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The use of fluorinated gases and quantification of carbon emission for common vitreoretinal procedures

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PURPOSE: To report the contribution to carbon dioxide equivalent mass [CO_2EM] of various types of VR surgery performed across three tertiary referral centres, according to their indication and fluorinated gas used. We secondarily reported on the difference in tamponade choice, and CO_2EM between the different centres.
MATERIALS: Retrospective, continuous, comparative multicentre study of all procedures using fluorinated gases between 01/01/17-31/12/20 at the Manchester Royal Eye Hospital and Birmingham and Midland Eye Centre, and between 01/01/19-31/12/2020 at the University Hospitals Coventry and Warwickshire.
RESULTS: Across 4877 procedures, the use of fluorinated gases produced 284.2 tonnes (71.2 tonnes annually) CO_2EM; an annual consumption of 30,330 l of gasoline. Rhegmatogenous-retinal-detachment (RRD) and macular hole repair had the highest CO_2EM by indication, accounting for 191.4 tonnes CO_2EM (67.3%) and 28.6 tonnes CO_2EM (10.1%); a mean 60.0 kg and 32.0 kg of CO_2EM produced per surgery respectively. The use of fluorinated gases and their respective CO_2EM contributions were significantly different across all three centres ($p < 0.001$) for all indications. SF_6, despite being used in 1883 procedures (38.6%), contributed to 195.5 tonnes CO_2EM (68.8%). Relative to C_2F_6, procedures using C_3F_8 and SF_6 produced 1.9 and 4.4 times more CO_2EM.
CONCLUSION: We demonstrated that SF_6 causes significantly higher carbon emissions relative to C_2F_6 and C_3F_8 with RRD and macular hole repair having the greatest environmental impact. We also reported large variations between different large VR centres in fluorinated gas use, and therefore in carbon emission contributions depending on indications for surgery. Evidence-based protocols might help in making VR surgery "greener".

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INTRODUCTION

Sulphur hexafluoride (SF_6), hexafluoroethane (C_2F_6) and octafluoropropane (C_3F_8) are the fluorinated gases commonly used in vitreoretinal (VR) surgery and they are among the most potent greenhouse gases. They have much longer atmospheric lifetimes than CO_2 (Table 1, adapted from the Intergovernmental Panel on Climate Change (IPCC) second assessment report) with 1 kg of SF_6 having a global warming potential (GWP) of 23,900 kg of CO_2 (Table 1) over 100 years (GWP100) [1–3]. GWP represents the amount of heat absorbed by a greenhouse gas, as a multiple of the equivalent heat, that would be absorbed by the same mass of CO_2 [1]. SF_6 has also been identified in the Kyoto Protocol as one of six gases which require strict regulation in order to reduce global warming [4].

This research group has previously published that the fluorinated gas use in VR surgery is contributing to 0.11% of annual SF_6 use in the United Kingdom (UK) across all industries [3].

The National Health Service (NHS) produces 5.4% of annual greenhouse gases in the UK, despite being committed to becoming carbon neutral by 2040 [5].

In this paper we aimed to investigate the contribution to carbon emissions of various types of VR surgery performed across three tertiary referral centres, according to their indication. We secondarily reported on the difference in tamponade choice, and therefore carbon emissions between the different centres and the surgeons involved.

METHODS

This is a retrospective, continuous, comparative multicentre study of all fluorinated gas use in vitreoretinal surgery for different indications. This study was conducted at the Manchester Royal Eye Hospital (MREH), the Birmingham and Midland Eye Centre (BMEC) (the second and third largest eye hospitals in the UK), and the University Hospitals Coventry and Warwickshire (UHCW). We included all VR surgeries involving fluorinated gases at MREH and BMEC over four years, between 1st January 2017 to the 31st December 2020. For UHCW, data were available for consecutive cases of a single surgeon (DYP) over a two-year period, from the 1st of January 2019 to the 31st of December 2020.

Data acquisition

For MREH, data were extracted from a centralised database of all VR procedures performed, recorded on Microsoft Access. For BMEC, data were

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Table 1. Global Warming Potentials at different time periods.

Gas	Lifetime (years)	Global Warming Potential (Time Horizon)		
		20 years	100 years	500 years
CO_2	Variable (100–300)	1	1	1
SF_6	3,200	16,300	23,900	34,900
C_2F_6	10,000	6,200	9,200	14,000
C_3F_8	2,600	4,800	7,000	10,100

Table adapted from the second Intergovernmental Panel on Climate Change (IPCC) report.

acquired from the electronic patient records (EPR, Medisoft Ophthalmology, Medisoft Limited, Leeds, UK). Finally, UHCW data were taken from DYP's surgical logbook.

Surgeries were divided according to common VR surgical indications: rhegmatogenous retinal detachment (RRD), macular hole repair, diabetic retinopathy (including segmentation, delamination, and diabetic vitreous haemorrhage), haemorrhagic posterior vitreous detachment (PVD), other causes of vitreous haemorrhage, epiretinal membrane peel, sub-macular haemorrhage and other (any procedure that does not fit into any of the categories indicated).

All air tamponade cases were excluded, and this study looks exclusively at procedures that used fluorinated gases.

Environmental factor calculations

The environmental aspect of gas tamponade was performed by converting millilitre of gas to mass (g) using the modified ideal law gas formula at standard temperature and pressure (STP). Intraocular gas masses were then converted to their GWP100 [6]. The respective GWP100 values were used: SF_6: 23,500, C_2F_6: 11,100 and C_3F_8: 8900, as per the fifth IPCC report [7]. The CO_2 equivalent mass (CO_2EM) was then calculated. For example, if a 75 ml canister of SF_6 was used per surgery, 75 ml of SF_6 was converted to the equivalent of 0.4887 g at STP [6], and multiplied by the GWP100 of 23,500 to be around 11,500 g (11.5 kg) of CO_2EM.

Context was given to CO_2 emissions using a greenhouse gas equivalencies calculator by the United States Environmental Protection Agency (EPA) [8]. This calculator converts CO_2EM, which is an arbitrary value to most readers, to give context to the user, such as how many miles driven, mobile phone charges, or litres of gasoline used are a certain number of tonnes of CO_2 equivalent to. While helpful in conceptualising the mass of CO_2, this calculator will depend on the conversion factors used, which are not published. For example, cars in the US may have higher fuel consumption than the UK and so their calculations may not be fully reflective for certain populations.

Our full environmental factor methodology can be found in this prior publication that includes a calculator to allow accessibility to perform similar calculations [3, 6]. In summary, all three centres utilise different gas delivery systems. Total fluorinated gas use was calculated by accessing pharmaceutical orders and gas that was not used by expiry date (as was the case with cylinder delivery systems) was counted towards total fluorinated gas use.

Surgical method

This study encapsulates a wide range of surgical procedures across multiple surgeons, with 23 G, 25 G and 27 G Pars Plana Vitrectomy (PPV) used routinely in our study duration. Tamponade choice was at the discretion of the operator.

Statistical analysis

Statistical significance was defined as $p < 0.05$. Mann–Whitney *U* and Kruskal–Wallis Test were used to compare two and three independent continuous variables, respectively. Fisher exact test and Chi-Squared test were used for nominal variables. All statistical analysis was performed using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp, Armonk NY).

Ethical approval/consent to participation

As this was a retrospective anonymized study, as per our local protocol from our Clinical Effectiveness Department, and as per national guidelines from the National Code of Clinical Research, and the Health Research Authority (HRA), this study has ethical approval exemption and no patient consent was required for participation [9, 10]. All procedures were completed prior to the design of this study. Patients were diagnosed and treated according to local guidelines and agreements and written consent from patients was acquired prior to all procedures as clinically indicated. This study does not report on the use of new or experimental protocols.

RESULTS

We included 4877 VR surgeries [3]. RRD, followed by macular hole repair were the most common indications for surgery (Fig. 1). Over the study period, the three centres contributed to 284.2 tonnes of CO_2EM which equates to 71.2 tonnes of CO_2EM annually due to the use of fluorinated gases. This corresponds to an annual consumption of 30,330 l of gasoline [8].

The two major contributors of emissions were RRD and macular hole surgery. RRD was responsible for the highest fluorinated gas use accounting for 191.4 tonnes CO_2EM (67.3%), followed by macular hole repair with 28.6 tonnes CO_2EM (10.1%). This corresponds to 60.0 kg and 32.0 kg of CO_2EM produced per surgery for RRD and macular hole, respectively. Figure 1A demonstrates the CO_2EM contributed by each gas tamponade by surgical indication while Fig. 1B shows the number of procedures performed with each respective tamponade. SF_6, despite being used in only 1883 procedures (38.6% of the total), contributed to 195.5 tonnes CO_2EM (68.8% of the total). We found that SF_6, C_3F_8 and C_2F_6 use resulted in 103.8 kg CO_2EM, 44.1 kg CO_2EM and 23.4 kg CO_2EM per procedure, respectively. Relative to C_2F_6, procedures using C_3F_8 and SF_6 produced 1.9 and 4.4 times more CO_2EM.

We also explored the differences in fluorinated gas use between the three centres and their respective contributions to CO_2EM (Fig. 2). For RRD repair, MREH used SF_6 in 880 (55.3% of the total RDD cases) surgeries while UHCW utilised SF_6 in only 24 (21.4%) of cases.

UHCW additionally did not use any fluorinated gas for ERM or haemorrhagic PVD surgery. The use of fluorinated gases and their respective CO_2EM contributions were significantly different across all three centres ($p < 0.001$) for all indications.

The total contributions of CO_2EM from each centre and the fluorinated gases use are summarised in Table 2. MREH had the highest CO_2EM production from SF_6 accounting for 70.2% of total CO_2EM compared to UHCW at 40.0%. C_2F_6 accounted for 52.3% of CO_2EM for UHCW relative to MREH at 16.6%. At BMEC 25.2% of the total CO_2EM originated from C_3F_8 compared to 7.7% at UHCW. Figure 3 compares the contribution to CO_2EM according to indication for VR surgery by centre.

DISCUSSION

In this study we reported how different indications in VR surgery and tamponade preference affect CO_2EM. While we found that RRD and macular hole are the two largest contributors to carbon emissions from fluorinated gas use, we also demonstrated the importance of type of tamponade choice on CO_2EM (Fig. 1A, B) with SF_6 having a 4.4 greater environmental impact than C_2F_6.

Our data showed significant differences in choice of tamponade between centres and among surgeons. This is multifactorial and complex decision. Local guidelines, and prior training have a significant impact on the surgeon's choice of tamponade. In addition, concerning RRD, previous studies have shown that the training level of a VR surgeon [11], as well as the patients' ethnicity and socioeconomic status, can play a role [12]. Therefore, different

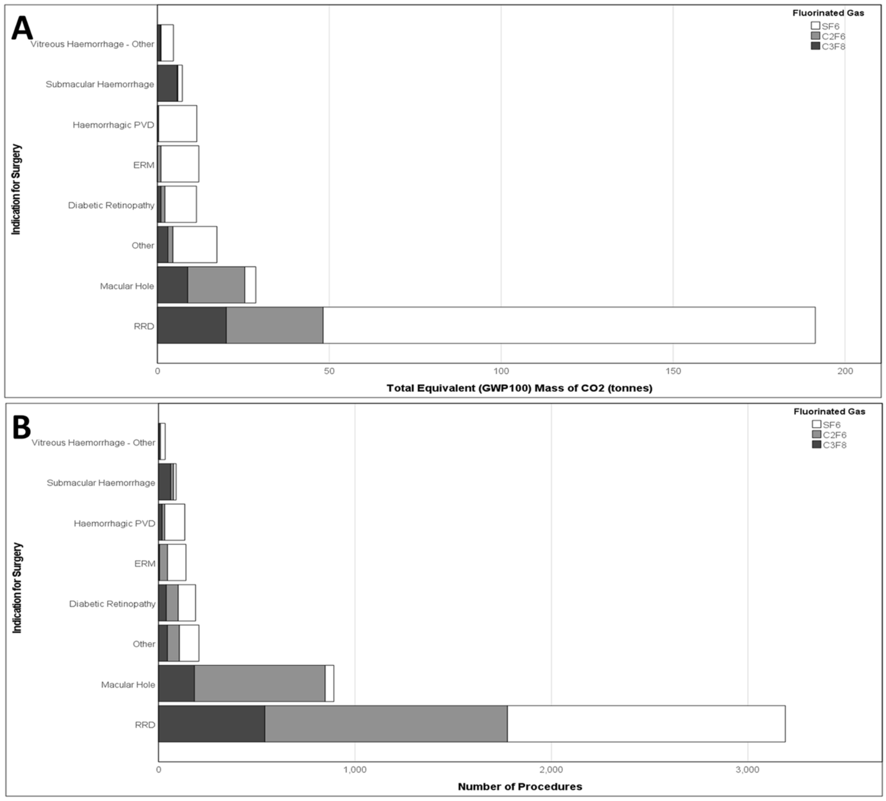

Fig. 1 Number of procedures and total equivalent CO_2 mass for different fluorinated gases by indication of surgery. The total equivalent mass of CO_2 over four years (**A**) show that SF_6 contributes the highest proportion of the fluorinated gases in carbon emissions. This is evident by comparing against the number of procedures performed by each fluorinated gas (**B**). SF_6 was used in 38.6% of procedures (**B**) but contributed to 68.8% of emissions (**A**).

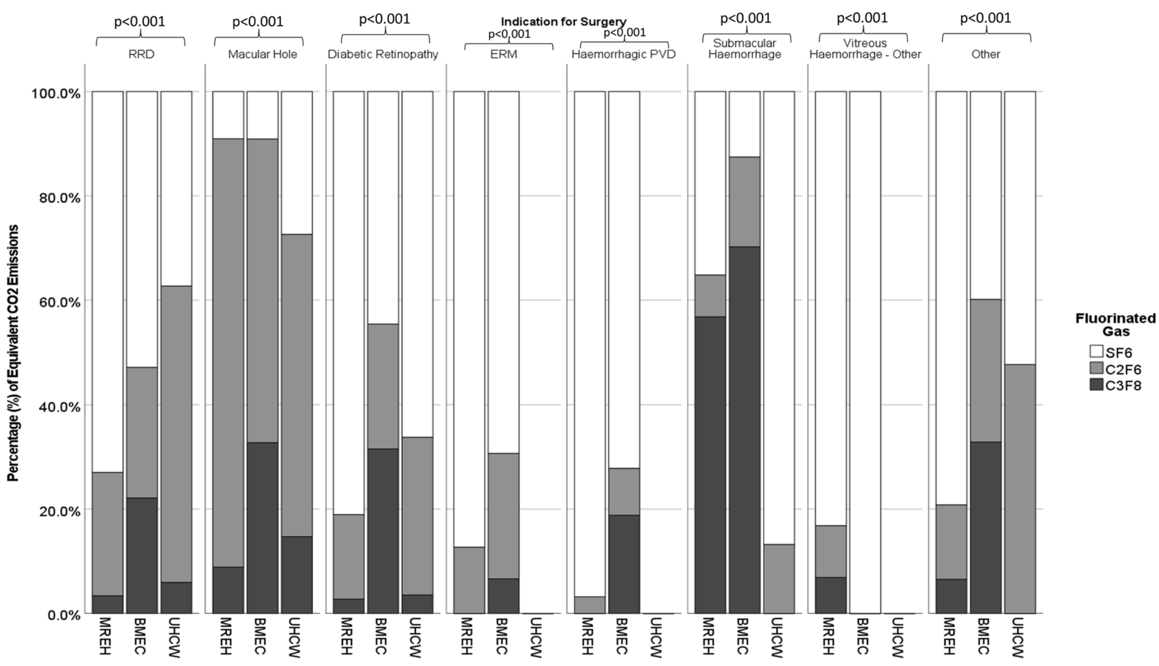

Fig. 2 Differences between centres in fluorinated gas use by indication and the respective CO_2 emissions contribution. Chi-Squared test utilised between groups. Significant differences were found for every indication in tamponade contribution to equivalent CO_2 emissions across the different institutions. UHCW did use any fluorinated gas for vitreous haemorrhage or ERM.

local populations, case complexity and the presence of VR fellows may have contributed to the differences observed between our centres. Ultimately, surgeons should use whichever gas they feel it achieves the best surgical outcome for their patient, but they should also be aware of their environmental impact. UHCW for example, used the least SF_6 due to routine integration of air tamponade in RRD repair, without detriment to their outcomes [13]. By changing their practice, UHCW had the lowest carbon emissions from fluorinated gas use in RRD repair among the centres involved in our study.

SF_6, as well as being the most potent greenhouse gas known [1], also has the shortest effect relative to C_2F_6 and C_3F_8. This provides several practical advantages for surgeons and patients over the longer acting alternatives. Air tamponade as an alternative for fluorinated gases (and especially SF_6) has been described for RRD [13–25], and even in macular hole repair [26]. If air tamponade is not appropriate, surgeons could also consider diluting C_2F_6 or C_3F_8 as an alternative to SF_6. However, although dilute concentrations of C2F6/C3F8 can be titrated to have the same duration gas bubble as SF6, the bubble volume will not be the same for all three gases and this will impact tamponade effect.

Table 2. Contribution to equivalent CO_2 emissions by gas tamponade and centre.

Equivalent CO_2 mass percentage	Total	MREH	BMEC	UHCW	*p* value
SF_6	68.8%	70.2%	46.4%	40.0%	**<0.001**
C_2F_6	17.3%	16.6%	28.4%	52.3%	**<0.001**
C_3F_8	13.9%	13.3%	25.2%	7.7%	**<0.001**

Statistical significance in bold.

Although ophthalmology causes a relatively small contribution to CO_2 emissions across the whole of medicine, this manuscript highlights a topic that is not often discussed. With climate change becoming an increasingly important issue, VR surgeons should be aware of the environmental impact of their surgery, and similar efforts are being made across other medical specialities [27–29]. Due to the wide variety in tamponade choice in VR surgery, evidence-based departmental protocols may provide environmentally friendlier surgery, without a detrimental effect on patients' safety.

Study limitations and strengths

This is a retrospective study with no agreed protocol for gas tamponade choice for case indication and complexity. In addition, although fluorinated gases have significant CO_2EM due to their high GWP100 values, they represent just a small part of the carbon emissions in VR surgery, with other hospital and patient factors such as the type of anaesthesia and the frequency of follow up visits, causing a significant environmental impact. Nevertheless, this large study reflects real-life environmental consequences of fluorinated gas use for different surgical indications at large VR centres in the UK.

CONCLUSIONS

In this study we demonstrated that SF_6 causes significantly higher carbon emissions relative to C_2F_6 and C_3F_8 with RRD and macular hole repair having the greatest environmental impact. We also reported large variations between different large VR centres in fluorinated gas use, and therefore in carbon emission contributions depending on indications for surgery. Evidence-based protocols might help in making VR surgery "greener".

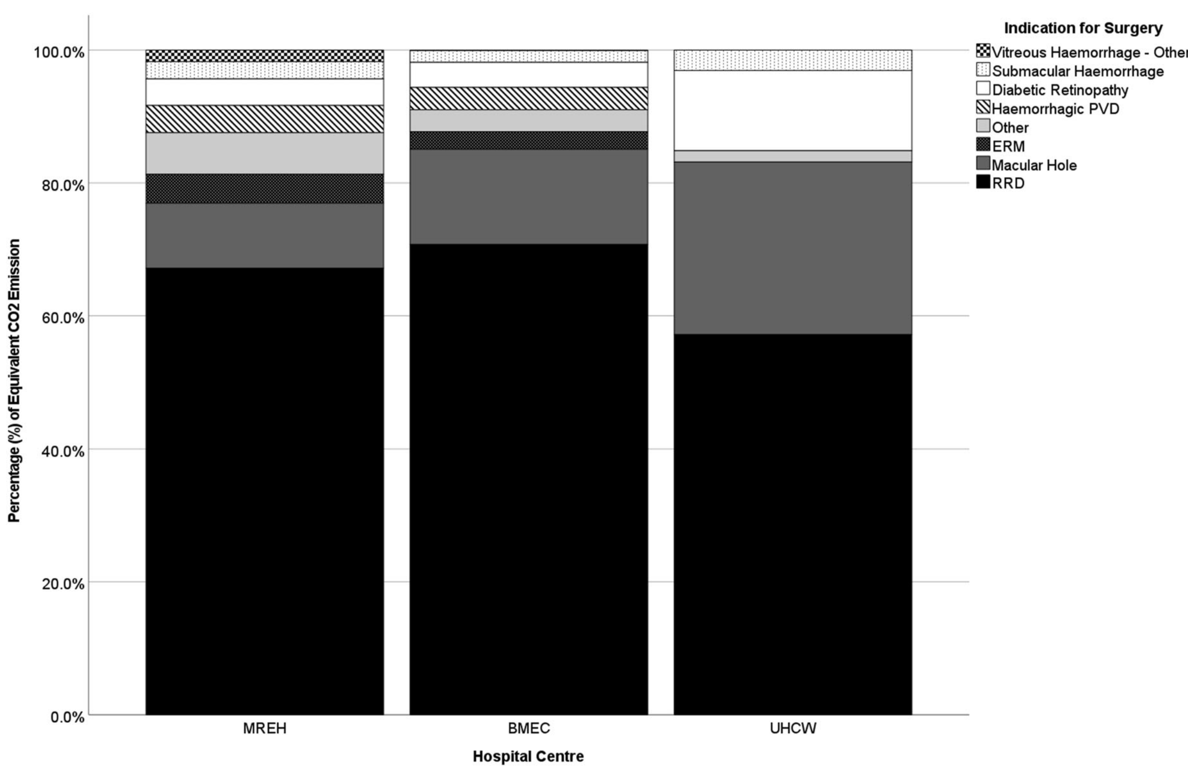

Fig. 3 The contribution to equivalent CO_2 emissions by indication of VR surgery by centre. The relative contributions of each centre to CO_2 emissions by indication.

Summary

What was known before

- The fluorinated gases used in vitreoretinal (VR) surgery, are the most potent greenhouse gases in existence.
- Large variability exists in the use of fluorinated gases across different clinicians.

What this study adds

- A multicentre study to realise the environmental impact of fluorinated gases across different indications.
- Variability in tamponade choice significantly affects the environmental carbon footprint of VR surgery.

DATA AVAILABILITY

The raw data are available upon reasonable request

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AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

COMPETING INTERESTS

All authors declare no competing interests.

ADDITIONAL INFORMATION

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