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EDITORIAL

Reducing the use of fluorinated gases in vitreoretinal surgery

Eye (2024) 38:229–232; https://doi.org/10.1038/s41433-023-02639-0

The concluding report of a year-long Commission conducted by *The Lancet* states that climate change is the most significant health hazard facing the world in the 21st century [1]. It was also thought that we are the first generation to feel the effect of climate change and the last generation who can do something about it [2].

The healthcare industry is responsible for an estimated 4.4% of global carbon emissions, which places it as the fifth-largest emitter worldwide [3]. In October 2020 the NHS became the first national health system pledging to attain 'net zero' emissions, a target it aims to achieve by 2040 [4]. Ophthalmologists have a role in making changes to mitigate our carbon footprint. One potential action is to consider our use of fluorinated gases ('F-gases') [5].

In the UK, sulphur hexafluoride (SF_6) is the most commonly used gas tamponade for rhegmatogenous retinal detachment (RRD) repair, followed by hexafluoroethane (C_2F_6) and perfluoropropane (C_3F_8) [6, 7]. SF_6 is a short-acting gas dissolving within 2–3 weeks after a full vitreous cavity fill; as compared to 4–5 weeks for C_2F_6 and 9–10 weeks for C_3F_8 [8]. The short tamponade duration is useful to avoid prolonged visual disability.

They are also potent greenhouse gases (GHG), SF_6 in particular has a warming potential 23900 times that of carbon dioxide (CO_2) over a 100-year period and an atmospheric lifetime of 3200 years [9]. In comparison, C_2F_6 and C_3F_8 are less potent GHG, with 9200 and 7000 times of CO_2 respectively over 100 years. As such, there have been suggestions that surgeons could use dilute C_2F_6 or C_3F_8 instead of 20% SF_6 to duplicate its characteristics with less GHG effect [10]. 8% C_2F_6 has been used in one UK Ophthalmology unit and is currently the tamponade choice as substitute for 20% SF_6 [11]. Air has the least GHG effect and has been used in vitrectomy for RRD repair with success rate ranging from 79% to even 100% [12]. Despite this, air tamponade only accounted for less than 1% of the tamponade used for RRD repair in the UK in the British and Eire Association of Vitreoretinal Surgeons (BEAVRS) database study [6]. One study comparing gas and air tamponade suggested that gas tamponade is superior to air in inferior pathology [13]. However at least one RCT and a systematic review have shown no difference, although there is a lack of high-quality data [14–16].

Tamponades are thought to promote retinal reattachment by closing retinal breaks related to their buoyancy and surface tension. Permanent closure occurs after chorioretinal scar formation in 5–10 days following surgery, faster with intraoperatively applied laser than cryotherapy. The ease of closure depends on the retinal contact area and the position of the break. Whilst superior breaks are easily closed, inferior breaks require more positioning aided by a larger bubble whilst adhesion is established. Gas kinetics are therefore key to considering the efficacy of tamponades.

To assess air and various diluted concentrations of C_2F_6 or C_3F_8 as potential substitutes mimicking 20% SF_6, we used a validated simulated model of gas kinetics in human eyes [17, 18]. We calculated predicted maximum volumes, time to maximum volume, duration of gas in vitreous cavity and percentage gas fill on various days postoperatively with the corresponding retinal contact angle using data from Fawcett et al. [19]. 4.0, 7.2 and 10.0 ml vitreous cavity volumes were used to represent hypermetropic, emmetropic and myopic eyes respectively [20]. We assumed a 75% fill of the vitreous cavity was achieved at the time of surgery.

16% C_2F_6 and 12% C_3F_8 were used as reference due to their isovolumetric concentration commonly used as a tamponade in vitrectomy for RRD repair [21].

A table of different concentration of F-gases injected in a 7.2 ml vitreous cavity was produced (Table 1). The calculations were repeated for 4.0 ml and 10.0 ml vitreous cavities (Supplementary Table 1 and 2). Figure 1a shows the data plotted for air, 20% SF_6, 8% C_2F_6 and 6% C_3F_8 in a 7.2 ml vitreous cavity. Figure 1b shows the first 10 days with the corresponding retinal contact angle in Fig. 1c. Figure 2 shows an illustration example of a 75% gas fill in vitreous cavity having retinal contact angle of 210°.

It can be seen that 'isovolumetric' is a misnomer, as all gases, other than air expand slightly after insertion due to the transfer of blood gases based on their partial pressures. 20% SF_6 achieves a greater gas fill on days 1–2 but quickly declines to a lower fill than dilute C_2F_6 and C_3F_8 by days 2–3. The gas dynamics of C_2F_6 and C_3F_8 are quite distinct. For the same concentration, C_3F_8 takes twice the time of C_2F_6 to achieve a similar maximum volume and lasts around 1.7 times longer in the vitreous cavity. On day 7, there will still be a 64% fill of 8% C_2F_6 and 75% of 6% C_3F_8, compared to only 46% in 20% SF_6. 8% C_2F_6 takes about 11 days to go below a 50% gas fill, compared to 18 days for 6% C_3F_8. There is a marked difference in the total duration of tamponade, and dilute mixes of gases have little effect on their duration.

Air achieves considerably lower percentage fills than the F-gases, declining below 50% after day 3, although the retinal contact angles show a less dramatic decline.

It should also be noted how these parameters vary by ocular size. Although percentage fill varies little, gases persist longer in larger eyes due to higher absolute gas volumes, explaining the variability between series dependent on the refractive case mix [8].

The results show that the tamponade characteristics of 20% SF_6 cannot be mimicked completely using weaker concentrations of C_2F_6 and C_3F_8. They maintain a greater fill for significantly longer and last approximately twice and three times as long respectively. However, the extent of retinal contact is similar for the first 7 days. Similarly, whilst air resolves rapidly, it maintains a retinal contact angle of over 140 degrees for the first 5 days based on a modest 75% fill at baseline, enough to close even inferior breaks with suitable positioning allowing laser-treated breaks to form a permanent adhesion.

Traditionally, gas use in RRD repair by vitrectomy is highly subjective, with SF_6 used for superior breaks and C_2F_6 and C_3F_8 preferred for inferior pathology [22]. Although only clinical studies can assess the equivalence of these options in terms of retinal reattachment, knowledge of gas dynamics can inform tamponade

Received: 5 June 2023 Revised: 6 June 2023 Accepted: 14 June 2023
Published online: 7 July 2023

Table 1. Predicted percentage gas fills and retinal contact angles in a 7.2 ml vitreous cavity.

	Air	**SF_6**			**C_2F_6**						**C_3F_8**				
	100%	**20%**	22%	24%	6%	*8%*	10%	12%	14%	**16%**	4%	*6%*	8%	10%	**12%**
Time to max volume (day)	0	**0.78**	0.80	0.83	1.1	*1.4*	1.7	1.9	2.0	**2.1**	1.3	*2.4*	2.9	3.4	**3.8**
Max volume (% fill)	75%	**92%**	93%	96%	81%	*83%*	88%	90%	94%	**97%**	79%	*82%*	86%	90%	**94%**
Retinal contact angle (°)	210	**260**	265	280	223	*228*	244	252	269	**290**	218	*226*	238	252	**269**
Total duration (days)	17	**22**	22	22	40	*41*	42	43	44	**44**	66	*68*	70	71	**73**
Size at day 1 (% fill)	68%	**90%**	93%	94%	81%	*83%*	86%	89%	92%	**94%**	79%	*81%*	83%	85%	**88%**
Retinal contact angle (°)	196	**252**	265	269	223	*228*	238	247	260	**269**	218	*223*	228	235	**244**
Size at day 3 (% fill)	51%	**75%**	76%	79%	76%	*81%*	85%	89%	92%	**96%**	78%	*82%*	86%	90%	**94%**
Retinal contact angle (°)	166	**210**	213	218	213	*223*	235	245	260	**280**	216	*226*	238	252	**269**
Size at day 5 (% fill)	38%	**60%**	61%	63%	69%	*72%*	76%	81%	85%	**88%**	74%	*79%*	83%	89%	**93%**
Retinal contact angle (°)	141	**181**	183	187	198	*204*	213	223	235	**244**	209	*218*	228	247	**265**
Size at day 7 (% fill)	26%	**46%**	47%	49%	61%	*64%*	68%	72%	75%	**79%**	69%	*75%*	81%	85%	**90%**
Retinal contact angle (°)	119	**157**	159	162	183	*189*	196	204	210	**218**	198	*210*	223	235	**252**

The commonly used 'isovolumetric' concentrations are shown in bold, with the suggested more dilute concentrations of C_2F_6 and C_3F_8 shown in italic.

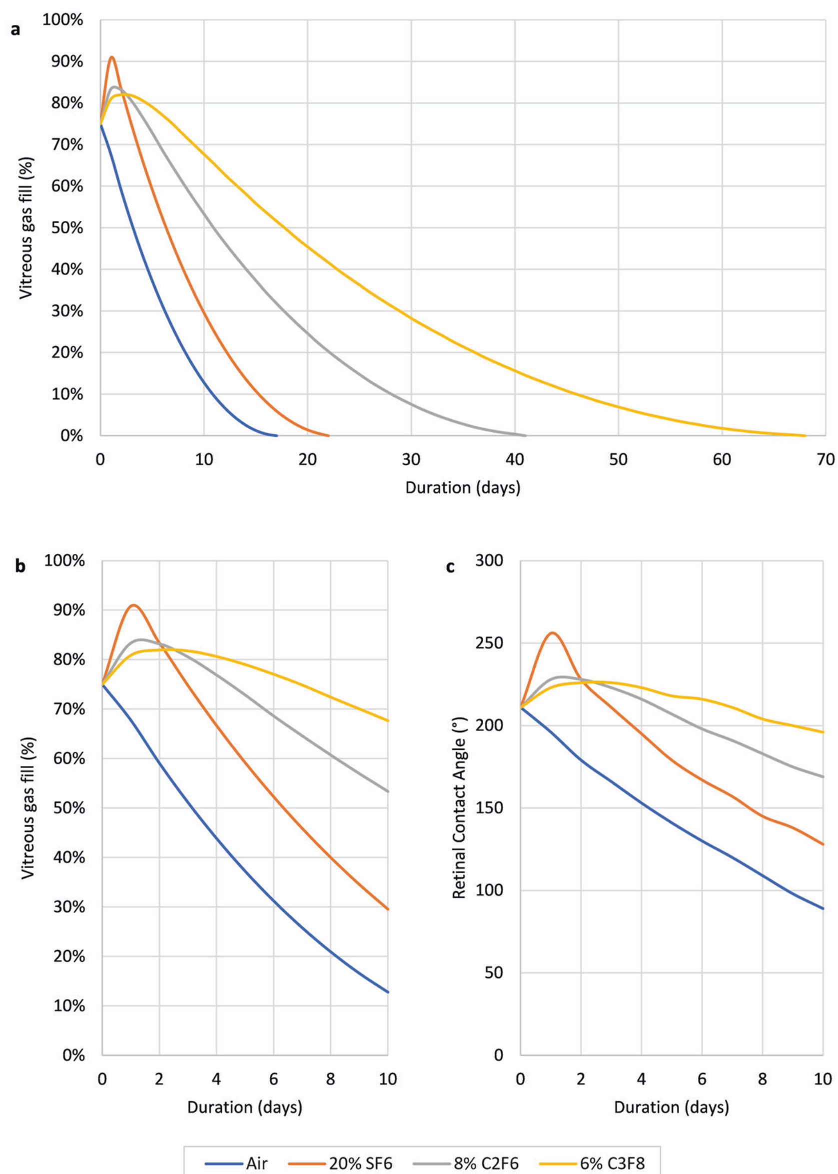

Fig. 1 Gas kinetics with corresponding retinal contact angle. a Plot of air, 20% SF_6, 8% C_2F_6 and 6% C_3F_8 in a 7.2 ml vitreous cavity. **b** Close up view of first 10 days of **a**. **c** Corresponding retinal contact angle graph for **b**.

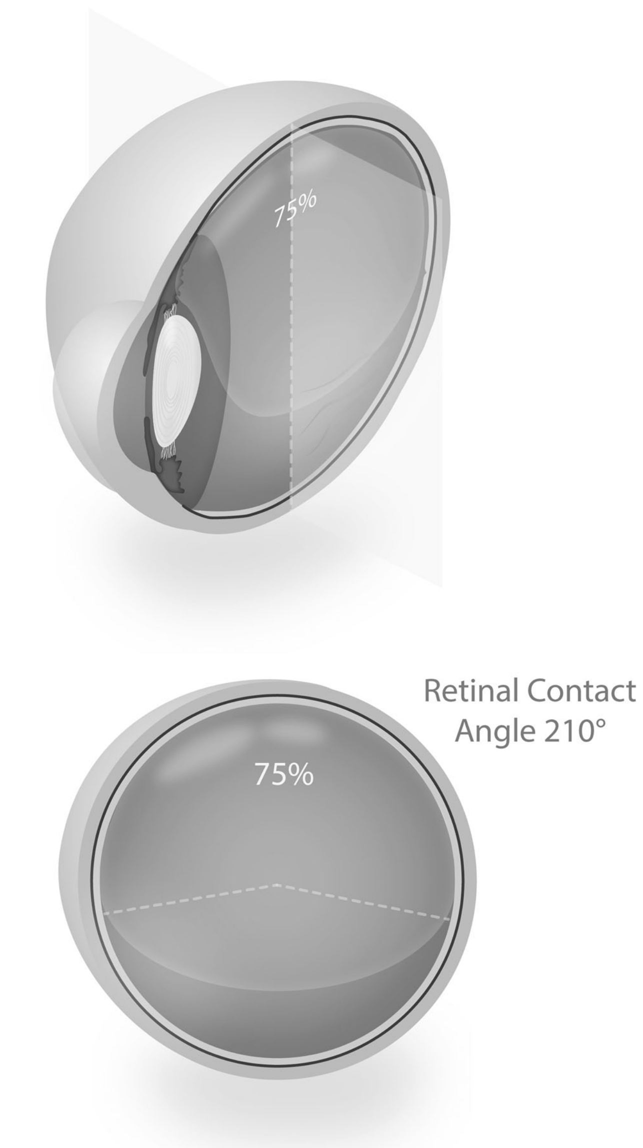

Fig. 2 Illustration example of a 75% gas fill in vitreous cavity having retinal contact angle of 210°.

choice based on factors such as retinal break position(s), posturing abilities, and other commitments (work or carer responsibilities) or planned flights.

Other surgical procedures for RRD repair, namely scleral buckle and pneumatic retinopexy (PnR) could be regarded as 'greener' techniques, due to no or lower volume of F-gas being used. Recently, PnR has been compared to vitrectomy in treating RRD, with evidence suggesting it may give improved visual results in macular-involving cases, albeit associated with reduced primary success [23]. Scleral buckling similarly has shown improved visual results in phakic medium complexity RRD compared to vitrectomy and possibly with less retinal shift, conveying the same advantages of PnR in macular-involving eyes [24]. Despite that, vitrectomy with tamponade remains the most utilised surgical technique for RRD repair in the UK [7]. Whilst encouraging other techniques in suitable situations, it is nevertheless important to explore ways to reduce our carbon footprint whilst performing vitrectomy.

In conclusion retinal surgeons should consider the use of air, weaker concentrations of C_2F_6 and C_3F_8 in selected cases to replace SF_6 during vitrectomy. Scleral buckling and PnR should also be considered where appropriate. Careful audit, with case pooling using initiatives such as the BEAVRS/Euretina database [25] and future prospective studies will be needed to ensure results are maintained. Other measures to reduce gas wastage include using small volume single-use F-gas canisters instead of traditional large gas cylinders [26], and pre-mixed diluted gas in quantities specific for one eye. The NHS is perhaps uniquely positioned to widely adopt these measures via its national procurement mechanisms.

Although the actual amount of F-gases used by retinal surgeons is low, it has been estimated for each RRD repair, the mean equivalent mass of CO_2 per patient range between 2 kg to nearly 120 kg, depending on gas type and gas delivery systems being used [27]. The European Chemicals Agency have released a proposal to limit the use of all per- and polyfluoroalkyl substances which will also include perfluorocarbon liquids (e.g., decalin and octane) and semi-fluorinated alkanes (e.g., F_6H_8, F_4H_5). Although exemptions for their use may be obtained, research into alternatives for the fluorinated compounds we use is needed.

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DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

REFERENCES

1. The L. A Commission on climate change. Lancet. 2009;373:1659.
2. The White House Press Office. Remarks by the President at U.N. Climate Change Summit 2014. https://obamawhitehouse.archives.gov/the-press-office/2014/09/23/remarks-president-un-climate-change-summit.
3. Karliner J, Slotterback S. Health care's climate footprint, How The Health Sector Contributes To The Global Climate Crisis And Opportunities For Action Produced in collaboration with Arup. 2019.
4. Torjesen I. NHS aims to become world's first "net zero" health service by 2040. BMJ. 2020;371:m3856.
5. Wakely L. Sustainability in eyecare: Intraocular gases and the climate emergency. Eye News. 2021;28. https://www.eyenews.uk.com/features/ophthalmology/post/sustainability-in-eyecare-intraocular-gases-and-the-climate-emergency.
6. Yorston D, Donachie PHJ, Laidlaw DA, Steel DH, Sparrow JM, Aylward GW, et al. Factors affecting visual recovery after successful repair of macula-off retinal detachments: findings from a large prospective UK cohort study. Eye. 2021;35:1431–9.
7. Jackson TL, Donachie PH, Sallam A, Sparrow JM, Johnston RL. United Kingdom National Ophthalmology Database study of vitreoretinal surgery: report 3, retinal detachment. Ophthalmology. 2014;121:643–8.
8. Kontos A, Tee J, Stuart A, Shalchi Z, Williamson TH. Duration of intraocular gases following vitreoretinal surgery. Graefes Arch Clin Exp Ophthalmol. 2017;255:231–6.
9. Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, et al. Changes in atmospheric constituents and in radiative forcing. Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. 2007. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf.
10. Moussa G, Ch'ng SW, Ziaei H, Jalil A, Park DY, Patton N, et al. The use of fluorinated gases and quantification of carbon emission for common vitreoretinal procedures. Eye. 2023;37:1405–9.
11. Chew FM, Jawaheer Lo, Hughes E. The Role of 8% C2F6 as an alternative gas tamponade to SF6 in vitreoretinal surgery to reduce environmental impact of healthcare services. Abstracts of the BEAVRS Virtual Meeting 2020.

12. Zhou C, Gu C, Li B, Wang Y, Hu Y, She X, et al. The cause of redetachment after vitrectomy with air tamponade for a cohort of 1715 patients with retinal detachment: an analysis of retinal breaks reopening. Eye Vis. 2023;10:9.
13. Tan HS, Oberstein SY, Mura M, Bijl HM. Air versus gas tamponade in retinal detachment surgery. Br J Ophthalmol. 2013;97:80–2.
14. Zhu A, Wu J, Yuan Y, Zeng L, Wang X, Tan W. The efficacy and safety of air tamponade in the repair of rhegmatogenous retinal detachment: a systematic review and meta-analysis. Ophthalmic Res. 2023. https://doi.org/10.1159/000530690. Online ahead of print.
15. Chen HJ, Tsai YL, Hsiao CH, Chang CJ. Air versus Gas Tamponade for Primary Rhegmatogenous Retinal Detachment: A Systematic Review and Meta-Analysis. Ophthalmic Res. 2023. https://doi.org/10.1159/000530232. Online ahead of print.
16. Zhou C, Qiu Q, Zheng Z. AIR VERSUS GAS TAMPONADE IN RHEGMATOGENOUS RETINAL DETACHMENT WITH INFERIOR BREAKS AFTER 23-GAUGE PARS PLANA VITRECTOMY: A Prospective, Randomized Comparative Interventional Study. Retina 2015;35:886–91.
17. Hall SK, Williamson TH, Guillemaut J-Y, Goddard T, Baumann AP, Hutter JC. Modeling the dynamics of tamponade multicomponent gases during retina reattachment surgery. AIChE J. 2017;63:3651–62.
18. Neffendorf JE, Guillemaut JY, Hutter JC, Ho J, Williamson TH. Effect of Aqueous Dynamics on Gas Behavior Following Retinal Reattachment Surgery. Ophthalmic Surg Lasers Imaging Retin. 2020;51:522–8.
19. Fawcett IM, Williams RL, Wong D. Contact angles of substances used for internal tamponade in retinal detachment surgery. Graefes Arch Clin Exp Ophthalmol. 1994;232:438–44.
20. Nagra M, Gilmartin B, Logan NS. Estimation of ocular volume from axial length. Br J Ophthalmol. 2014;98:1697–701.
21. Mohamed S, Lai TYY. Intraocular gas in vitreoretinal surgery. Hong Kong J Ophthalmol. 2010;14:8–13.
22. Neffendorf JE, Gupta B, Williamson TH. THE ROLE OF INTRAOCULAR GAS TAMPONADE IN RHEGMATOGENOUS RETINAL DETACHMENT: A Synthesis of the Literature. Retina 2018;38:S65–s72.
23. Hillier RJ, Felfeli T, Berger AR, Wong DT, Altomare F, Dai D, et al. The Pneumatic Retinopexy versus Vitrectomy for the Management of Primary Rhegmatogenous Retinal Detachment Outcomes Randomized Trial (PIVOT). Ophthalmology 2019;126:531–9.
24. Heimann H, Bartz-Schmidt KU, Bornfeld N, Weiss C, Hilgers RD, Foerster MH. Scleral buckling versus primary vitrectomy in rhegmatogenous retinal detachment: a prospective randomized multicenter clinical study. Ophthalmology 2007;114:2142–54.
25. Yorston D, Donachie PHJ, Laidlaw DA, Steel DH, Aylward GW, Williamson TH, et al. Stratifying the risk of re-detachment: variables associated with outcome of vitrectomy for rhegmatogenous retinal detachment in a large UK cohort study. Eye (Lond). 2023;37:1527–37.
26. Moussa G, Ch'ng SW, Park DY, Ziaei H, Jalil A, Patton N, et al. Environmental Effect of Fluorinated Gases in Vitreoretinal Surgery: A Multicenter Study of 4877 Patients. Am J Ophthalmol. 2022;235:271–9.
27. Moussa G, Andreatta W, Ch'ng SW, Ziaei H, Jalil A, Patton N, et al. Environmental effect of air versus gas tamponade in the management of rhegmatogenous retinal detachment VR surgery: A multicentre study of 3,239 patients. PLoS One. 2022;17:e0263009.

AUTHOR CONTRIBUTIONS

BLT and ST contributed equally to the paper as joint first authors (collected, analysed, interpreted data and wrote up the manuscript.) THW, BO and JYG revised manuscript with approval of the final version. DHS analysed, interpreted data and revised manuscript critically with approval of the final version.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41433-023-02639-0.

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