and C₃F₈) in the management of complex retinal detachment associated with PVR grade C or above. Silicone oil and C₃F₈ were equivalent in terms of improving visual acuity and low complication rates, but SO was found to be as effective as C₃F₈, and better than SF6, in reattaching the retina, however silicone oil had lesser complications than SF6 in terms of hypotony and keratopathy. These findings were also supported by The Cochrane Collaboration in the meta-analysis published in 2009. The relative indications for SO use in retinal detachment with PVR remain controversial. The relative contraindications for usage of SO include a deficient iris diaphragm (e.g. aniridia) as this may be predisposing risk factor for keratopathy.

**Giant Retinal Tear**

Before the introduction of perfluorocarbon liquids (PFCL), silicone oil was traditionally used for two purposes in eyes with giant retinal
tear – to unroll the folded retina and to act as an extended tamponade agent. With the advent of PFCL, unfolding of the retina is a lot easier.\textsuperscript{29}

SO usage in giant retinal tears without PVR remains controversial. In the USA, intraocular gases remain the agent of choice, while in Europe, surgeons still prefer SO. Till date, there are still no randomized controlled trials to compare the efficacy of SO and gas in the management of giant retinal tears.

The PFCL is used to unroll the retinal flaps and reposition the retina. Laser retinopexy is then performed along the edges of the tear and the horns up to the ora. This is followed by either direct PFCL-SO exchange,\textsuperscript{30} or a PFCL-air exchange and air-SO exchange. It has been shown that direct PFCL-SO exchange reduces the risk of slippage during the exchange process.\textsuperscript{31} In patient with difficulty in posturing or in inferior giant retinal tears, it is preferable to use SO.

**Severe proliferative diabetic retinopathy**

SO is often used at the primary vitrectomy for tractional retinal detachment associated with severe proliferative diabetic retinopathy.\textsuperscript{32} This means that eyes would require a second operation for removal of silicone oil, but SO has several advantages: it allows rapid visual recovery, it reduces postoperative vitreous cavity haemorrhage and allows clear visualization of the fundus during examination. It also provides better tamponade for those who cannot maintain posture after surgery.\textsuperscript{33} It confines all dissolved oxygen in the anterior segment and prevents vascular proliferative factors in the posterior segment coming anteriorly. This is beneficial in eyes with neovascularization of the anterior segment and requiring vitrectomy.\textsuperscript{34,35} Also, silicone oil injection should only commence after hemostasis has been achieved and preferably all preretinal haemorrhage has been aspirated, to avoid the risk of proliferation in the postoperative period.

**Macular hole**

Pars plana vitrectomy with removal of the posterior cortical vitreous, ILM peeling, followed by internal tamponade with intraocular gas or silicone oil, combined with postoperative facedown posturing has been the treatment of choice of idiopathic macular holes.\textsuperscript{36} In a study
comparing C3F8 and SO tamponade, C3F8 was found to be more effective in achieving initial closure of macular holes.\textsuperscript{37} Gas tamponades macular hole better as it has a higher buoyancy and interfacial surface tension, which accounts for its greater success than with oil. The use of SO in macular hole surgery is mainly indicated in patients with anticipated difficulty in posturing in the postoperative period, in those who need to travel by air and in those who are monocular.

**Pathologic myopic retinal detachment with macular hole.**
Retinal detachment in pathologic myopia with macular holes, especially with posterior staphyloma has been treated with pars plana vitrectomy with intraocular SO tamponade with variable degree of success.\textsuperscript{38-40} The current trend is to perform vitrectomy with removal of the cortical vitreous, internal limiting membrane and placement of intraocular gas tamponade.\textsuperscript{41}

**Retinal detachment associated with viral retinitis.**
Retinal detachment with viral retinitis has a high rate of recurrence due to the diffuse and relentless nature of the disease and associated retinal necrosis. This necrosis is associated with retinal atrophy and large retinal defects that lead to detachment.\textsuperscript{42} SO provides long-term, often permanent, internal tamponade with reduced rate of recurrent retinal detachments.\textsuperscript{43} Most patients with cytomegalovirus (CMV retinitis) are immunocompromised, young patients and have a clear crystalline lens. Clear lens extraction with IOL implantation may be combined with pars plana vitrectomy with SO in these eyes.\textsuperscript{44} In eyes where retinitis is active in the presence of retinal detachment, combining vitrectomy, SO tamponade and ganciclovir implant insertion has shown to achieve long-term stabilization of the atrophic retina, preservation or improvement of vision, and extended control of the CMV retinitis.\textsuperscript{45}

**Complicated pediatric retinal detachment**
Silicone oil tamponade is preferable to gas tamponade in the pediatric retinal detachment since it is difficult for children to maintain prone positioning after the procedure. Main indications for SO tamponade in
the pediatric retinal detachment are trauma, retinopathy of prematurity, congenital anomalies and myopia. The outcome, however, are generally poor.\textsuperscript{46}

**Retinal detachments associated with choroidal coloboma.**

The incidence of retinal detachment in eyes with choroidal coloboma is 23-42\%.\textsuperscript{47} Anatomical success rates of scleral buckling ranged from 35\% to 55\%.\textsuperscript{47,48} Pars plana vitrectomy with SO tamponade achieved better anatomical success as shown by Pal and associates.\textsuperscript{49} Achieving chorioretinal adhesion for retinal breaks within the area of coloboma is not possible because there is no choroid for the retina to adhere to. So the retinal breaks within the coloboma tend to remain open. Some surgeons attempt to produce chorioretinal adhesion at the edges of the coloboma by laser ing the whole extent of the coloboma. SO tamponade may be required as a permanent tamponade in some of these eyes.

**Endophthalmitis.**

It has been postulated that SO may possess some antimicrobial activity. Azad and associates showed that vitrectomy with SO tamponade achieved visual acuity of 20/200 or better in more eyes than vitrectomy alone (58\% versus 8\%) for post-traumatic endophthalmitis cases.\textsuperscript{50} The presence of SO in vitreous cavity may lead to increased concentration of the intravitreal antibiotic than expected, possibly leading to retinal toxicity. One way to ensure appropriate dosing of intravitreal antibiotics is to inject antibiotics of correct concentration in an air-filled vitreous cavity, before SO is injected.

**Trauma**

Silicone oil tamponade may help in severely traumatised eyes to flatten the retina, to prevent and minimize intra and postoperative haemorrhage, which is a risk factor for PVR.\textsuperscript{51} It maintains retinal attachment and prevents hypotony. Primary pars plana vitrectomy and silicone oil tamponade resulted in encouraging outcomes.\textsuperscript{52} Silicone oil tamponade can be used for eyes with recurrent retinal detachment following failed pars plana vitrectomy, but in these eyes the final
visual acuity of 5/200 or better was obtained in only 5 of the 42 eyes (12%). Generally, the prognosis in these eyes is poor even with oil.

**Surgical techniques in the use of silicone oil:**

**Types of silicone oil used in vitreoretinal surgery:**

Viscosities of commercially available SO ranges from 1000cSt to 5700cSt. In the Silicone Study, SO with the lower viscosity (1000cSt) was used, while the 5000cSt is the only SO approved by the Food and Drug Administration (FDA) for use during vitreoretinal surgery.

**Physiochemical differences between the SO with different viscosities relate to**

- ease of injection reduces as the viscosity of SO increases
- difficulty of removal increases as the viscosity goes up
- rate of emulsification (lower with SO of higher viscosity)

The tamponade effect is not related to viscosity and appears to be equal between SO of different viscosities.

**Infusion of Silicone oil**

Due to the lower surface tension of SO, the tendency of SO to be infused subretinally is much greater compared to gas especially in presence of large retinal breaks and unrelieved retinal traction. Hence, retina should be mobile and free from traction, achieved by thorough membrane peeling or relaxing retinotomy prior to SO injection. Plastic syringes with Luer-lock are preferred over glass syringes for safety reasons. As the flow is inversely proportional to its length, in order to reduce the resistance during injection of SO, infusion line / cannula should be short in length, rounded and with the largest diameter permissible. The plastic ones should be cut short for use. High pressure is needed to infuse SO into the eye through a syringe due to its high viscosity. Injection of SO is done with automated pneumatic pumps inbuilt in the current generation of vitrectomy machines. The SO-containing syringe is connected to the automated pneumatic pump. The advantage of using this pump for SO injection is that it is less time consuming and allows the surgeon more control.
through a foot pedal controlled system. There is no pressure-feedback mechanism when using the automated pump, hence there is a risk of over or underfill of SO. Infusion of SO can be done using either one of the two open sclerotomies, while monitoring the IOP digitally. Even a minimal overfill of the globe with silicone oil can cause exponential increase in IOP.

**Status of crystalline and choice of IOL**

SO is known to induce cataractous changes in the crystalline lens, even if SO is removed shortly after surgery (i.e. 6 weeks). In phakic eyes, silicone oil has better tamponade effect on the superior and inferior retina. So if the primary pathology is posterior, the lens can be left behind. In phakic eyes, it is essential to decide whether to remove the lens, and whether to implant an IOL. The lens can be removed by phacoemulsification with IOL implantation, or lensectomy. Some surgeons prefer to leave the anterior lens capsule behind for subsequent secondary lens implantation, this may help reduce complications related to SO use. Removal of the lens helps in vitreous base dissection and shaving. If lensectomy is done to leave the eye aphakic, there is an increased risk of silicone oil keratopathy even if an inferior peripheral iridectomy has been performed. To avoid the risk of silicone oil adhesion to the IOL, it is better to avoid silicone IOL, IOLs made up of polymethyl methacrylate (PMMA) or acrylic are preferable. The oil droplet adherent to the IOL can cause high and irregular astigmatism, monocular diplopia, polyopia, blurred and distorted vision.

**Silicone oil injection in microincisional vitrectomy system**

Silicone oil infusion can be done with ease both with 23-gauge and 25-gauge micro-incisional vitrectomy system. Erakgun and Egrilmez used 1000cSt SO as a tamponade agent in 40 patients who were operated with 23-gauge system. Riemann and associates used 24-gauge angiocatheter for injection of 1000cSt and 5000cSt by trimming the length of the angiocatheter to 4mm. In both series, no difficulties were encountered during the injection process. Commercially, 23 and 25-gauge cannula designed for SO infusion are available (Polytip-VFI, MedOne, Sarasota, FL and Alcon Surgical systems).
Air-silicone oil exchange

Silicone oil injection is commonly done after the fluid-air exchange has been performed. At this stage, the retina is flattened and retinal holes and breaks have been treated with endolaser. SO injection is done through either of the two superior sclerotomies using viscous fluid injection mode on vitrectomy machines. It is important to ensure that the vitreous cavity is cleared of fluid (to reduce underfill of SO) or blood component to reduce the chance of oil emulsification later. The illumination should be removed once the SO starts entering the vitreous cavity, to allow the air in the vitreous cavity to escape through the vacant sclerotomy port. To ensure a good fill of SO, the eye is rotated such that the vacant sclerotomy port lies at the highest point to allow residual air to escapes. Also, vitreous cutter or a flute needle can be used at the end to remove residual air present in the vitreous cavity.

The endpoint of SO infusion is either when SO starts following out of the vacant sclerotomy port, SO is seen entering the infusion cannula, or when SO touches the undersurface of the posterior capsule in pseudophakes or it reaches the iris plane in aphakes. The IOP should be monitored digitally and should be within normal limits after the ports are closed and the encircling band has been tightened. In the postoperative period, overfilling with SO can cause a shallow anterior chamber and intractable glaucoma that can only be managed by removal of some SO from the vitreous cavity.

In eyes with aphakia, pseudophakia with an open posterior capsule, scleral fixated lens and eyes with anterior chamber intraocular lens, an inferior peripheral iridectomy (Ando’s inferior iridectomy) is needed to prevent pupillary block glaucoma. To perform an inferior iridectomy, the tip of the vitreous cutter is placed under the iris at the appropriate location (as peripheral as possible), followed by active suction. This creates a dimple on the iris. If the position is not ideal, the suction is released and another site is chosen. Once the positioning is correct, the cutter is activated with a low cut rate to create an opening in the iris. For aphakic, the vitreous cutter can be passed through the pupil and positioned on the anterior surface of the iris with the port facing down to achieve an iridectomy at the preferred position under direct visualization.
In pseudophakic eyes, SO may pass into the anterior chamber, especially if there is an open posterior capsule or zonular dehiscence. This SO bubble in the anterior chamber can be removed by injection of viscoelastic agent. To avoid SO from entering the anterior chamber, a stable low IOP during the last stages of oil fill is advisable. This can be achieved by keeping a low viscous infusion pressure, low air pressure setting in the infusion line, careful IOP monitoring during SO fill, minimal manipulation and distortion of the globe and stopping the oil injection once the oil is seen entering the infusion cannula. As the vitreous cavity beginning to fill with SO and there is minimal residual air in the vitreous cavity, the viscous infusion pressure should be reduced. No attempt should be made to remove small residual air bubble through the vacant sclerotomy port by injecting more SO. This would ensure adequate infusion pressure towards the end of the infusion and prevent SO from entering the anterior chamber.

In aphakia, at the conclusion of SO infusion, removal of the air bubble from the anterior chamber is essential to achieve complete oil fill as well as ensuring a well-formed anterior chamber. Once the air bubble from the anterior chamber has been aspirated, the SO from the vitreous cavity enters the anterior chamber. Using a fluid filled syringe with a bent cannula introduced through one of the superior sclerotomies such that its tip passes through the inferior iridotomy to reach the anterior chamber, the anterior chamber is reformed. Injection of BSS over the iris will force any oil prolapsing into the anterior chamber back through the pupil into the retroiridial plane. Excess fluid injection should be avoided and IOP needs to be checked at the end. Minimal oil may be allowed to extrude from the open sclerotomy if the pressure is felt to be high.

A facedown posture should be adopted immediately after SO infusion. This may be difficult sometimes if the patient was given general anaesthesia. In this instance, the patient should be postured with the head tilted to one side.

**Perfluorocarbon liquid-silicone oil exchange**

This technique is employed in cases where there is a risk of slippage especially eyes with large retinal breaks, giant retinal tears and 360° retinotomy. During PFCL-air exchange, the incoming air
bubble tends to push the residual fluid posteriorly. The residual fluid or aqueous is located in the peripheral trough of the convex PFCL bubble. Slippage occurs as this residual fluid or aqueous is displaced under the retina posteriorly leading to collection of subretinal fluid under the posterior pole, posterior displacement of the retinotomy edge and retinal folds, while leaving a larger area of retinal pigment exposed. The latter may in turn increase the risk of PVR formation. PFCL-SO exchange is performed by employing a flute needle in the dominant hand, while the other takes the syringe containing the SO. The SO can be infused either through the infusion cannula or one of the superior sclerotomies, in which case, an alternative light source as an illuminated cannula or a separate chandelier illumination system is needed.62,63,64 As the SO is actively infused, the PFCL gets passively extruded through the flute needle. The tip of the flute needle has to be within the progressively reducing PFCL bubble during the whole process. If the tip of the flute needle is accidentally positioned within the SO bubble, then flute needle would get blocked with SO. If further SO is continuously being infused with a blocked flute needle, IOP can rise quickly. It is therefore essential to monitor the pulsation of the central retinal artery during the entire process. Direct PFCL-SO exchange is less likely to cause slippage.65 Since both PFCL and SO are hydrophobic in nature, and prefer to be in contact with one and other, once joined, these liquids form a single bubble with an interface and generally exclude the aqueous from the interface. Also this coalesced bubble tends to have a specific gravity greater than water. More importantly, the residual fluid or aqueous is pushed anteriorly and laterally towards the sclerotomy ports from where is gets extruded out of the eye.

**Fluid-silicone oil exchange**

This procedure involves direct exchange of fluid in the eye with the silicone oil. Silicone oil injection has a tendency to push the subretinal fluid posteriorly towards the macula, hence a posterior drainage retinotomy is needed to allow internal drainage of the subretinal fluid. As the silicone oil is being injected, the extrusion needle should be placed through the posterior retinal break / posterior drainage retinotomy. This maneuver is technically difficult and is not commonly performed.
Complications

Silicone oil in the anterior chamber

SO in the anterior chamber can occur either during the surgery or in the postoperative period. It can be due to inadequate lens-iris diaphragm such as in aphakia, loose zonular support, blocked inferior peripheral iridectomy or opening in the posterior capsule.

If the entire anterior chamber is completely filled with silicone oil, it is often difficult to detect due to the absence of the fluid-oil meniscus. There are some signs suggestive of oil in the anterior chamber – slight posterior bulging of the iris, shimmering reflex on the iris crypts, absence of aqueous flare in the AC, mid-dilated pupil with raised IOP, edge of the silicone oil bubble can be visible on gonioscopy. Cornea remains clear as silicone oil in the anterior chamber prevents hydration of the cornea, however corneal edema can occur, if SO is later removed due to contact damage of the corneal endothelium by the SO.

SO can enter in the anterior chamber during surgery in eyes with aphakia or pseudophakia. In addition to the causes mentioned previously, it can be due to overfilling of the eye with SO. Intraoperatively, the SO can be displaced back into the vitreous cavity by injecting viscoelastic agents in the anterior chamber. Also, it is preferable to leave the eye normotensive after silicone oil injection, before closure of the sclerotomies. This helps to avoid overfilling of the eye with SO. In eyes with pseudophakia, inferior peripheral iridectomy may not be necessary in all eyes.

In the early postoperative period, silicone oil can migrate into the anterior chamber due to inadequate lens-iris diaphragm, or non-patent inferior peripheral iridectomy. Blockage of the peripheral iridectomy can occur if the surgery involves excessive retinectomies, 360° photocoagulation, extensive cryotherapy, inflammatory debris or blood. If the SO bubble is small and IOP is not raised, then the bubble can be removed at the time of the silicone oil removal. In eyes with aphakia and patent PI, face down or supine positioning allows the small bubble to merge with large bubble in the vitreous cavity. If the bubble is large and is associated with blocked peripheral iridectomy, YAG laser treatment can be attempted to reopen the iridectomy. If
it fails, then a surgical maneuver is needed. Delayed migration of SO into the anterior chamber is commonly due to recurrence of detachment or hypotony. Ciliary body shutdown due to anterior PVR and overdrainage of uveal-scleral pathway (especially if large retinotomies have been done) can contribute to hypotony.

**Glaucoma**

Increased intraocular pressure may be associated with pupil block glaucoma, oil overfill, secondary open angle glaucoma, migration of SO into the AC and secondary angle closure glaucoma.66,67,68

Pupil block glaucoma usually occurs during the early postoperative period, where the peripheral iridectomy is nonfunctioning. It is more common in aphakes, due to the close proximity of the anterior surface of oil and the pupillary margin. It occurs due to closure of the peripheral iridectomy69 or blockage by inflammatory products such as fibrin or blood. This leads to aqueous misdirection, forcing the SO bubble through the pupil, causing shallowing of the anterior chamber and increased intraocular pressure. Reopening of the peripheral iridectomy either with a YAG laser or surgical maneuver relieves pupillary block.70,71 If peripheral iridectomy is blocked by fibrin or blood clot, injection of tissue plasminogen activator (tPA) into the AC can be tried.72

The signs suggestive of silicone oil overfill include absence of an inferior SO meniscus over aqueous in the posterior segment with high IOP and shallow AC in the immediate postoperative period. In pseudophakes or phakic eyes, silicone oil is seen herniating through the pupil and coming in front of the crystalline lens or intraocular lens.73 In aphakic eyes, partial removal of SO via a corneal or pars plana incision is necessary to control the IOP. If the silicone oil is trapped between the iris and crystalline lens or intraocular lens, partial removal of SO may not be sufficient. This requires complete evacuation of the silicone oil and reinjection. This complication can be avoided by making sure the intraocular pressure is normal or slightly low and the SO remains posterior to the lens-iris diaphragm after injection into the vitreous cavity especially after tightening the encircling band / buckle.
Secondary angle closure glaucoma is suspected in eyes with high IOP, patent iridectomy, no oil in AC and no oil trapped between the iris and crystalline lens or intraocular lens. Secondary open angle glaucoma associated with SO could be due to mechanical blockage of the trabecular meshwork or trabeculitis induced by emulsified oil. Initial treatment includes medical therapy. If IOP continues to rise, surgical options such drainage devices or trans-scleral cyclophotocoagulation could be used to lower the IOP.

**Persistent hypotony**

In the Silicone Study, prevalence of chronic hypotony was noted in 18% of the SO filled eyes at 36 months. Chronic hypotony was defined as having IOP \( \leq 5 \text{ mmHg} \). The cause of chronic hypotony is multifactorial and poorly understood. Large retinectomies are thought to cause increased uveoscleral outflow leading to reduced IOP. Reduction of aqueous production due to ciliary body alteration may also lead to hypotony. Ultrasound biomicroscopy study of the ciliary body revealed tractional & exudative ciliary body detachments, combined tractional & exudative choroidal detachments, atrophy, hypotrophy and edema of the ciliary body. Chronic hypotony with IOP \(< 10 \text{ mmHg} \) is a relative contraindication to SO removal, as removal of SO risks progression to phthisis bulbi. Treatment of postoperative hypotony is difficult. In the early postoperative period, a repeat surgery to relieve traction and proliferation on the anterior retina and ciliary processes may be beneficial. Subconjunctival injection of long acting steroids may help in normalization of intraocular pressure in these eyes. However, there is no current effective treatment for eyes with established hypotony.

**Cataract**

Cause of cataract formation in phakic eyes with SO tamponade is multifactorial. The proposed mechanisms are impaired metabolic exchange across the posterior lens capsule and/or direct toxicity of SO. If SO is kept in situ for prolonged time period, eventually cataract forms, which could be in the form of posterior subcapsular cataract or nuclear sclerosis. Since cataract formation is inevitable
when SO is used, some surgeons routinely perform combined phaco-vitrectomy when SO use is intended. This allows more complete vitrectomy, and a better SO fill can be achieved.

If the SO is in situ, then a combined phacoemulsification, in-the-bag posterior chamber intraocular lens implantation and SO removal can be performed. Posterior capsulectomy with vitreous cutter after IOL implantation may be necessary for eyes with thickened, fibrosed posterior capsule and can avoid the need for YAG capsulotomy in future. If the SO has already been removed and posterior capsular opacification if noted later after cataract surgery, YAG laser capsulotomy can be performed. Implantation of silicone IOLs is best avoided in eyes with SO due to risk of formation of intractable adhesion of SO onto the surface of IOLs. This SO adhesion to the silicone IOL can give rise to blurred vision (due to high refractive errors, irregular astigmatism), polyopia and distortion.

Intraocular lens power calculation can be difficult as estimation of axial length with ultrasound biometry can induce inaccuracy when a SO bubble is in situ. This is due to the difference in speed of sound waves in vitreous and SO. The speed of sound in normal vitreous is approximately 1.552 meter per second (m/s), whereas that in SO is 986 meter per second (m/s). So, the time taken for the sound waves to return to the receiving sensor after being reflected from the anterior surface of the retina is longer than when the same eye is filled with vitreous. The resultant axial length will be 40% falsely longer than the actual length, which would cause a hyperopic shift if this uncorrected measurement were used for IOL power calculation. A conversion factor of 0.71 was used to modify the measured axial length and readings obtained were used to estimate the IOP power with good accuracy with a mean of only 0.74 diopters difference between the predicted and actual postoperative refraction. However, impurities within the SO bubble, and underfilling of SO may effect the A-scan signals. In a study, immersion B-scan guided ultrasound biometry has been found to give better accuracy as compared to contact A-scan biometry in SO-filled eyes. In the recent times, interest has grown in using partial coherence laser interferometry (PCI) for axial measurement in SO filled eyes. Parravano et al showed that axial lengths measured before and after SO removal using PCI was almost similar.
This is because speed of light is constant irrespective of the nature of the medium. The only pre-requisite is media clarity; hence in eyes with media opacity, measurements with PCI may be affected. In these eyes, ultrasound based measurements are more reliable. Another approach is to have preoperative (prior to retinal surgery) biometry on record. This can be used to confirm precataract measurements, especially in cases where buckling procedures have not been performed.

**Keratopathy**

Prolonged SO tamponade is associated with keratopathy, either as band-shaped keratopathy or bullous keratopathy. Band keratopathy is more common in younger patients, while bullous keratopathy is seen more in older patients. The incidence of corneal abnormalities in the Silicone Study at 24 months was 27%. However, there was no significant difference in rate of keratopathy between SO and C$_3$F$_8$ gas. In eyes with severe PVR, the independent risk factors for keratopathy are aphakic or pseudophakic status, preoperative iris neovascularization, postoperative aqueous flare and eyes with repeated surgery. Corneal touch by SO has been thought of as a major contributor for development of keratopathy. The management strategies to prevent keratopathy is to ensure a patent peripheral iridectomy, to ensure no SO in the AC at the conclusion of the surgery, to try and preserve an intact posterior capsule and early SO removal to prevent prolonged corneal endothelium-SO contact. Chelation and phototherapeutic keratopathy are useful options for treatment of band-shaped keratopathy. In eyes with useful vision and bullous keratopathy, keratoplasty with or without silicone oil removal is a good option. However, graft failure rates are higher when the silicone is retained in the eye (67%) compared to when it is removed before or during keratoplasty (25%).

**Recurrent retinal detachment**

In the Silicone Study, rate of recurrent retinal detachment was not related to type of intraocular tamponade used – gas or silicone oil. The risk factors associated with recurrent retinal detachment include the number of previously unsuccessful retinal detachment surgeries, preoperative visual acuity, incomplete removal of the vitreous base and absence of encircling band. Early redetachment
of the retina is mostly likely due to unrelieved retinal traction, while reproliferation is the cause of late recurrent retinal detachment.\textsuperscript{97,98,99} If the retina remains attached three to five months after SO removal, retinal redetachment is unlikely.\textsuperscript{99} Identification of all retinal breaks, and meticulous removal of all tractional membranes by membrane peeling and retinectomy are keys to ultimate anatomical success and reduction of risk of redetachment. Some surgeons recommend the use of prophylactic $360^\circ$ laser before or during SO removal to reduce the chance of redetachment.\textsuperscript{100,101}

**Silicone oil emulsification**

Emulsification of silicone oil is an inherent problem especially if it is retained for prolonged duration. Emulsification can lead to glaucoma, inflammation, PVR and keratopathy.\textsuperscript{102,103} It is virtually impossible to remove all emulsified silicone oil bubbles during SO removal. Hence postoperatively, patient may have visual disturbances, troublesome floaters, and increased IOP. Emulsified SO droplets may enter the subretinal space and can lead to retinal redetachment. Emulsification can occur as early as one week after surgery, but generally occurs a few months after surgery.\textsuperscript{104} It has been postulated that emulsification occurs due to a combination of saccadic eye movement, friction between SO and other intraocular fluids, and a reduction of interfacial tension by active components (blood, fibrin) in the intraocular fluids. The tendency for SO to emulsify is dependent on its viscosity and surface tension.\textsuperscript{105} Generally, higher viscosity oil has lower tendency to emulsify,\textsuperscript{106} hence its preference if prolonged oil retention is anticipated.

**Suprachoroidal infusion of SO**

The surgeon can avoid placing SO in the wrong anatomical space by using proper technique and adequately managing retinal pathology. It is important to ensure the tip of the infusion cannula is within the vitreous cavity before initiating the silicone oil injection through the cannula. This would avoid suprachoroidal infusion of SO, especially in eyes with thickened choroid such as in eyes with hypotony due to chronic retinal detachment, inflamed eyes and eyes with choroidal detachment, effusion and haemorrhage.
Subretinal migration of SO

It is imperative to relieve all traction on the retina by membrane peeling or retinectomies before injection of SO. Hence, any residual traction, which prevents retinal flattening under air, should be relieved. This prevents migration of SO into the subretinal space through persistent open breaks. SO migration into the subretinal space can occur in the postoperative period through new breaks in the presence of PVR and persistent traction.

Unexplained visual loss following silicone oil tamponade

The exact mechanism is unknown. Unexplained visual loss can occur due to sudden change in the physiological environment affecting potassium pumping by Muller cells or phototoxicity. The oil bubble may act as a strong condensing lens, focusing the light from the microscope on to the macula, during silicone oil removal, causing this phototoxicity. Optical coherence tomography, fluorescein angiography did not reveal any possible explanation for this visual loss. Multifocal electroretinogram may localize the damage to the foveal segment.107

Silicone oil removal

As a general rule, silicone oil should be removed once the objectives of the tamponade have been achieved and the retina is stable with the aim to reduce the long-term complications associated with SO.108,109,110,111,112 Theoretically, chorioretinal adhesion following retinopexy would certainly be achieved by 1 month, however SO is retained often longer than this. The aim being that the presence of the oil and the tamponade force might resist any traction caused by reproliferation of tractional membranes. In the Silicone Study, SO removal was allowed after a minimum of 8 weeks following the surgery.185 Removal within the first 6 months after surgery is generally recommended. Various methods of SO removal have been described.113,114,115,116,117

Procedure

The method employed for silicone oil removal is influenced by type of SO and its viscosity, lens status and whether or not additional maneuvers are to be carried out. Generally, an infusion is first placed at the pars plana to allow saline to replace the globe volume during
removal of SO. In aphakic eyes, silicone oil removal can be performed using passive or active egress of SO through a corneal wound. In phakic or pseudophakic eyes, two port system can be employed – one for infusion and other for aspiration. The sclerotomy for aspiration should be placed in the uppermost position, because SO floats on top of the infusate. Aspiration of the SO should always be active using the silicone oil injection / aspiration feature of the newer micro-incisional vitrectomy systems. It is important that the aspiration cannula stays within the SO bubble. If the cannula comes out of the SO bubble, small individual bubbles of SO get isolated and may be left behind. Also, during aspiration of SO, whirling mass of fluid is observed within the vitreous cavity. This mass of fluid should be observed and the cannula should be manipulated to stay within this mass of fluid. Isolated SO bubbles adherent to the peripheral retina or ora can be pushed into the vitreous cavity with gentle depression of the ciliary body area.

Complete removal of SO is seldom achieved. Emulsified SO bubbles remain adherent to the posterior surface of the iris, zonules, posterior surface of the lens, posterior capsule and to the ciliary processes. Multiple fluid-air exchanges had been suggested to allow removal of these emulsified bubbles.\textsuperscript{113} The principle is to force the residual oil droplets to coalesce to form an “oil slick” on the surface of the fluid. During the fluid-air exchange, the fluid can be aspirated using a soft tipped cannula or the vitrectomy cutter, which is placed at the air-fluid meniscus, since this is the plane where oil comes to float and can be seen and removed. Multiple repetitions of fluid-air exchange may be needed. If emulsified oil bubbles are observed in the anterior chamber, anterior chamber should be washed thoroughly with attention to the angles.

In eyes where combined phacoemulsification and silicone oil removal has been planned, micro-incisional cannulas are placed as an initial step. Following a standard phacoemulsification with IOL implantation, silicone oil can be removed by active suction, additional posterior capsulotomy can be done. Otherwise, after the phacoemulsification, posterior capsulotomy can be done to allow removal of the silicone oil through the corneal wound as in aphakic eyes. Anterior-chamber
maintainer can be substituted in place of a pars plana infusion cannula, but the height of the infusion bottle needs to be higher when the AC maintainer is used. Following removal of SO, an IOL can be implanted in-the-bag.

**Permanent silicone oil tamponade.**

Eyes with partial retinal detachment under silicone oil are re-operated to repair the detachment with reinjection of silicone oil until the retina is entirely attached. Silicone oil can be left behind in eyes with poor anatomic or visual prognosis, especially with a healthy fellow eye and with history of multiple operations. Long-term silicone oil tamponade may be necessary in eyes with chronic hypotony despite an attached retina, and in eyes with trauma due to the prolonged course of reproliferation in these patients.

**Conclusion**

Silicone oil is an effective endotamponade agent especially in eyes with retinal detachment, associated with proliferative vitreoretinopathy. There are numerous unanswered questions such as how long should SO be placed in the eye, whether eyes with high viscosity are better than low viscosity in term of endotamponade effect and whether high-molecular additives can reduce the risk of emulsification. The Silicone Study revealed that SO is equally effective when compared to C$_3$F$_8$. The decision to use SO or C$_3$F$_8$ should be made on case-to-case basis. In principle, the final anatomical success is dependent on the completeness of removal of proliferating membrane and relief of traction on the retina, while the tamponade agents serve best as adjunct to it.

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HEAVY SILICONE OIL

Introduction
Silicone oil (SO) is an excellent endotamponade agent with a specific gravity of 0.97 at 25°C, which causes the silicone oil to float over the aqueous (specific gravity 1.01).1 Hence it provides good tamponade effect to the superior breaks. Fawcett and associates showed that even a slight underfill of SO leaves a large area of inferior retina unsupported.2 Hence there is a tendency for inflammatory and
cellular proliferation to involve the inferior retina and cause inferior proliferative vitreoretinopathy (PVR). Therefore there was a need for heavier-than-water endotamponade agents.

Fluorinated SO have been tried for temporary inferior retinal tamponade. These agents were associated with high rate of complications such as inflammation and PVR formation. Next, perfluorocarbon liquids (PFCLs) were used as short term tamponade agents in few selected cases such as giant retinal tears. This technique is popular among surgeons in Australia. However the retained PFCL causes inflammation, inferior retinal damage, high intraocular pressure (IOP) and corneal opacification, hence it is not a choice for long term tamponade. Partially fluorinated or semifluorinated alkanes such as perfluorohexylethane (O62) and the high-viscosity oligomer OL62HV, were used initially as intraoperative tools to unfold the retina and as a solvent during removal of silicone oil. Since these agents were found to be physiologically inert and lighter than PFCL, less biological reaction as compared to PFCL was expected if these were used as endotamponade agents. These agents were found to cause various complications – emulsification (almost 100%), inflammatory membranes, severe PVR, necrosis. Hence their use as endotamponade was not pursued. Another method to tamponade the inferior retina was using “double filling” that is combination of SO and fluorosilicone oil, SO and PFCL or SO and perfluorohexyloctane (F₆H₈). Though “double filling” with these agents achieved no aqueous in the interface, it created an aqueous environment in the superior and lateral quadrants of the vitreous cavity. The profile of this combined bubble was found to be “egg-shaped” with poor tamponade effect in the superior quadrant. When the patient was exposed to a cold environment or when the eye was subjected to excessive movements, SO became cloudy due to droplets of F6H8 coming out of the solution. This hampered the patient’s vision. Hence the concept of “double-filling” did not gain popularity.

Heavy silicone oils (HSO)

Newer generation of heavy silicone oils includes three different prefabricated mixtures – Oxane HD, Densiron 68, and HWS 46-3000. Densiron 68 (Fluoron Co, Neu-Ulm, Germany) is a solution of
perfluorohexyloctane (F₆H₈) and 5000cSt silicone oil. Hence the name “Densiron 68” (68 denotes F₆H₈) was coined. It has a specific gravity of 1.06 (higher than water). By mixing these agents, the viscosity of F₆H₈ increases from 2.5 to 1387mPa, this reduces the tendency of F₆H₈ for dispersion, which is one of the major clinical issues with usage of pure F₆H₈ as a long-term tamponade. The clinical experience with Densiron 68 has been extensively reported in the literature especially in the management of complicated retinal detachment. It was removed 2-3 months after tamponade and seemed to be more stable and better tolerated than pure F₆H₈. Wong et al reported the results of Densiron 68 in the management of complicated rhegmatogenous retinal detachment (RRD). They achieved anatomical success in 81% of eyes and a final success of 93% with additional surgery. Visual acuity improvement was seen in 66% of cases at last follow-up. The authors concluded that Densiron 68 may add to the repertoire in managing selected retinal detachments. Sandner and Engelmann treated 48 eyes with RRD with PVR, previous trauma, endophthalmitis and achieved primary success in 46% and final success of 92%. According to them, Densiron 68 has proven to be well worth further evaluation. Densiron 68 was used as a heavier-than-water tamponade in the first multi-centric comparative trial of a heavy versus conventional silicone oil (HSO study). In this prospective, multi-centered, randomized controlled trial, heavy silicone oil tamponade (Densiron 68) was compared to conventional SO in eyes with inferior and posterior PVR grade C or above. All tamponade agents were removed from the eye at 2-3 months after the initial surgery. The study concluded that there was no significant difference between the two groups regarding anatomical success, visual outcomes and adverse effects.

Oxane HD (Bausch & Lomb, Toulouse, France) is a mixture of silicone oil (Oxane 5700; Bausch & Lomb) and a mixed fluorinated and hydrocarbonated olefin (RMN3). It has a specific gravity of 1.02 and a viscosity of 3300cSt. The complication rates were found to be significantly lower than F₆H₈. In some study, Oxane HD was associated with significant emulsification and IOP rise. The redetachment rates were slightly higher as compared to other heavy tamponade agents especially in eyes with previous scleral buckling surgery. It does not produce significant tamponade effect in the area central to the scleral indentation. Oxane HD is the lighest of all...
the newer tamponades, this is thought to be one of the reasons for its lesser efficacy.\textsuperscript{17}

HWS 46-3000 is the heaviest and most viscous of the three tamponade agents, hence emulsification rates are low. The initial reports are encouraging with high success rates and lower complication rates. Due to its higher viscosity, it has associated problems like difficulty in injecting and removal with the small gauge vitrectomy systems.\textsuperscript{27}

**Clinical Applications**

Heavy endotamponade agents are commonly used for complicated RRDs and redetachments. Those eyes with PVR following previous scleral buckling, pars plana vitrectomy, blunt and penetrating trauma can be possible indications for use of these heavier-than-water SO.\textsuperscript{17-20} Eyes without PVR such as giant retinal tears,\textsuperscript{6,9,24,28,29} myopic macular holes with retinal detachment,\textsuperscript{26} and large, multiple, posterior breaks\textsuperscript{15,17,24,25,27,29} can also be managed with HSO. The uncommon indications include tractional retinal detachment with proliferative diabetic retinopathy,\textsuperscript{8,13,28,31} retinoschisis,\textsuperscript{9} endophthalmitis,\textsuperscript{19,32,33} retinopathy of prematurity\textsuperscript{32} and detachment associated with retinal necrosis.\textsuperscript{31}

**Surgical techniques**

Similar to conventional SO, heavy silicone oil can be injected following fluid-air exchange or direct PFCL/heavy SO exchange.\textsuperscript{15,17,26,28,29,30} The technique of HSO injection may be one of the factors responsible for the rate of complications. Generally, air-heavy silicone oil exchange is a preferred method. Due to its higher specific gravity, it can be injected over the posterior pole to unfold the retina and appose the retina to the underlying retinal pigment epithelium in eyes with giant retinal tears without PVR. Some surgeons prefer a direct PFCL-HSO exchange.\textsuperscript{24} However when the PFCL comes in contact with HSO, it might cause contamination of the HSO which may increase the risk of emulsification, inflammation and sticky SO formation.\textsuperscript{25,34,35} In aphakic eyes with HSO, a superior peripheral iridectomy should be done to avoid pupillary block glaucoma.

One of the main advantages of HSO is that it eliminates the need of
additional scleral buckling. This reduces the overall surgical time, prevents complications associated with scleral buckling such as changes in refraction, strabismus, anterior segment ischaemia, buckle infection and extrusion. Also, as mentioned previously, the “lighter” HSO such as Oxane HD do not provide good tamponade effect central to the area with scleral indentation. Eyes in which HSO is used generally have severe PVR and require retinotomies, where the edge of the retinotomies are usually located posterior to the indent where no indentation effect of the buckle is expected. Wong et al have had high success rates with HSO without the additional scleral buckling, while other surgeons achieved excellent results when HSO was combined with buckling. Hence, there is no consensus where scleral buckling is needed in conjunction with use of heavy silicone oil in the management of complicated retinal detachment.

The duration of intraocular heavy tamponade is critical as it is related to the success and complication rates. Removal of the HSO is indicated when the retina is attached and stable, with no inflammation, laser photocoagulation spots become pigmented and retinotomies are scarred. On the other hand, the longer the HSO stays in the eye, the higher the rate of emulsification, which in turn is mainly related to the viscosity of the HSO. With the new generation of heavier-than-water tamponade agents having higher viscosity, better tolerance has been demonstrated. This is indicated by the longer times to removal, for example – Densiron 68 – 108 days to 4 months, Oxane HD – 88 days to 4 months, HWS 26-3000 – upto 3 months. The HSO study recommended to leave the tamponade (Densiron 68) for at least 2 months and to remove it between 2 to 6 months. In the past, HSO removal was done by using a long cannula and high suction. This was associated with risk of retinal injury. Stappler and associates have described a phenomenon known as “tubeless siphoning”. When a bubble is aspirated, extensional flow occurs, which causes the HSO bubble to assume a conical shape such that it is possible to remove all the oil in one go using a short cannula. This property of elongation of the bubble in the direction of the aspiration force is due to the viscoelastic nature of the HSO. The author showed that using a 7mm long 20-gauge polyurethane cannula (Venflon), the HSO can be extracted without the need to reach down to the optic disc or the retina. However to achieve a complete removal of HSO, it is essential
that the tip of the cannula or needle should not come out of the heavy oil bubble at any stage. If this does happen, then there is discontinuity of the “siphoning” effect and the smaller bubble over the retina needs to be removed by using a longer cannula. Removal of HSO with short small gauge cannula such as 23gauge has also been described.38 Smaller HSO droplets have a tendency to sink to the posterior pole, where these can be aspirated by passive or active suction.

Complications

Both Densiron 68 and Oxane HD have been found to be well tolerated in patients, and have fewer complications even if these agents have been left in the eye for a long duration. However Oxane HD does show lack of homogeneity as there is tendency for the olefin RMN3 to come out of the solution when the patient is exposed to cold environment or when the solution is vigorously agitated. Hence it is advisable to avoid Oxane HD. Though Densiron 68 does not share these issues of homogeneity, it does have problems similar to the conventional SO. It does not conform to the contour of the vitreous cavity. In eyes with scleral buckling, HSO does not support the retina on the slope.

Corneal complications

There are no reports of possible corneal toxicity with the new generation of heavy silicone oils – Densiron 68, Oxane HD, HWS 46-3000. The reported corneal problems such as corneal stromal and epithelial edema have mostly been associated with use of F6H8. Sandner et al reported one case of a corneal graft failure following vitrectomy with Densiron 68, but the causal relationship could not be established.20 Thus, currently corneal complications are not considered typical complications associated with intraocular use of HSO, but oil keratopathy may occur if the AC is filled with HSO.

Cataract

Significant cataract progression is known to occur in almost all phakic patients treated with vitrectomy and HSO.39 In eyes with pseudophakia, HSO causes rapid opacification of the posterior capsule.40 Wong and colleagues have shown that all patients developed nuclear cataract with posterior subcapsular cataract during the early postoperative
In eyes treated with $F_6H_8$, Kirchhof and associates observed feathery posterior subcapsular opacification in 90% of the eyes. It has been suggested that foreign body reaction to the emulsified tamponade triggers an increased cellular proliferation in the lens, when the lens is in contact with the heavy silicone oil. Since cataract formation with use of HSO is unavoidable, some surgeons perform phacovitrectomy and intraocular lens implantation in all eyes where HSO use is deemed necessary. This facilitates dissection of anterior vitreous membranes, vitreous base shaving and provides media clarity throughout the postoperative period. Another approach is to leave the crystalline lens in situ during the initial surgery if possible. Later a combined removal of the HSO with phacoemulsification, IOL implantation and posterior surgical capsulotomy can be done.

Intraocular inflammation

Early clinical reports of heavy tamponade agents were highlighted by the relatively high rates of intraocular inflammation, such as fibrin and retro-pupillary membrane formation. This led to the discontinued use of agents such as O62. It was postulated that heavy tamponades would aggravate PVR rates by amplifying wound healing response. Theelen et al noted keratitic precipitates and granulomatous anterior chamber inflammation in 37% of cases, which did not resolve with topical steroid therapy, when Oxane HD was used as a tamponade agent. Wong and colleagues observed moderate anterior chamber inflammation in 8% of eyes with Densiron 68. Similarly, Sandner and Engelmann reported mild to moderate reaction in 21% (10/48 eyes), however intraocular fibrin developed in six cases and two cases developed a severe intraocular inflammation with sterile hypopyon. All eyes showed resolution of inflammation with topical anti-inflammatory therapy. Majid et al reported a lower rate of inflammation in their series of eyes managed with Densiron 68, a single case of severe fibrinous uveitis out of 40 eyes. No patients with intraocular inflammations were seen following HWS 46-3000 intraocular tamponade.

Posterior segment inflammation has also been described with heavy endotamponade agents. The risk factors include emulsification of the heavy tamponade agent, causing a foreign body-type inflammation.
“contamination” of the tamponade agent by perfluorocarbon liquid used during intraoperative maneuvers,\textsuperscript{25} vigorous physical activity causing mechanical trauma of the tamponade agent.\textsuperscript{33} These risk factors are mainly related to use of semifluorinated alkanes and alkenes. Pigmented clumps on the back of the crystalline lens following F\textsubscript{6}H\textsubscript{8} tamponade,\textsuperscript{28} fluffy material on the anterior surface of the tamponade,\textsuperscript{8} “pea soup vitreous” following vigorous physical activity\textsuperscript{33} and whitish precipitates on the posterior lens surface\textsuperscript{9} have also been described. No cases of severe posterior segment inflammation have been reported in eyes managed with Densiron 68, Oxane HD or HWS 46-3000.\textsuperscript{2,17,20,24,27,43}

**Emulsification**

Emulsification is a phenomenon of clinically visible separation of small droplets from the ideally single large bubble of an intraocular liquid tamponade agent. The emulsification can have the following undesirable effects

1. Reduced tamponade effect – decreased tamponade bubble size.
2. Visually disturbing droplets – attached to lens, capsular bag, intraocular lens, sometimes presenting as a hypopyon
3. Inflammation and PVR formation – foreign body response with fibrin formation, whitish precipitates or epiretinal PVR membranes
4. Glaucoma – due to mechanical blockage of trabecular meshwork leading to secondary open angle glaucoma
5. Difficulty in removing sticky droplets, which remain adherent to the posterior lens capsule in phakic eyes.

Hoerauf et al observed 100% emulsification starting 2 weeks after injection of O62.\textsuperscript{9} Similarly Gerding and Kolck noted 100% emulsification with F\textsubscript{6}H\textsubscript{8} during removal of oil, this is related to the low viscosity of F\textsubscript{6}H\textsubscript{8} (1-2cSt).\textsuperscript{32} Rate of emulsification varies with the new HSO. With Oxane HD, Rizzo et al\textsuperscript{13} and Wolf et al\textsuperscript{24} demonstrated no emulsification with the tamponade in situ. In contrast, emulsification of Densiron 68 was noted in 15% -20% of eyes.\textsuperscript{17,21} No emulsification
was observed with the new HWS 46-3000. The rate of emulsification is mainly dependent on the viscosity, and various other patients factors such as extent of blood-ocular barrier breakdown, inflammation, presence of phospholipids and other surfactants.

**Sticky silicone oil and subretinal tamponade**

Heavy tamponade oil can stick to posterior capsule, undersurface of the iris, ciliary body, and the retina. This could be due to presence of residual vitreous left behind during the vitrectomy. “Contamination” by PFCL might cause the physical properties of HSO rendering them more likely to adhere to various intraocular surfaces. Subretinal remnants of F$_6$H$_8$ have been observed to cause retinal atrophy in the area of the residual bubble. Sim and Hero have described a single case of sticky SO in a phakic eye injected with Oxane HD. There have been no reports of such complications with Densiron 68 and HWS 46-3000.

**Persistent hypotony**

Chronic hypotony is the most dreaded complication of complicated RRD. It is usually caused by persistent retinal detachment, membrane proliferation over the ciliary body with ciliary detachment, atrophy of the ciliary processes, recurrent PVR and extensive surgical retinectomy. Another plausible explanation could be that the foreign body reaction to heavy tamponades such as F$_6$H$_8$, triggers increased membrane formation with subsequent detachment, PVR and cyclitic membranes. Gerding and Kolek noted a very high rate of hypotony of 81% in their series of 16 patients with F$_6$H$_8$ tamponade. The reported rate of hypotony with Densiron 68, Oxane HD and HWS 46-3000 are between none and 8% and are similar to that with the conventional silicone oil. Thus, there are no indicators to suggest that HSO are associated with higher rate of chronic hypotony as compared to conventional silicone oil.

**Increased intraocular pressure**

The mechanism of acute rise in intraocular pressure (IOP) in the early postoperative period with HSO use is theoretically similar to that seen with conventional SO. The commonest causes of increased IOP are
pupillary block glaucoma in aphakic eyes and overfilling of HSO. A superiorly placed peripheral iridectomy is effective in preventing pupillary block glaucoma. In eyes where encircling band is placed in combination with HSO tamponade, the encircling band should be tightened before injection of HSO. This prevents overfilling of HSO and rise in IOP.

The causes of chronically raised IOP are – intraocular inflammation, blockage of the trabecular meshwork by emulsified droplets and steroid response. Rate of persistent high IOP are - for Oxane HD – none to 18%,25,35 for Densiron 68 – 8 to 19%,17,19,20 and for HWS 46-3000 – one out of 32 treated.27 Topical antiglaucoma medications are useful for IOP control in mild to moderate cases. For severe cases and those non-responsive to antiglaucoma therapy, removal of the HSO, washout of droplets from the anterior chamber may be tried. Eyes that fail to respond to this treatment eventually require antiglaucoma surgery.

**Redetachment of retina and PVR**

Redetachment following HSO usage commonly occurs in the superior half of the retina,9,15,17,32 although inferior retinal detachment has also been published.19 Redetachment can occur after the HSO removal or even with the HSO in situ.15,17,29,30,32 However, total redetachment with HSO in situ is uncommon, as usually the inferior retina and posterior pole remain attached. The superior retina with HSO tamponade is the most common site of PVR formation, in contrast to the inferior retina with conventional SO.15,17,29,32 Macula off redetachments occur less frequently with HSO tamponade than with conventional SO, perhaps due to better tamponade effect over the posterior pole when the patient is supine.17,22 Most surgeons think redetachments following HSO use are easier to treat because these involve the superior retina and are more amenable to intraocular gas tamponade than following conventional SO tamponade. The redetachments with HSO in situ are mainly caused by PVR rather than new breaks or insufficient tamponade of the pre-existing retinal breaks. Wong and associates have suggested HSO tamponade can be used to treat cases with redetachment due to failure of conventional SO tamponade. They suggested that long-term anatomical success could be achieved with sequential filling
with conventional tamponade followed by HSO tamponade (or vice versa). The authors achieved 100% anatomical success by following this strategy and concluded that this approach helped to reduce the number of reoperations in complicated RRD.22

Uncommon complications
There are anecdotal reports of some uncommon complications with unclear association with heavier-than-water tamponade. These include one case of ischaemic optic neuropathy,19 central retinal artery occlusion,24 scattered retinal haemorrhages,24 retinal necrosis8 and optic atrophy with no perception of light.8

Conclusion
Heavier-than-water tamponades were developed as postoperative tool for treatment of complex RRD of the inferior fundus periphery. Early heavy endotamponade agents such fluorosilicone oils, perfluorocarbons, semifluorinated alkanes, and semifluorinated alkanes were associated with high complication rates and were not found to be suitable agents. Newer generation of heavy tamponade agents or heavy silicone oil (HSO) – Densiron 68, Oxane HD, HWS 46-3000 have lower complication rates and have better in vivo tolerability. The multicenter, randomized controlled “Heavy Silicone Oil Study” has demonstrated that there was no significant difference between eyes treated with Densiron 68 versus eyes treated with conventional silicone oil in terms of anatomical success, visual success and adverse effects. There is enough clinical data to indicate that Densiron 68 is well tolerated. Heavy silicone oils add an effective postoperative endotamponade agent to the surgeon’s repertoire for management of complex RRD of the inferior retina.

Heavy Silicone oil

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Complications of MIVS

Manish Nagpal

Vitrectomy has evolved into a high technology based surgery over the years. Since its introduction in 2002, microincision vitrectomy has been gaining in popularity amongst retinal surgeons for the surgical management of a wide variety of vitreoretinal disorders. MIVS allows for more efficient surgery, faster recovery times, reduced postoperative inflammation, and good visual outcomes compared to 20-G. However, the advancement in technology and techniques bring in newer complications that need to be dealt with.

A. INTRAOPERATIVE COMPLICATIONS:

1. Rise of IOP:
A theoretical risk of increased IOP to above 60 mmHg during port construction has been proposed in patients with compromised intraocular blood flow. Moreover, increased intraocular pressure during the placement of trocar cannulas can put undue stress on prior corneal or limbal wounds such as in eyes that have had sutureless cataract surgery or recent corneal transplants. Suture closure of any recent corneal and scleral wounds before trocars are inserted may be desirable. Wu PC et al have proposed a simple modification of the twisting manoeuvre for sutureless vitrectomy trocar insertion to reduce IOP.

2. Cannula retraction:
Intraoperative retraction of the infusion cannula is known to occur leading to serous or haemorrhagic choroidal detachment in about
3.5% of the cases as reported by Tarantola et al. It is more common in repeated surgeries and during scleral depression.

3. Retinal break formation:
Retinal breaks may occur following direct mechanical trauma or due to vitreous traction during removal and introduction of instruments or due to excessive pull on existing traction bands. The rate of retinal tears discovered during sutureless vitreous surgery has been reported to be between 0 and 24%, with most series reporting an incidence of less than 5%. Some studies have reported a higher incidence with 25-G (15.8%), while other studies found lesser incidence compared to 20-G.

4. Damage to adjacent structures:
Inadvertent damage may occur to structures adjacent to the site of sclerotomy. Lens damage, ciliary detachment, or vitreous base dialysis may occur while making the sclerotomy or during insertion or removal of instruments. The internal opening of the infusion cannula is to be well within the vitreous cavity, prior to starting the infusion, especially in cases with choroidal thickening. A subretinal infusion cannula, once started can be disastrous for the surgeon.

B. POSTOPERATIVE COMPLICATIONS:

1. Wound leak/hypotony
The reported rates of postop hypotony with MIVS ranged from 3.8 to 16 percent. Hypotony at the early postoperative period may be a risk factor for a ciliochoroidal detachment, bleeding, vitreous enhancement, and re-surgery for wound apposition. With the straight incisions, wide-open wounds are found regardless of the pressure in the eye. In contrast, the angled incisions are apposed and closed, regardless of the pressure. Fluid air exchange at the end if surgery also helps in closure of sclerotomy. Misalignment between conjunctival and scleral wounds also help in reducing hypotony. Removing the cannula at an angle similar to the angle of entry helps maintain wound architecture. When removing the cannula, place a solid instrument into the wound first, like a light pipe, and then remove the cannula over this
solid instrument. This is helpful to prevent suction and vitreous wick. Alternatively, the cannula can be removed with a plug in place. Wound leaks can also cause conjunctival ballooning with air, gas or oil.

2. Wound healing
With the 23 and 25 Gauge angled incisions, the closure of the outer lip of sclerotomy is visible by AS- OCT even on the first post – operative day.

3. Cataract
Irrigating solution, contact of SF6 gas bubble with the lens can produce cataract. The incidence of cataract following vitrectomy is high. The over oxygenation of lens after removal of normal vitreous barrier to diffusion of electrolytes may be a hypothesis.

4. Endophthalmitis:
Post operative endophthalmitis is a rare, albeit serious complication of vitrectomy, initially suspected to occur more frequently after sutureless vitrectomies. In 2005, Taylor et al\textsuperscript{9} reported the first case of endophthalmitis after a 25G sutureless vitrectomy. Similar case report was published by Taban et al\textsuperscript{10} in 2006.

Those authors assumed that open sclerotomies, combined with use of low flow rate cutters facilitated the invasion of bacteria to the vitreous cavity. Other factors that may play a role include post-surgery subconjunctival antibiotics, intraoperative use of corticosteroids, and whether or not a partial or complete air-fluid exchange was performed at the end of surgery. Incomplete removal of the peripheral vitreous skirt has also been hypothesized to result in bacterial in-growth,\textsuperscript{11} possibly predisposing the patient to endophthalmitis.

Various comparative studies between 20G and 25G reported a 12 fold to 28 fold\textsuperscript{12, 13} increases in the occurrence of endophthalmitis. But, later studies did not support this finding.

Parolini et al\textsuperscript{14} and Gupta et al\textsuperscript{15} found no case of endophthalmitis after vitrectomy with the 23G sutureless system.

Overall the recently published large retrospective studies do not
indicate that sutureless small-gauge vitrectomy is associated with higher rates of endophthalmitis than in 20G vitrectomy.

5. Vitreous haemorrhage:
Vitreous haemorrhage, primary or recurrent, is a common complication after diabetic vitrectomy. Intraoperative bleed may be prevented by avoiding the vascular component of proliferations while attempting to remove the surrounding traction or by use of prophylactic coagulation. Temporary increase in the infusion pressure or use of endodiathermy usually controls the bleed. Complete removal of the posterior vitreous cortex reduces the risk of haemorrhage by removing the scaffold necessary for proliferation of new vessels.

UBM has been able to detect FVIG (fibrovascular ingrowth) in a high proportion of cases and its use has been advocated as an aid in planning resurgeries. In diabetic vitrectomy, along with PRP, ARC with cryotherapy of sclerotomy sites reduces the incidence of FVIG and post vitrectomy diabetic vitreous haemorrhage (PDVH).

Fluid-gas exchange and vitreous cavity lavage are popular, less invasive methods of treating this kind of recurrent vitreous haemorrhage and may be needed in some cases. However, these methods do not immediately clear vision and have even appeared to exacerbate cataract formation.

Use of intravitreal injection of 30ug of tPA for lysis of post vitrectomy blood clot, administered 4 days prior to the vitreous cavity lavage, has shown an immediate clearing of the vitreous cavity in 80% of eyes. Post vitrectomy tamponade with 10% C3F8 may also be a useful adjunct in the reduction of early PDVH.

6. Vitreous incarceration and retinal detachment:
Iatrogenic retinal breaks leading to post operative RD is a serious complication of vitrectomy. Breaks are more common anterior to the equator and majority of these occur in relation to the sclerotomy site. Following scleral penetration in PPV, vitreous incarceration is seen in all cases histopathologically. Often this is related to high flow rate of infusion fluid and associated increase in intraocular pressure.
Use of an external diaphanoscopic illuminator doubling up as an indenter can help in removal of peripheral vitreous or incarcerated vitreous from sclerotomies. Traction on the retina should be minimized by using higher cut rates and lower suction especially near the vitreous base. The use of vital dyes has led to better visibility of the internal limiting membrane, epiretinal membrane and the posterior hyaloid, potentially making their removal more controllable, easier and safer.

Though postoperative retinal detachment following microincision sutureless PPV has been reported in several studies, the investigators concluded that development of retinal detachment did not directly result from the microincision 23G or 25G technique.18

C. OTHER COMPLICATIONS:

1. Fibro-vascular ingrowth
2. Lens related complications
3. Jamming & breakage of vitrectomy cutter
4. Retinal toxicity with subconjunctival gentamicin
5. Visual field defects
6. Photic injury
7. Conjunctival pigmentation
8. Macular infaction

References:


Transition to MIVS- Conclusions and practical pearls

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Just as phacoemulsification has become the norm rather than an option, MIVS using smaller than 20 gauge instruments has become the norm rather than exception. Although initially, MIVS was used only for macular surgery, with increasing experience and availability of instruments, most vitreo retinal problems can be handled through small gauge approach. Very little readjustment is required for adopting 23-gauge vitrectomy. However 25-gauge vitrectomy needs a little more readjustment and 27-gauge would need a lot more readjustment to balance between the fragility of the instruments and their ability to execute all the maneuvers required in complex vitreo retinal surgery. The surgeon should not be fixed with the idea of not having sutures and to only use MIVS for all cases. The ability to use 20- gauge vitrectomy is as important for the vitreo retinal surgeon as is the ability to perform a good extracapsular cataract extraction for the cataract surgeon. The following paragraph lists some random points of interest for the practicing vitreo retinal surgeon.

1. While transferring the trocar and cannula from the table for use, it is useful to keep the tip of the instrument facing up. Facing the tip down can lead sometimes to the cannula falling off and becoming non usable.

2. In eyes with narrow palpebral fissure, the sclerotomies should
be positioned very close to the horizontal meridian to avoid lid becoming an obstacle for the surgery.

3. In eyes with shallow fornices, indenting the periphery may not be always convenient while performing MIVS since the fornix is intact and the indenting instrument may not slide deep enough to indent the peripheral retina.

4. Surgeon must be conscious of the possibility of the cannulas slowly slipping out of the sclerotomy during the surgery. This is not an issue with the active sclerotomies as much as it is with the infusion cannula.

5. Introducing the trocar in a soft eye could be an issue. It is best to form the eye by injecting BSS using a 30-gauge needle before this step.

6. In eyes with weak anterior segment wounds (eg. recent cataract surgery with corneal wound), the wound should be secured first with 10-0 nylon sutures before placing the cannula. Failure to do so can potentially result in iris prolapse, hyphema, vitreous prolapse, IOL displacement and choroidal hemorrhage.

7. In a previously vitrectomised eye, the second and third sclerotomies can be difficult to make, despite the infusion having been turned on. This is due to the facility with which the intraocular fluid escapes refluxes into the infusion cannula on pressure on the eye. This progressive softening of the eye makes it difficult to make the sclerotomy. This can be avoided by temporarily pinching the infusion and making the globe a closed chamber while penetrating with the trocar.

8. Before fluid air exchange, one must be certain about the location of the infusion cannula. Silent slippage of the cannula can potentially occur leading to supra choroidal air injection with disastrous results.

9. ‘A stitch in time saves nine’ is an adage that can be applied to MIVS as well. Failure to place a stitch when there is a leaking sclerotomy can potentially lead to complications of hypotony and increase the risk of infection.