How an Audit-and-Feedback-Based Educational Program Contributed to a Reduction in Environmentally Harmful Waste Anesthetic Gases Among Anesthesiology Residents

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ABSTRACT

Background Waste anesthetic gases (WAGs) contribute to greenhouse gas emissions. US anesthesiology resident education on how to reduce WAG-associated emissions is lacking, so we developed an electronic audit-and-feedback-based program to teach residents to reduce fresh gas flow (FGF) and WAG-associated emissions.

Objective To assess the program's effectiveness, we measured individual and combined mean FGF of residents during their first, second, and last weeks of the 4-week rotation; then, we calculated the extrapolated annual emissions based on the combined resident mean FGFs. Resident attitudes toward the program were surveyed.

Methods During 4-week rotations at a teaching hospital, anesthesia records were scanned to extract resident-assigned cases, FGF, and volatile anesthetic choice during the 2020-2021 academic year. Forty residents across 3 training years received weekly FGF data and extrapolated WAG-associated emissions data via email. Their own FGF data was compared to the low-flow standard FGF of $\leq$1 liter per minute (LPM) and to the FGF data of their peer residents on rotation with them. An online survey was sent to residents at the end of the project period.

Results Between their first and last weeks on rotation, residents decreased their mean FGF by 22% (1.83 vs 1.42 LPM; STD 0.58 vs 0.44; 95% CI 1.67-2.02 vs 1.29-1.56; $P<.0001$). Ten of 18 (56%) residents who responded to the survey reported their individual case-based results were most motivating toward practice change.

Conclusions An audit-and-feedback-based model for anesthesiology resident education, designed to promote climate-conscious practices with administration of volatile anesthetics, was effective.

Introduction

Of all US greenhouse gas emissions, 8.5% can be attributed to the health care industry.[1] These emissions have wide-ranging, detrimental effects on human health.[2-4] Within the health care industry, volatile anesthetics (sevoflurane, isoflurane, and desflurane) have been identified as a significant source of greenhouse gas emissions, comprising greater than 50% of all perioperative emissions.[5] As such, the American Society of Anesthesiologists (ASA) has called upon anesthesiologists to reduce their own emission footprint, creating the "Anesthesiology Sustainability Checklist" with practice recommendations in 2014 and more recently, providing useful tools to calculate the environmental impact of anesthesia care.[6,7]

Despite the ASA initiative, there has been little mention in the academic literature of how best to adapt these practice recommendations into a US anesthesiology residency program. In a 2020 survey, most Canadian anesthesiology residency program directors felt that their residents could benefit from more teaching on the topic of environmental sustainability.[8] However, they were unsure of how to effectively do this, given a lack of faculty expertise, lack of time within the structured curriculum, and lack of support at their academic institutions.[8]

To address this deficit in resident education, we developed a sustainability education program for anesthesiology residents who rotated at the Clement J. Zablocki Veterans' Administration Medical Center (VAMC). In accordance with the ASA's practice recommendation of using low fresh gas flows (FGFs),[6,9] this education program involved auditing resident cases and providing weekly feedback to residents via email on their FGF use and emissions from waste anesthetic gases (WAGs). We tested the hypothesis that this innovative program would lower resident FGF use across the 4-week rotation and subsequently reduce extrapolated annual WAG-associated emissions at the VAMC.

DOI: http://dx.doi.org/10.4300/JGME-D-23-00402.1

Editor's Note: The online supplementary data contains further data and the survey used in the study.

Methods

The Medical College of Wisconsin (MCW) Department of Anesthesiology Residency Program is a 4-year residency program with approximately 20 residents in each cohort: postgraduate year 1, clinical anesthesia (CA) year-1, CA-2, and CA-3. MCW anesthesiology residents in their CA years rotate at a variety of MCW-affiliated teaching hospitals in Milwaukee, Wisconsin, including the VAMC for at least one 4-week rotation.

At the VAMC, anesthetic vaporizer labels with environmental impact information (online supplementary data Appendix A, VAMC Vaporizer Labels), inspired by the work of Zuegge et al,[10] were applied during the 2019-2020 academic year. Due to a perceived lack of consistent practice change from the labels, an audit-and-feedback-based educational program was developed for residents in the 2020-2021 academic year to supplement the vaporizer labels. Some residents may have also previously learned about the environmental impact of volatile anesthetics in a didactic or grand rounds lecture, but not all residents.

All CA residents were enrolled in this exploratory quality improvement education program at the start of their 4-week VAMC rotation. However, to be included in the analysis, CA residents must have been present for at least 2 weeks of the 4-week VAMC rotation (randomly scheduled throughout the year), performed at least 1 general anesthetic case per week (average was 3), and received at least 1 email (average was 2). Forty residents on rotation met the criteria for analysis: 13 CA-1 residents, 13 CA-2 residents, and 14 CA-3 residents.

The education program involved auditing resident cases and providing feedback to residents each week via email. Email was chosen as the method of communication to ensure all residents received the same information from the same source and to not take away from already allocated didactic/classroom time. Resident-assigned cases, FGF, and volatile anesthetic choice were extracted weekly from an automated process to query the electronic anesthesia and medical record system used by the VAMC during the 2020-2021 academic year.

At the end of each week within the 4-week rotation, residents were sent an email that included an educational "introduction" to the next week, as well as their own FGF and WAG emissions data and the FGF usage of their fellow trainees on assignment at the same time (online supplementary data Appendix B, Weekly Emails). These brief introductions were intentionally varied week-to-week and served to call residents' attention to the goal of reducing their WAG emissions and adopting a more climate-conscious practice. The introduction to the fourth email (sent after the fourth week) included the overall results of the residents as a group during the rotation. The core of each email was comprised of a resident's own FGF and WAG emissions data. Individualized feedback has been shown to be successful in driving practicing change at other institutions.[11-13] Their own FGF data was compared to an environmentally preferable standard FGF of $\leq$1 liter per minute (LPM) in support of the ASA's low flow practice recommendation[6,9] and to the FGF data of their resident peers on rotation with them. The residents were also provided the equivalent of their WAG-associated emissions in miles driven of gasoline-powered passenger vehicles using the Environmental Protection Agency Greenhouse Gas Equivalencies Calculator.[14]

Operating room (OR) scheduling restrictions during the COVID-19 pandemic resulted in only 2 to 7 cases per resident per week with typical case lengths of 2 to 3 hours. A resident's *first* week of data in this study could be week 1, 2, or 3 of the rotation and was *prior to* receiving their first email. A resident's *last* week of data in this study could be week 2, 3, or 4 of the rotation and was *prior to* receiving a final email.

Resident general anesthesia cases were included in the analysis unless: (1) low FGF was not practical for the surgical case or patient care needs (eg, bronchoscopies, one-lung ventilation cases, and cases where a laryngeal mask airway was used) or (2) case management included a continuous intravenous infusion of propofol, an opioid, or dexmedetomidine. Additionally, desflurane vaporizers were removed from the ORs for the 2020-2021 academic year to align with the ASA's practice recommendation to minimize use of high environmental impact anesthetics,[6] which resulted

KEY POINTS

What Is Known
Anesthesiology professional associations have developed guidelines to reduce environmentally harmful waste anesthetic gases (WAGs) in the operating room, but less focus in the literature has been on how to best implement these guidelines into a US anesthesiology residency program.

What Is New
This novel program at a single site involved auditing anesthesiology resident general anesthesia cases and providing residents with feedback via email on their own practice to reduce WAG-associated emissions.

Bottom Line
This model, based on electronic audit and feedback of individual resident cases, can be implemented into an anesthesiology residency program to teach and promote climate-conscious practices in accordance with professional association guidelines.

in no residents using desflurane while on a VAMC rotation. Similarly, nitrous oxide use was negligible due to an earlier education initiative on its environmental impact as both a greenhouse gas and an ozone-depleting substance[15]; therefore, we did not collect data or offer additional educational feedback on nitrous oxide use.

Case data were collected from the steady-state maintenance phase of anesthesia, defined as 30 minutes after gas flow began to 30 minutes before gas flow ended. This assessment period intentionally excluded the anesthesia induction period, when FGF widely varies as the anesthesiologist's primary goal is to establish a secure airway and achieve sufficient anesthetic depth for surgery. While there are opportunities to lower FGF use and reduce WAG emissions during induction as demonstrated in the literature,[16,17] that goes beyond the scope of this article.

Extrapolated annual WAG emissions generated by residents at the VAMC were calculated by using the weekly mean FGF and a set of assumptions representative of the type and number of resident cases performed at the VAMC (online supplementary data Appendix C, Fresh Gas Flow and WAG-Associated Emissions Calculations). It was assumed that residents on rotation together performed 18 sevoflurane and 2 isoflurane resident cases per week at the VAMC; each case had a 120-minute maintenance period of anesthesia; percent volume of sevoflurane used was 2% and isoflurane used was 1%.

Finally, to gauge attitudes about this new sustainability education program and global warming/climate change in general, the research team sent individual emails with a link to a single online Qualtrics survey to the 21 residents available for contact at the end of the academic year (online supplementary data Appendix D, Qualtrics Online Survey Questions and Selected Results). Residents could have received the survey anywhere between 0 and 11 months after their particular rotation ended. The survey questions were created by a medical student (E.J.N.) and reviewed by both the VAMC's local environmental sustainability expert (C.A.S.) and Director of Anesthesiology (T.J.E.); they were otherwise not piloted. All survey responses were anonymous and collected over one week. Prompts for survey completion occurred twice. Consent was implied by participation in the survey.

One-way ANOVA was used to seek an effect on FGF reduction from early to later rotation blocks within the academic year and from the clinical anesthesia year in training. General linear models were used to perform repeated measures ANOVA to observe changes in mean FGF per case per resident over time. Survey results were reported as percent of total. All analyses were completed using SAS 9.4 14.3 (SAS Institute Inc). A power analysis for sample size was not done because sample size was a convenience sample from total residents on rotation at the VAMC in the 2020-2021 academic year.

This exploratory quality improvement education project was approved by the VA Human Studies Committee that determined the activity does not meet the definition of research and was intended for internal VA purposes in support of the VA mission. Written informed consent of participants was not required. The work conforms to the Standards for Quality Improvement Reporting Excellence 2.0.[18]

Results

Forty residents participated in the initiative and met criteria to be included in the following analysis. Between their *first* week (pre-email) and *second* week (ie, after receiving one email) on rotation, residents decreased their mean FGF by 12% (1.83 LPM vs 1.61 LPM; STD 0.58 vs 0.55; 95% CI 1.67-2.02 vs 1.44-1.78; P=.0026). Between their *first* week (pre-email) and *last* week (ie, after receiving an average of 2 emails) on rotation, residents decreased their mean FGF by 22% (1.83 LPM vs 1.42 LPM; STD 0.58 vs 0.44; 95% CI 1.67-2.02 vs 1.29-1.56; P<.0001; FIGURE 1). Thirty of 40 (75%) residents reduced their mean FGF between their *first* and *last* week of the rotation (FIGURE 2).

Extrapolated annual WAG emissions generated by residents at the VAMC were calculated using the weekly mean FGF and a set of assumptions representative of the type and number of resident cases performed at our facility. The results are summarized in the TABLE. Further detail on calculations can be found in online supplementary data Appendix C, Fresh Gas Flow and WAG-Associated Emissions Calculations.

Twenty-one of the 40 (53%) residents were available for contact via an online survey at the end of the academic year (ie, residents who had graduated or were otherwise not available—on vacation or extended leave—were not contacted). Eighteen of 21 (86%) residents responded to the survey; all residents who responded were ≤40 years old.

Fourteen of 18 (78%) residents read their weekly emails "every time" or "most times" on a 5-point Likert-type scale. Ten of 18 (56%) residents reported their individual case-based results were most motivating toward practice change; another 7 of 18 (39%) residents were primarily motivated by the introduction section of the emails (online supplementary data Appendix D, Qualtrics Online Survey Questions and Selected Results).

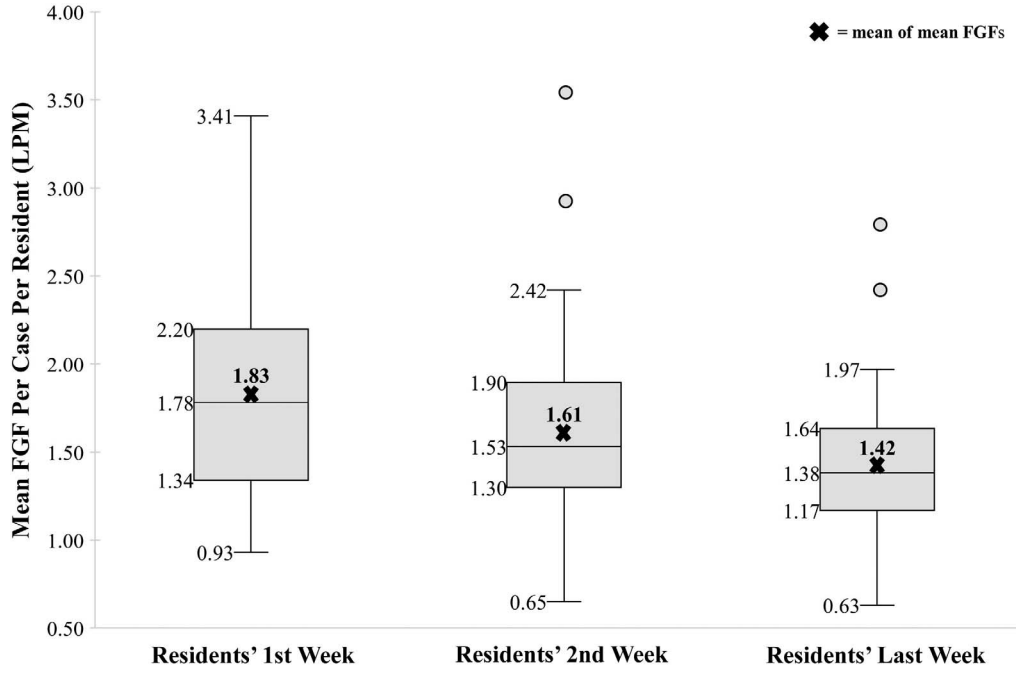

FIGURE 1
Distribution of Mean Fresh Gas Flows (FGFs) Per Case Per Resident of Residents on a 4-Week Rotation at the VAMC

Abbreviation: VAMC, Clement J. Zablocki Veterans' Administration Medical Center.

Note: Box plots showing the distribution in mean FGFs per case for residents' *first*, *second*, and *last* week of rotation. Within each box, the horizontal black line denotes median FGF; X denotes mean FGF of all 40 residents for that period. A box extends from the 25th to 75th percentile of each period's distribution of values; vertical extending lines denote the minimum and maximum FGF within 1.5 interquartile range of the 25th and 75th percentile. Dots denote outliers.

Discussion

This novel audit-and-feedback-based educational program, based on the ASA's sustainability guidelines,[6,9] resulted in a reduction in FGF use and extrapolated annual emissions from WAGs. Between their *first* and *last* week of rotation (ie, after receiving on average 2 emails), residents were able to reduce their mean FGF by 22% (from 1.83 LPM to 1.42 LPM). While these reductions in FGF may seem modest, any decrease in volatile anesthetic wastage brought on by lowering FGF has an impact on greenhouse gas emissions. By reducing their mean FGF between their *first* and *last* week, our residents would save 1.1984 metric tons of carbon dioxide equivalent ($MTCO_2e$) annually, which is the emissions equivalent of preventing 1326 pounds of coal from being burned. Most residents wanted to reduce their environmental impact; they looked at the program's emails each week and found that their specific, case-based results were most motivating in terms of changing to a more environmentally preferable practice.

We know from other institutions that an audit-and-feedback approach is successful in encouraging anesthesia providers to reduce their FGF.[11-13] Our approach was unique in the respect that residents received electronic feedback in the form of mean FGF *and* mean emissions generated from WAGs for *each case each week*, rather than a longer term summary of their average FGF for many cases over time (eg, monthly). Some institutions have—excitingly—found ways to offer FGF feedback to anesthesia providers in real time in the OR, such as through an automated alerting system connected to the anesthesia record.[13,19] However, for an anesthesiology department just starting its mission to practice more sustainably (as ours was), this might not be a first-line option, given the resources required to enact such a systemic change in the OR.

Regarding the limitations of our project, not all residents met the evaluation criteria of weeks on rotation, limiting our sample size. Second, this prospective evaluation did not include a control group not receiving education, in part due to the lower number of residents and case numbers during the pandemic year. A retrospective evaluation of a control group from a prior training year was not part of the original study design. Third, although residents were linked as the primary provider of anesthesia for each case, we can't be certain that other providers, such as attending anesthesiologists or nurse anesthetists, did not adjust the FGF when giving relief to residents during a case. This may explain why all of the residents surveyed identified themselves as being

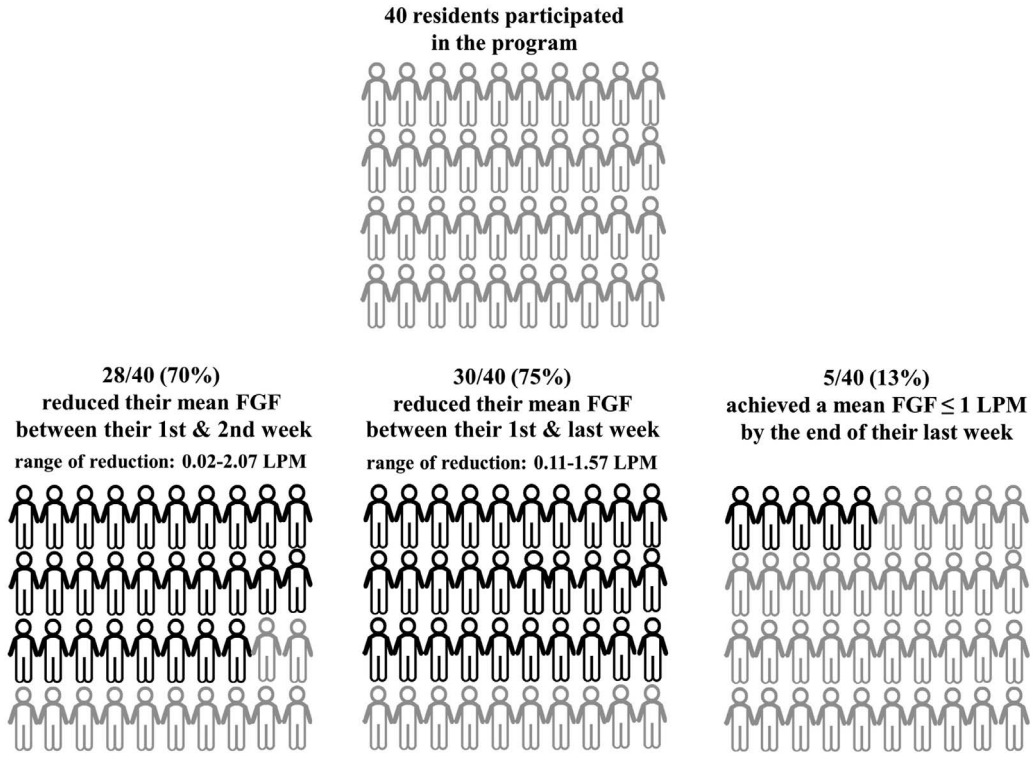

FIGURE 2
How VAMC Residents Responded to the Educational Program, by Number

Abbreviation: VAMC, Clement J. Zablocki Veterans' Administration Medical Center; FGF, fresh gas flow.

Note: People graphs showing the breakdown of resident responses to the educational program by number. One person depicted pictorially equals 1 resident.

capable of practicing almost exclusively at ≤1 LPM for all their general anesthesia cases, but only 5 of 40 (13%) residents achieved a mean FGF per case of ≤1 LPM in their *last* week on rotation.

Finally, it should be noted that we did not collect FGF data during the induction phase of anesthesia delivery. This period (vs the maintenance phase) offers additional opportunity to reduce FGF and WAG-associated emissions.[16,17] Challenges with this period include balancing the need of establishing a secure airway and anesthetizing the patient quickly/sufficiently enough for surgery with the desire to practice with a low FGF. Relatedly, we also assumed that the maintenance phase for all our cases was 120 minutes, likely resulting in an underestimate of the true extrapolated annual WAG-associated emissions at the VAMC.

The effectiveness of this educational program *in the long term* is a future area of study, as well as whether this program can be expanded to other

TABLE
Extrapolated Annual WAG-Associated Emissions From Resident Cases at the VAMC, Calculated From Weekly Mean FGF

Week of Rotation	Mean FGF of Residents	Annual WAG-Associated Emissions Generated, Extrapolated ($MTCO_2e$)	% Change From 1st Week	Annual WAG-Associated Emissions Saved ($MTCO_2e$)	Annual WAG-Associated Emissions Saved (Pounds of Coal Burned)
1st week	1.83 LPM	5.3489	…	…	…
2nd week	1.61 LPM	4.7059	-12	0.6430	711
Last week	1.42 LPM	4.1505	-22	1.1984	1326

Abbreviations: WAG, waste anesthetic gas; VAMC, Clement J. Zablocki Veterans' Administration Medical Center; FGF, fresh gas flow; LPM, liter per minute.

anesthesia providers in the OR (ie, nurse anesthetist students, nurse anesthetists, attending anesthesiologists). This evaluation also begs the question if a more formal Accreditation Council for Graduate Medical Education-required assessment of an anesthesiology resident's environmental impact should be considered.

Interestingly, it was observed that some residents had an informal competition over who could (safely) practice at the lowest mean FGF per case. Gaming and competition are well-used and effective tools in learner education,[20,21] and institutions wanting to implement a program similar to ours should consider growing the gamification concept (eg, publicly reporting individual resident results during grand rounds).

Conclusions

Our framework for an audit-and-feedback-based program on FGF and WAG-associated emissions achieved a reduction in mean FGF per case per resident during the maintenance portion of care and achieved decreases in extrapolated emissions from WAGs. Residents identified their desire to practice in a climate-friendly manner and responded positively to timely electronic feedback on their own cases.

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Funding: The authors report no external funding source for this study.

Conflict of interest: The authors declare they have no competing interests.

This work was previously presented as an abstract at the Midwest Anesthesia Residents' Conference, April 29-May 1, 2022, St. Louis, Missouri, USA.

Disclaimer: The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the US Government.

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Received June 6, 2023; revisions received October 15, 2023, and January 30, 2024; accepted February 9, 2024.