

Review Article

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The Role of 8% C₂F₆ as an Alternative Gas Tamponade to SF₆ in Vitreoretinal Surgery to Reduce Environmental Impact of Healthcare Services

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Background

The use of air as an intraocular tamponade was first described by Ohm in 1911 where two patients with retinal detachments were successfully treated with intravitreal injections of air as an adjunct, although the term “tamponade” was not used [1]. Rosengren subsequently described the successful use of air as an intraocular tamponade in patients with rhegmatogenous retinal detachment with an 75% success rate [2]. However, the use of air as an intraocular tamponade was insufficient in providing a tamponade of sufficient duration against retinal breaks in rhegmatogenous retinal detachments as air often dissipated before adequate chorioretinal adhesions were formed. This led to the search for a longer acting intraocular gas tamponade by Fineberg, who showed that in owl monkey eyes, sulfur hexafluoride (SF₆) at varying concentrations (30%-60%) remained twice as long in the vitreous cavity compared to air (9-11 days) vs (5-6 days) [3].

SF₆ was discovered by Henri Moissan and Paul Lebeau in 1901. It's inert nature and lack of toxicity to the retina combined with its ability to remain in the vitreous cavity for 9-11 days makes it ideal as a short-duration intraocular tamponade in retinal surgery as it allows sufficient time for chorioretinal adhesions seal the edge around the retinal tear by preventing fluid ingress into the retinal tear [4,5]. Other popular intraocular gases in use in vitreoretinal surgery include perfluoroethane (C₂F₆, ‘medium-duration’) and perfluoropropane (C₃F₈, ‘long-duration’) which last on average 34 days and 67 days respectively in the vitreous cavity when used at isovolumetric concentrations of 20% C₂F₆ 15% C₃F₈, [6].

These gases which are less soluble in water expand when injected into the vitreous cavity in their pure forms. Oxygen (O₂), Carbon Dioxide (CO₂) and Nitrogen (N₂) diffuse into the gas bubble filled vitreous cavity from the surrounding tissues more rapidly than these gases can diffuse out. This results in a net expansion of the gas bubble which continues until the steady state of partial pressures of O₂, CO₂, N₂ inside and outside the bubble are reached. When the partial pressure of N₂ equilibrates with that in the surrounding tissue, the second phase begins. During this time N₂ from the surrounding tissues continue to enter the bubble. However, because the rate of the long-acting gas leaving the bubble is greater than N₂ entering the bubble, the volume of bubble decreases. The gradual dissolution of the bubble happens

as there is an efflux of gases in the bubble according to first order exponential decay [7-9].

Gases used as intraocular tamponade in vitreoretinal surgery (SF₆, C₂F₆, C₃F₈) are known as fluorinated gases. They are used in a wide range of industrial applications, mainly as substitutes for ozone-depleting substances such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons which are being phased out under the Montreal Protocol and EU legislation due to their greenhouse effect [10,11]. These fluorinated gases are controlled by the European Union as they contribute towards global warming. Their contribution can be measured in terms of global warming potential which compares the greenhouse effect of a unit mass of a particular gas over a specific period of time to that of CO₂, known as the carbon dioxide equivalent (CO₂e) Under the Montreal Protocol and EU legislation, the goal is to reduce the use of these fluorinated gases by two-thirds by 2030 compared to 2014 levels [11].

In September 2019, the Intergovernmental Panel on Climate Change (IPCC) listed SF₆ as a greenhouse gas with a global warming potential 23,900 times greater than that of CO₂ over a 100year period, and being a synthetic gas, it is not absorbed or destroyed naturally [12]. Compared to the other fluorinated gases, SF₆ has the highest global warming potential and has an atmospheric lifespan of 3200 years [13]. SF₆ is mainly used in the electrical industry as dielectric insulation of electrical equipment, semiconductor processing, window insulation, metal casting and audio equipment. Due to its widespread use in the industry, the concentration of SF₆ in the atmosphere is expected to rise and has more than doubled from 4.5 parts per trillion in 2000 to 10 parts per trillion in 2019 [14].

Despite the relatively small amount of SF₆ used in healthcare and specifically vitreoretinal surgery in comparison to the manufacturing industry, a reduction in the amount of SF₆ emissions would help reduce the carbon footprint contributed by vitreoretinal surgery to the environment even if by a small amount. As such, our group has been using a lower concentration of C₂F₆ to replace the use of SF₆ as a short-duration intraocular gas tamponade. This study aimed to clearly define the duration of intraocular tamponade of a reduced concentration (8%) C₂F₆.

Methods

Surgical Procedure

The study was a prospective case series. Patients undergoing vitreoretinal surgery at Sussex Eye Hospital between August 2019 and April 2020 for retinal detachments, vitreomacular traction, epiretinal membrane surgery were identified. All patients were operated on by three surgeons (FMC, EHH and HM) using 23G pars plana vitrectomy using the Constellation (Alcon Laboratories Inc., Fort Worth, TX) sutureless 23-gauge (G) vitrectomy system and a noncontact wide viewing system, the Resight 700 (Carl Zeiss Meditec AG, Jena, Germany). Phacoemulsification was combined concurrently at the surgeon’s discretion.

Intraoperatively, the suitability of the patients for 8% C₂F₆ were assessed. Patients who would otherwise have SF₆ gas tamponade had 8% C₂F₆ tamponade instead. This inclusion criteria included the location of the retinal breaks in patients with retinal detachment, the duration of the tamponade required and the ability of the patient to note the exact date where the bubble disappeared.

Data Collection

The following baseline characteristics were collected: age, sex, Intra Ocular Pressure (IOP), percentage gas fill, indication for surgery. Patients were seen at week 1, month one post- surgery and two months post-surgery to assess primary reattachment rate.

The percentage of gas fill at week 1, and two-months post-surgery was noted. Patients were asked to note down the exact date the bubble disappears from their sight. This date signified the exact date of the bubble dissolution.

Results

A total of 32 patients were recruited in this study from August 2019 to April 2020. A total of 5 patients were excluded from the study as they were unable to recall the exact date of the gas bubble disappearance from their vision. Out of the 27 patients who had 8% C₂F₆ as an intraocular tamponade, 18 (67%) of the patients had a rhegmatogenous retinal detachment, of which 11 out of 18 were macula off retinal detachments (61%). The rest of the patients had epiretinal membranes (n=3), macular holes (n=3), submacular haemorrhage (n=2) and vitreomacular traction (n=1).

The percentage of 8% C₂F₆ in the vitreous cavity at week one ranged from 40% to 70%, with a mean of 58% (Standard deviation +/- 8.8%). The mean number of days for complete disappearance of the 8% C₂F₆ bubble was 27.6 days (Standard deviation +/- 3.6 days) with a range of 21-32 days. All the patients enrolled in this study were followed up for a minimum of 2 months. Out of the 27 patients enrolled in this study, one patient had a retinal redetachment secondary to proliferative vitreoretinopathy requiring further surgery.

Table 1: Indications for Patient Recruitment in Study, Including Percentage Gas Fill at Week 1 and days to Complete Disappearance of Gas Bubble and Post-Operative adverse Events.

	Procedure	Percentage Fill (at Surgery)	Week 1 fill	Days to Disappearance	Adverse Events
1	Combined cataract/ Epiretinal membrane	60% fill	40%	26 days	Nil
2	Macular Hole	Complete fill	60%	26 days	Nil
3	Sub macular bleed	50% fill	40%	21 days	Nil
4	Retinal detachment (Macula off)	Complete fill	60%	30 days	Nil
5	Combined cataract/ Epiretinal membrane	50% fill	40%	30 days	Nil
6	Chronic retinal detachment (Macula on)	Complete fill	60%	28 days	Nil
7	Epiretinal membrane + Pseudohole	80% fill	60%	29 days	Nil
8	Retinal detachment (Macula off)	Complete fill	70%	26 days	Nil
9	Retinal detachment (Macula on)	Complete fill	60%	24 days	Nil
10	Vitreous haemorrhage with Macula on Retinal detachment	Complete fill	60%	27 days	Nil

11	Vitreomacular traction	80% fill	60%	27 days	Nil
12	Retinal detachment (Macula off)	Complete fill	70%	26 days	Nil
13	Retinal detachment (Macula off)	Complete fill	60%	29 days	Nil
14	Retinal detachment (Macula off)	Complete fill	60%	28 days	Nil
15	Retinal detachment (Macula off)	Complete fill	60%	28 days	Nil
16	Retinal detachment (Macula on)	Complete fill	70%	22 days	Nil
17	Retinal detachment (Macula off)	Complete fill	70%	29 days	Nil
18	Retinal detachment (Macula off)	Complete fill	65%	29 days	Redetachment 6 weeks post op secondary to PVR
19	Retinal detachment (Macula off)	Complete fill	60%	30 days	Nil
20	Retinal detachment (Macula off)	Complete fill	60%	28 days	Nil
21	Vitreous haemorrhage with Retinal detachment (Macula on)	Complete fill	60%	28 days	Nil
22	Retinal detachment (Macula off)	Complete fill	40%	42 days	Nil
23	Retinal detachment (Macula on)	Complete fill	60%	28 days	Nil
24	Sub macular bleed	Complete fill	60%	30 days	Nil
25	Macular hole	Complete fill	60%	28 days	Nil
26	Retinal detachment (Macula on)	Complete fill	60%	27 days	Nil
27	Macular hole	Complete fill	50%	26 days	Nil

Discussion

Despite the small contribution of vitreoretinal surgery to greenhouse gas emissions in comparison to other industries, it is still imperative to explore alternate means of reducing our carbon footprint. In designing this study, we looked at the global warming potential of these gases, and the lifetime of these gases in the atmosphere. Of these three intraocular gases used in vitreoretinal surgery, SF₆ has the highest global warming potential of 23 900, followed by C₂F₆ 11 900, and C₃F₈ 8600. The lifetime of these gases in the atmosphere the longest in the atmosphere being C₂F₆ followed by SF₆ (3200 years) and C₃F₈ (2600 years) which is shown in the table below [15].

Table 2: Properties of SF₆, C₂F₆ and C₃F₈

	Concentration used in PPV (%)	Approximate Time to Resorb from Eye (Weeks)	100-YEAR GWP	Lifetime
SF ₆	20-24	2	22200	3200
C ₂ F ₆	16	5	11900	10000
C ₃ F ₈	14-16	8-10	8600	2600

From the table above, C₂F₆ would be a suitable choice as an intraocular tamponade in terms of selecting a gas with a lower global warming potential and less restrictive to the patient in terms of time taken for complete gas resorption for recovery of visual

potential and air travel limitations. Hence our group chose 8% C₂F₆ as the gas concentration

Our study shows that 8% C₂F₆ can be successfully used and is an appropriate substitute for 24% SF₆ in patients who required a longer intraocular tamponade than air, with intraocular volumes at week one comparable to that of 24% SF₆ at week one post operatively. To our knowledge, this is the first study looking at the time to complete resorption of reduced intraocular gas concentrations of C₂F₆ in clinical subjects. Our group is also in the process of studying lower concentrations of C₃F₈ which may have the most favourable environmental profile of the three widely available fluorinated gas tamponade options.

In exploring various other intraocular tamponades for vitreoretinal surgery, various groups have explored the use of air as a substitute for fluorinated gases with success [16-18]. The advantage of air would be the lack of use of fluorinated gases which contribute towards carbon emissions, quicker visual recovery and reduced duration of patient positioning. However, in rhegmatogenous retinal detachments with multiple breaks or larger macula holes where patient positioning may be problematic, a longer tamponade may be beneficial.

In order to reduce the amount of greenhouse gases expelled into the atmosphere during vitreoretinal surgery, the use of gas cylinders would play a role in generating less greenhouse gaseous release to the atmosphere compared to that of single use cannisters which are discarded after every use. To quantify the amount of greenhouse gas emissions reduced by substituting SF₆ with C₂F₆, we calculated the emissions produced by 100 single use cannisters (30mL) of SF₆ and compared that to 100 cannisters of C₂F₆ (assuming complete release of 30mL into the atmosphere). The total of CO₂e equivalent emissions came to 0.661 metric tonnes of CO₂e for SF₆ (0.02901kg SF₆) compared to 0.317 metric tonnes of CO₂e in C₂F₆ (0.2601kg C₂F₆). This difference in gas substitution alone equates to 0.344 metric tonnes of CO₂e which is equivalent to 854 miles driven by an average passenger vehicle [19]. This reduction in CO₂e by the substitution of SF₆ with C₂F₆ may seem rather modest in comparison to the emissions of that by the electrical industry, however these figures were calculated by assuming the substitution of 100 cannisters of SF₆ gas (30mL each). A tertiary vitreoretinal unit would in most likelihood use more than 100 cannisters annually hence standing to reduce CO₂e even further.

In the UK the NHS is responsible for 5% of all carbon emissions in the UK. In 2015 the carbon footprint of the NHS in England was 22.8 million metric tonnes of CO₂ which is equivalent to the greenhouse gas emissions of 11 coal-fired power stations [20]. Its emissions are not much lower than both those for aviation, agriculture forestry and landuse in the UK (6.5% each) [21].

The NHS was one of the first healthcare systems to produce a carbon reduction strategy, the national strategy and its 2010 update set out targets for reducing carbon dioxide equivalent emissions (CO₂e) in the NHS as follows

- A 10% reduction of CO₂e emissions by 2015 (based on 2007 baseline data) from 21MtCO₂e to 19Mt CO₂e
- A 34% reduction of CO₂e by 2020 from 1990 baseline
- An 80% reduction of CO₂e by 2050 from 1990 baseline [20].

In 2020, the estimated percentage of carbon emissions in the NHS had reduced by 62% compared to 1990 and the NHS has now pledged to be the world's first carbon net zero national health

system by the year 2040 by adopting a multiyear plan [22]. In facilitating the plan for the NHS to be a carbon net zero national health system, it is essential for all parts of the NHS to play their role in reducing their carbon footprint and as vitreoretinal surgeons, this could be as simple as using alternative gaseous tamponade.

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