ENVIRONMENTAL STEWARDSHIP IN ANESTHESIA: AN EDUCATIONAL INTERVENTION FOR CLINICIANS

by

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As members of the DNP Project Committee, we certify that we have read the DNP project prepared by Alexa Gina Darrow, titled Environmental Stewardship in Anesthesia: An Educational Intervention for Clinicians, and recommend that it be accepted as fulfilling the DNP project requirement for the Degree of Doctor of Nursing Practice.

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Final approval and acceptance of this DNP project are contingent upon the candidate's submission of the final copies of the DNP project to the Graduate College.

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DEDICATION

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ABSTRACT

Purpose: The purpose of this educational quality improvement (QI) project was to increase awareness of the environmental impact of anesthetic gases among anesthesia providers to support self-driven environmentally sustainable changes to routine practice.

Background: Operating rooms are remarkably energy intensive. Among numerous resources utilized for surgery, anesthetic gases are responsible for much of the environmental burden of operating rooms. Environmentally sustainable anesthesia practice is an ongoing important area of interest in the setting of widespread global efforts to address the climate crisis.

Methods: Volatile agent-specific labels were affixed to anesthesia workstations at Abrazo West Valley Hospital (AW). Following initial recruitment efforts, a pre-recorded educational presentation on environmental stewardship in anesthesia was made available to anesthesia clinicians at the institution over an 11-day period. After viewing the presentation, participants were asked to complete a retrospective pre-then-post survey on content knowledge.

Results: Nineteen surveys were received by the end of the implementation period, yielding a 68% participation rate. Survey data revealed several areas of knowledge inadequacies: impact of climate change on the human health, burden of inhalational anesthetic agents, and green anesthesia strategies. Free-text narratives demonstrated that responders intend to consider more TIVA (52.9%) and/or modify or limit anesthetic gases administration (36.8%) after participation.

Conclusions: Key findings across all project aims were statistically significant and suggest value in offering a pre-recorded educational presentation with complementary workstation labels to support environmental stewardship among anesthesiology clinicians.

INTRODUCTION

Inhalational anesthetic agents are greenhouse gases with a sizable environmental toll. Considering broad public concerns regarding the imminent threats related to a rising global climate, there is growing interest within the anesthesia profession to improve sustainability. Of particular concern is the ongoing use of anesthetic gases in modern practice.

Inhalational anesthetic agents are core pharmaceutical drugs utilized for rendering anesthesia. Modern agents commonly administered in practice include isoflurane, sevoflurane, desflurane, and nitrous oxide. These agents inevitably reach the atmosphere as a consequence of minimal metabolism by the body and absence of atmospheric disposal regulations (Wyussek et al., 2018). Innovative technology to recycle or reduce environmental wasting of such agents are not yet (or readily) accessible (McGain et al., 2020).

Literature suggests that some practice settings may produce a greater proportion of emissions from volatile anesthetic agents than from the combined emissions generated from surgical supplies, waste, heat, ventilation, and air conditioning (MacNeill et al., 2017). Cumulatively, global healthcare activities account for 4.4% of worldwide net emissions (Health Care Without Harm [HCWH], 2019). However, limited attention is put forth on the healthcare sector across most, if not all, sustainability agendas at the national and international political levels. Consequentially, almost no external pressure or incentives exist to align healthcare with other major trades currently adopting sustainable business practices. Anesthesia providers administer anesthetic gases with a clear environmental burden and have the professional decision-making capacity mitigate the toll. Therefore, these clinicians are in an excellent position to demonstrate public health accountability by engaging in healthcare sustainability initiatives.

Background Knowledge and Significance

Atmospheric release of inhalational anesthetics is a concern in relation to climate change. Climate change, or global warming, is a phenomenon that describes widespread weather permutations attributed to the rising average surface temperature of the globe (United States [US] Environmental Protection Agency [EPA], 2021b). Global observations continue to exhibit a trajectory of intensifying temperatures and, thus far, the warmest year on record is 2016 followed by 2020 (US EPA, 2021c). On a national level, the average surface temperature in the US has risen faster than the global rate (US EPA, 2021b).

Implications of increasing temperatures reflect direct and indirect hazards to public health. According to the World Health Organization (WHO) (WHO, 2021), severe heat, flooding, storms, and drought will jeopardize access to safe shelter, food, clean air, and water supplies. Projections by Carleton et al. (2021) suggest that the direct global mortality cost of climate change may be as high as 73 deaths per 100,000 by the year 2100 in a business-as-usual emissions scenario. However, the mean mortality rate may be as low as 11 deaths per 100,000 under hypothetical conditions that reflect a stabilization and decline of emissions according to the United Nations Intergovernmental Panel on Climate Change (IPCC). The IPCC's projections account for the estimated influence of climate change adaptations to mortality rate (in general, adaptations should decrease mortality rate). Overall, this information suggests that broad yet robust efforts to mitigate emissions can collectively decrease future risks to public health.

With or without sustainability efforts, the carbon footprint of human activities will shape the conditions of public health in the future (Centers for Disease Control and Prevention [CDC], n.d.; WHO, 2021). High-income nations will have the resources to adapt to climate change and, therefore, the capacity to mitigate local damages of climate change in the future (HCWH, 2019). However, communities of low-income nations will ultimately suffer the greatest morbidity and mortality consequences related to climate change (HCWH, 2019). Indeed, individuals residing in these vulnerable regions are key stakeholders of every climate change mitigation initiative. Without collective strategies, global health disparities will compound because low-income nations are less equipped with assets to adapt to a changing environment (HCWH; 2019).

The healthcare sector is a major global trade that undoubtedly generates emissions. Pollution produced by healthcare industries, especially in commercially robust nations, will grow secondary to healthcare advancements (Pichler, 2019). The substantial environmental burden of US healthcare services is particularly problematic and necessitates engagement from not only policymakers and administrators but clinicians as well. Mounting research suggests that the US healthcare sector is the leading contributor of greenhouse gas emissions per capita among healthcare systems across the globe (Eckelman et al., 2020; Eckelman & Sherman, 2016). A report from Health Care Without Harm (HCWH; 2019) suggests that the climate footprint of healthcare is equivalent to the emissions produced by 514 coal power stations on an annual basis. Research suggests that operating rooms specifically may be up to six times more energy-intensive than hospitals as a whole and anesthetic gases may be responsible for over half of the overall burden of operating rooms (MacNeill et al., 2017). Despite such remarkable data, “green” initiatives in US healthcare remain limited to micro-level efforts (Salas et al., 2020; Wyssusek et al., 2018).

All healthcare professionals have inherent responsibilities to support health equity and prevent harm to patients and communities. However, literature suggests that environmentally conscious clinical decision-making remains unrealized by practitioners. In a survey of over 2,100 physician anesthesiologists, less than 15% of respondents reported consideration for the environmental impact of inhaled anesthetic agents when making clinical decisions (Ard Jr. et al., 2016). Major challenges for greening anesthesia and critical care reflect the relative novelty of research on sustainability within these scopes and inconsistencies sustainable clinical decision-making and practice (McGain et al., 2020; Sherman & Ryan, 2010; Zuegge et al., 2019). Although there is growing support to increase environmental stewardship across the anesthesia profession, sustaining engagement in green practice habits and reducing excessive anesthetic gas waste are ongoing challenges (Carter et al., 2019; Zuegge et al., 2019).

All inhalational anesthetic agents are environmentally burdensome chemical vapors. These compounds are greenhouse gases (GHGs) with chemical properties that result in heat retention (Sulbaek Anderson et al., 2012). Major GHG species include carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydrofluorocarbons, sulfur hexafluoride, and nitrogen trifluoride (Lenzen et al., 2020). Nitrous oxide is a non-volatile gas whereas modern volatile agents include hydrofluorocarbons (e.g., sevoflurane & desflurane) or chlorofluorocarbons (e.g., isoflurane) (Gaya da Costa et al., 2021). Therefore, and from here forth, the term “inhalational” anesthetic agents (or gases) will be used as a general term to refer to isoflurane, sevoflurane, desflurane, and nitrous oxide. In contrast, the term “volatile” anesthetic agents (or gases) will specifically reflect the pharmaceutical compounds isoflurane, sevoflurane, and desflurane only.

GHGs contribute to rising temperatures of the earth’s surface owing to the capacity to absorb and emit infrared light radiation for an extensive duration or lifespan (Sulbaek Anderson et al., 2012). Nitrous oxide remains in the atmosphere for 114 years, whereas sevoflurane, isoflurane, and desflurane have atmospheric lifespans of 1.1, 3.2, and 14 years, respectively (Sherman et al., 2017). Of note, xenon is an anesthetic agent with an ideal environmental profile given because it has no atmospheric impact as a sole agent (Guetter et al., 2018). However, xenon is costly to manufacture and not readily available at institutions; therefore, this agent remains an unlikely alternative to the other anesthetic gases at present (Guetter et al., 2018).

In addition to atmospheric lifespan, global warming potential (GWP) is a common metric throughout climate change literature and is a dynamic measurement that is useful for the appraisal of the environmental impact of anesthetic agents. Generating a GWP value involves comparing the climate impact of one gram of a substance relative to one gram of carbon dioxide over a specific duration (McGain et al., 2020; Sulbaek Anderson et al., 2012). The 100-year GWP (GWP_{100}) is the standard index of the IPCC (McGain et al., 2020). For nitrous oxide, a GWP_{100} of 265 indicates that the climate potential for nitrous oxide is equivalent to 265 times that of carbon dioxide over the course of 100 years (McGain et al., 2020). In comparison, sevoflurane, isoflurane, and desflurane have GWP_{100} values of 130, 510, and 2540, respectively (McGain et al., 2020). As a dynamic measure, GWP values may exhibit slight variations. Although GWP values are not standardized in anesthesia literature, minor discrepancies in reported GWP values are inconsequential in terms of clinical significance.

GWP is a simple index of comparison, it does not reflect ozone-depleting capacities of anesthetic gases. For example, an interpretation of nitrous oxide and isoflurane solely based on GWP values would suggest that these agents have a relatively low impact. However, nitrous oxide and isoflurane also contribute to ozone destruction (Gaya da Costa, 2021). Ozone depletion is a pertinent consideration because it affords protection from ultraviolet radiation to all living entities (US EPA, 2021a). Experts emphasize that ozone destruction will directly contribute to higher incidences of skin cancer and cataracts (US EPA, 2021a). Although climate science parameters are complex, exploring the limitations of these metrics are beyond the scope of this project. Nevertheless, there is much value for such discussions on an interdisciplinary level and a basic understanding of environmental impact measures, such as GWP, may simplify professional discourse by allowing stakeholders to comparatively appreciate the burden of anesthetic agents.

Across the available literature inhalational anesthetic impacts are commonly translated to driving distance equivalencies. Seminal experts recommend the use of the driving distance equivalences to measure the impact of inhalational agents and describe outcomes of mitigation initiatives (Sherman et al., 2017). This simple translation allows stakeholders to readily understand the impact of inhalational anesthetic agents with meaningful context. As an outcome measurement, the use of driving distance equivalencies also supports consistency across the growing literature body.

In a general sense, the burden of inhalational anesthetics administration is comparable to driving motorized vehicles. The type of car (e.g., electric, hybrid, & gasoline/diesel [motorcycle, sedan, sports utility vehicle, truck, van, etc.]) is analogous to minimum alveolar concentration (MAC) of an anesthetic agent. MAC is a common parameter used in anesthesia and an index without units. It generally reflects the potency and the steady-state concentration (end-tidal percentage) of an anesthetic agent in the lungs sufficient to deliver an equivalent desired effect of immobilization with another agent (Aranake et al., 2013). For example, McGain et al. (2020) describes one MAC as an end-tidal concentration of 6.7%, 1.2%, and 2.2%, for desflurane, isoflurane, and sevoflurane, respectively. Therefore, one might describe desflurane as a van and isoflurane s a sedan in this example. The use of MAC can also express the differences of impact between, and across, various anesthetic agents on an hourly scale of administration time. In addition to the type of car, driving speed is analogous to fresh gas flow for a specific duration. Total fresh gas flow (FGF) describes the carrier (fresh) gas(es) that deliver(s) the anesthetic agent to the patient at a flow rate, in liters per minute (L/min). This FGF flow rate is set and adjusted by the provider. As an example, one might consider the impact of an agent administered at 2 L/min (e.g., 20 mph) or 6 L/min (e.g., 60 mph) for one hour. In this paper, the term "fresh gas" collectively describes the use of oxygen and/or air.

Of the various inhalational anesthetic agents, key culprits are nitrous oxide and desflurane. McGain et al. (2020) specify that every MAC-hour of desflurane, isoflurane, and sevoflurane delivered at 1 L/min FGF will produce emissions comparable to driving roughly 190 miles, 8 miles, and 4 miles, respectively. In contrast, administration of 60% nitrous oxide at 2 L/min FGF equates to driving 57 miles every hour (Sherman et al., 2017). However, nitrous oxide is unique in that concurrent administration of this agent with a volatile anesthetic may worsen emissions (e.g., sevoflurane or isoflurane) or not alter the impact (e.g., desflurane) (Sherman et al., 2017). Nevertheless, the substantial burden of nitrous oxide is associated with its prolonged atmospheric lifespan of 114 years (Axelrod et al., 2017). Despite its comparatively shorter atmospheric lifespan of 14 years, a MAC of desflurane can produce CO_2 emissions equivalent to driving 200 to 400 miles for every hour of administration at 1 to 2 L/min FGF (Axelrod et al., 2017). Emissions from inhalational anesthetics are a practical concern considering their noteworthy contribution to the environmental burden of the healthcare industry.

Anesthesia providers hold an especially influential position given their capacity to independently select a particular anesthetic technique and/or agent(s) and deliver such anesthetics at their professional discretion. For example, and notwithstanding decisions based on patient-specific physiologic indications, a clinician may be less willing to administer a low-impact agent that is not readily available to them in the operating room. Furthermore, anesthesia providers may administer inhalational anesthetic agents at excessive FGF rates unknowingly (e.g., neglecting to decrease flows after induction), routinely (e.g., predictably setting oxygen and air to 1 LPM each), or deliberately (e.g., creating a semi-open breathing circuit mid-case after observing exhaustion of the carbon dioxide absorber). In a study of 303 patients, providers administered inhaled anesthetics at FGFs 30% and 130% above manufacturer recommendations during anesthesia maintenance with sevoflurane and isoflurane, respectively (Tollinche et al., 2018). However, there are regulatory FGF recommendations for sevoflurane. These recommendations are to minimize the potential for exposure to Compound A, a toxic degradation product from an interaction with the carbon dioxide absorber which contains a strong base (potassium hydroxide or sodium hydroxide) (US Food and Drug Administration [FDA], n.d.-b). Interestingly, administration of sevoflurane below manufacturer recommendations (e.g., using low FGFs) with a non-reactive carbon dioxide absorber may not afford substantial benefit in terms of financial or environmental costs (e.g., anesthetic gas consumption vs. absorbent purchases) (Epstein et al., 2016). It is clear that efforts to improve sustainability of healthcare must involve strategies to increase environmental stewardship from key stakeholders responsible for direct clinical administration of these agents.

Within the research and development domains of anesthesia, there is interest in advancing waste anesthetic gas management technology. Multiple pioneering firms offer products and services to recycle and reclaim volatile anesthetics (Anesthetic Gas Reclamation [AGR] Incorporation, n.d.; Blue-Zone Technologies, n.d.; McGain et al., 2019). However, present scarcity and inaccessibility constrains widespread adoption of such technologies. For example, the cryogenic condensing anesthetic recapturing system engineered by the AGR Incorporation (n.d.) is not yet in large-scale production. Furthermore, the cost of installation and maintenance are certainly factors to consider at the institutional level. Experts reflect that manufacturer support and maintenance of such innovations provides an excellent opportunity to improve the technology and optimize reclamation processes in contrast to single-use equipment (MacNeill et al., 2020). Nevertheless, the American Association of Nurse Anesthesiology (AANA) (AANA, n.d.) encourages anesthesia professionals to stay apprised of such developments and seek opportunities to mitigate the negative impact to the environment through the implementation of waste anesthetic gas management innovations.

Administration of anesthetic gases also carries an occupational risk. Outdated guidelines do not specify recommended exposure limits (RELs) for isoflurane, desflurane, and sevoflurane; however, personnel should not be exposed to any halogenated anesthetic agent at ceiling concentrations above 2 parts per million (ppm) (Occupation Safety and Health Administration [OSHA], 2000). For nitrous oxide, the REL is no greater than 50 ppm of nitrous oxide during an 8-hour workday (OSHA, 2000). Findings from Hiller et al. (2015) suggest that personnel in the post-anesthesia care unit (PACU) may be at risk for chronic exposure to waste anesthetic gases well above OSHA recommendations. Most patients transition directly from the operating room to the PACU; therefore, patients will continue to expel anesthetic gases from their lungs during recovery phases of care. This heightened risk of occupational exposure to waste anesthetic gases may be an area of knowledge deficit for anesthesia and surgical personnel (Kim et al., 2018). Although relatively marginal, exposure to an anesthetic gas likely occurs each time while filling an anesthetic vaporizer with an agent when using the standard closed vaporizer filling system (Varughese & Bacher, 2020). The AANA (n.d.) recommends filling vaporizers when there is less foot traffic (e.g., beginning or end of the day) to prevent gas exposure to personnel and ensuring the use of proper functioning equipment to minimize leaks when filling vaporizers.

Although atmospheric release of inhalational anesthetics is inevitable after administration, occupational exposure to anesthetic gases is largely dependent on adequacy of air control and efficiency of scavenging systems within the institution (Varughese & Ahmed, 2021). These organizational factors are certainly relevant in developing countries that may lack the resources and/or regulations to scavenge waste anesthetic gases. Adverse effects of chronic occupational exposure to low concentrations anesthetic agents may include oxidative stress, mutagenicity, genotoxicity (Braz et al., 2020; NIOSH, 2007; Souza et al., 2016). Some studies also suggest an increased incidence of miscarriage and cancer in exposed workers or spouses, as well as reports of birth defects in their children (Li & Chiu, 2019; NIOSH, 2007). Short-term exposure to high concentrations of waste anesthetic gases, even if brief, can result in neurologic symptoms including headache, irritability, fatigue, sleepiness, and nausea (NIOSH, 2007). These effects could occur in any setting but, again, are particularly relevant to poorly ventilated areas. Although it is currently unrealistic and clinically inappropriate to abandon or prohibit use of all inhalational anesthetic agents, teaching diligent techniques of gas administration is a meaningful way to minimize environmental contamination.

Low-flow anesthesia (LFA) is a recognizable term across modern anesthesia literature as an environmentally sustainable approach to anesthesia. The term may be familiar to many but the definition of LFA is inconsistent across literature and thus clinical application lacks uniformity across the profession (Feldman, 2012; Upadya & Saneesh, 2018). The objective of LFA is to avoid the unnecessary financial and environmental costs of excessive consumption of anesthetic vapors (AANA, n.d.; Suttner & Boldt, 2000). Conceptually, LFA has two aims: (1) deliver fresh gas flow at a rate equivalent to the patient's rate of consumption, and (2) ensure adequate removal of carbon dioxide before recirculation (or rebreathing) of previously exhaled gases (Suttner & Boldt, 2000). Some authors have attempted to specify a flow rate (or range) that constitutes as low (e.g., 1 L/min) (Feldman, 2012). However, others prefer the designation of "minimum flow anesthesia" because demands for fresh gas flows are not absolute (Feldman, 2012). Flow adjustments are patient-specific and dynamic during various phases of anesthesia (Feldman, 2012). During the maintenance phase of anesthesia, for example, a minimal flow rate is an individualized calculation based on multiple factors including the patient's estimated rate of oxygen consumption and rate of gas extraction from the sampling line (Feldman, 2012). Nevertheless, LFA and minimal flow anesthesia are generally interchangeable terms with similar objectives.

Multiple demands must be met to successfully implement LFA in the clinical setting. Functional limitations of LFA use relate to situations where the gas leakage occurs. Examples include maintenance of anesthesia by face mask, procedures within the airway lumen (e.g., leakage from a rigid bronchoscope), or high gas leakage in anesthesia equipment (e.g., large tear in the bellows) (Upadya & Saneesh, 2018). Theoretically, low FGFs limits the extent of occupational exposure to agents during an accidental disconnection of the breathing circuit. The practice of LFA is also dependent on careful matching of oxygen flows to patient consumption which requires appropriately functioning and calibrated gas analyzing equipment (Feldman, 2012). Furthermore, anesthesia providers lacking familiarity with delivering LFA are certainly ill-equipped to satisfactorily perform the technique (Upadya & Saneesh, 2018). Anesthesia machine automation technology may support efficiency concerning this issue.

The consensus across several studies favors the use of anesthesia machines with automated control of end-tidal gas concentrations. In comparison to manual delivery of inhalational anesthetic agents, studies suggest that automated control may improve efficiency of anesthetic gas consumption (Arora et al., 2020; Kandeel et al., 2017; Moran et al., 2019; Potdar et al., 2014; Tay et al., 2013; Singaravelu & Barclay, 2013; Skalec et al., 2017), cost-savings (Potdar et al., 2014; Tay et al., 2013), and increase accuracy of administration (Kandeel et al., 2017; Moran et al., 2019; Singaravelu & Barclay, 2013; Skalec et al., 2017). Despite availability in over 100 countries and in Europe since 2010, the manufacturer of the technology only recently received pre-market approval from the FDA as of April 2022 (Freund, 2022; US FDA, n.d.-a). General Electric (GE) Healthcare is the sole manufacturer of this optional software feature for use as part of GE's Aisys CS^2 Anesthesia Delivery System (Freund, 2022). Implementation of this software is an important consideration for institutions to supplement and support but not replace independent decision-making, for example, when choosing between sevoflurane, desflurane, or total intravenous anesthesia.

Implementation of creative and less technologically dependent interventions are also vital considering the urgent demand for mitigating climate change. Zuegge et al. (2019) reported a 64% reduction in emissions per case after delivering provider education and deploying a cognitive aid directly to their anesthetic gas vaporizers. Their intervention supported not only increased awareness but also encouraged environmental stewardship from providers in real-time. The use of a visual cue regarding anesthetic gas emissions at the workstation is a notable strategy to support environmental stewardship until green technologies become readily available across surgical and procedural settings and accessible to most anesthesia providers.

The potential cost-savings following the implementation of innovative sustainable practices and technology may be of pertinent interest to leadership and hospital administrators. Educational quality improvement (QI) projects have reported institutional reductions in volatile anesthetic purchasing secondary to provider stewardship (Carter et al., 2019; Zuegge et al., 2019). Furthermore, institutions could potentially reduce thousands of dollars of spending on volatile anesthetics by simple adjustments in FGFs (Edmonds et al., 2021; Zuegge et al., 2019). For example, Zuegge et al. (2019) described a 64% reduction in emissions per case after their intervention, including a 55% reduction in desflurane purchases per month. Carter et al. (2019) also observed a trend towards low FGF patterns based on their findings of an 18% reduction in agent purchases compared to the same timeframe of the previous year. Institutions may experience financial benefits owing to implementation of innovative sustainable technologies and reductions in consumption of inhalational anesthetic agents, particularly desflurane, a comparatively costly anesthetic gas. Therefore, educational initiatives to encourage sustainable anesthesia practice has potential to reap benefits for clinicians, institutions, and public health.

Local Problem

Maricopa County has a total population of over 4.5 million people, including approximately 1.6 million individuals residing in the state capitol of Phoenix (Arizona Commerce Authority, 2018). Within the region, over a fifth of the population are employed in the education, healthcare, and social assistant sectors (Arizona Commerce Authority, 2018). Industry-specific greening initiatives have enormous potential to reach numerous change agents given this large representation of healthcare employees in the region.

Among healthcare workers, anesthesia providers continue to express interest in environmental sustainability at the local, national, and global levels. In an OR recycling survey distributed across four Mayo Clinic campuses within the US, Azouz and colleagues (2019) reported that more than 60% of their survey responses came from operating room (OR) personnel employed at the Phoenix campus. Specifically, nearly one-fifth of respondents were certified registered nurse anesthetists and physician anesthesiologists. The majority of their survey participants indicated that they actively recycle at home and felt they lacked sufficient knowledge regarding how to appropriately recycle in the operating room. Although recycling concerns has limited generalizability to the topic of this DNP project, findings of the study suggests that a degree of interest in sustainability may exist among OR personnel, particularly anesthesia professionals. More importantly, the survey results were generally consistent with the findings of multiple quality improvement initiatives in terms of deficiencies in knowledge of green anesthesia practices (Carter et al., 2019; Zuegge et al., 2013). Therefore, provider education is a crucial step in facilitating environmental stewardship on a professional level.

Unsurprisingly, the most populous cities in the US appear to contribute the greatest absolute quantities in emissions across the nation (C40 Cities Climate Leadership Group, 2021b). The city of Phoenix exhibits a particularly substantial environmental burden. Most notably, emissions output from Phoenix exceeds those from New York City and Los Angeles, per capita (C40 Cities Climate Leadership Group, 2021b). Emissions produced by the metropolitan area also ranks third highest in North America following Houston and Chicago (C40 Cities Climate Leadership Group, 2021b). A report produced by the city of Phoenix's Office of Environmental Programs (2021) indicated a marginal 0.5% reduction in emissions despite a 12% increase in population and 26% economic growth between 2012 and 2018. To meet current climate change mitigation goals, the city strives to achieve a 67% reduction in emissions by 2030. This reduction target is 17% greater than the average goal across C40 Cities, suggesting that Phoenix has a larger burden to reduce than most metropolitan US cities. The report also places emphasis on addressing several barriers to success, including establishing industrial partnerships, project funding, and public outreach to motivate use of alternative transportation. Achieving such a substantial goal demands collective engagement at the macro and micro levels and across different industries. This report, however, does not offer to discuss the environmental impact of health institutions. Nationally, the US healthcare sector continues to lag in efforts improving the sustainability of healthcare (Salas et al., 2020; Sherman & Lagasse, 2018). Therefore, the industry's unofficial status of exemption from political pressure to reduce emissions is generally consistent with the local and national levels.

Phoenix is among several metropolitan cities across the nation that have pledged to improve environmental sustainability at the local level with a goal of achieving net-zero emissions by 2050 (Office of Environmental Programs, 2021). Certainly, city authorities must identify target sectors important for mitigating greenhouse gas emissions and climate change preparation while incorporating unique, region-specific action plans to achieve emissions goals. Specific areas of interest in the local Phoenix agenda include community infrastructure, transportation, and water in terms of long-term sustainability (Office of Environmental Programs, 2021). Examples of strategic plans involve doubling tree canopy to reduce heat, increasing public access to electric vehicle charging stations, and expanding community transit for 90% of the local population (Office of Environmental Programs, 2021). Given local attention to the aforementioned sectors, such projects will certainly offer value to residents and are important for reaching net emissions goals. However, execution of these action items demands a considerable financial investment. For example, the city dedicated over five million dollars in annual funding to campaigns and projects to increase tree canopy and shade throughout the city (Office of Environmental Programs, 2021). In addition to cost, stakeholders should also anticipate a substantial investment in time to accomplish these sizable project goals and observe improvements in local emissions output. Although the agenda also includes plans to promote and support green practices on a grassroots level (e.g., through financial incentives, community outreach strategies, & public education initiatives), several of these interactive activities are awaiting community partnerships (Office of Environmental Programs, 2021).

Air quality is another concerning factor regarding the problem of local emissions. Designation of an F-grade quality of air in Maricopa County indicates an ongoing presence of unclean air in Phoenix (American Lung Association [ALA], 2022-a; ALA, 2022-d). Phoenix also remains one of the top 10 metropolitan areas in terms of unhealthy annual particle pollution and days of high ozone, or “smog” (ALA, 2022-c). Individuals of color, low income, extremes of age (under 18 or over 65 years age), and especially those that are pregnant and/or living with chronic pulmonary diseases (e.g., asthma, chronic obstructive pulmonary disease [COPD], or lung cancer) may be particularly vulnerable to negative health effects from air pollution, including illness, disease exacerbation, and death (ALA, 2022-b). Out of millions of residents of the Phoenix metropolitan region, there are nearly 95,000 children living with asthma, over 380,000 adult asthmatics, almost 850,000 adults over 65 years of age, and over 2.3 million individuals of color (ALA, 2022-d). These groups can certainly benefit from air quality improvement directly or indirectly driven by environmental initiatives.

As of 2021, the Phoenix mayor has shown dedication to establishing clean air by joining local leaders of nearly 100 global cities as a member of the C40 Cities Climate Leadership Group (Office of Environmental Programs, 2021). Leadership of member cities must adhere to performance-based standards and group principles that seek to address the climate crisis through collaboration and action (C40 Cities Climate Leadership Group, 2021a). Despite this commitment, there are substantial hurdles for achieving clean air in the region. Currently, air quality in the region remains poor and well below the World Health Organization’s (WHO) standards for particulate matter and ozone (Office of Environmental Programs, 2021). In addition, regional policies and programs to improve air quality in Phoenix remain in infancy. Enactment is further complicated by an inability to monitor air quality and progress towards meeting clean air standards (Office of Environmental Programs, 2021). Currently, baseline air pollutant levels in Phoenix are undergoing establishment (Office of Environmental Programs, 2021).

In addition to poor air quality, regional changes in temperature continue to threaten vulnerable populations within the local community. Over the past 20 years, Phoenix has observed an increase in average nighttime temperatures by nine degrees Fahrenheit (Office of Environmental Programs, 2021). Experts and local authorities recognize and attribute this change to an effect known as an urban heat island (Dialesandro et al., 2021; Mohajerani et al., 2017; Office of Environmental Programs, 2021). This phenomenon suggests that regional development may have a direct impact on local climate (Dialesandro et al., 2021; Mohajerani et al., 2017). Specifically, the quantity of hardscape and concrete surfaces is growing across the regional landscape (Associated Press, 2018; Office of Environmental Programs, 2021). Such surfaces have the capacity to store daytime heat then gradually release that heat throughout the evening hours resulting in higher nighttime temperatures (Mohajerani et al., 2017). Increasing temperatures in this already hot desert region certainly has an impact on the community and highlights population disparities. Latinx and low-income areas in Phoenix and Tucson often experience average temperatures up to five degrees higher than more affluent, white communities (Dialesandro et al., 2021; James, 2021). Phoenix observed 145 days of temperatures above 100 degrees Fahrenheit in 2020 (Arizona Department of Health Services [ADHS], 2021). In the same year, there were 2,414 heat-related emergency room visits and 323 heat-related deaths in the area (ADHS, 2021). Most alarming is that the number of heat-related deaths is growing exponentially each year (James, 2021). However, the impact of climate on vulnerable populations from extreme heat is not a new concern. In fact, the Heat Relief Network program came to fruition after 30 homeless individuals in Phoenix died during a deadly heatwave lasting nine days in 2005 (Maricopa Association of Governments, n.d.). Today, this program continues to offer thousands of individuals with respite and support from extreme heat (Maricopa Association of Governments, n.d.). Although such efforts support communities from suffering the consequences of increasing temperatures, proactive efforts to mitigate climate emergencies are unquestionably in demand.

Intended Improvement

Project Purpose

Literature suggests that administration of inhalational anesthetic agents has serious implications for the environment. Although research is evolving, the absence of substantiative investigations on direct public health consequences of these anesthetic agents challenges environmental stewardship movements across the anesthesia profession. Nevertheless, professional leaders continue to raise awareness of these issues and encourage individual providers and institutional leadership to educate providers and establish green practice initiatives. This quality improvement (QI) project intended to examine the effects of disseminating an educational intervention on anesthesia sustainability and green anesthesia practices among anesthesia providers and residents at the implementation site.

Project Question

Compared to common knowledge, does education on reducing greenhouse gas emissions from anesthesia effectively foster understanding of environmental stewardship in anesthesia among anesthesia providers?

The term *common knowledge* was included in the project question to describe conditions or settings involving individuals that share a unique trait, characteristic, or other feature (e.g., profession) with others. These individuals thereby identify as members of a particular group who are critically familiar with, and have shared knowledge of, information known across other group members (Kuhlman et al., 2020). This information is otherwise known as *common knowledge*.

Project Objectives

Aim 1: Assess for an increase in participant knowledge of the environmental impact of inhalational anesthetic agents.

Aim 2: Implement visual aids at the anesthesia workstations and assess for an increase in practicing stewardship in real-time.

Aim 3: Assess for an increase in participant ability to compare the environmental impact of commonly used inhalational anesthetic agents.

Aim 4: Assess an increase in provider understanding of environmental stewardship strategies that can be integrated into practice.

Aim 5: Identify potential barriers to incorporating environmental stewardship strategies into individual practice.

Theoretical Framework

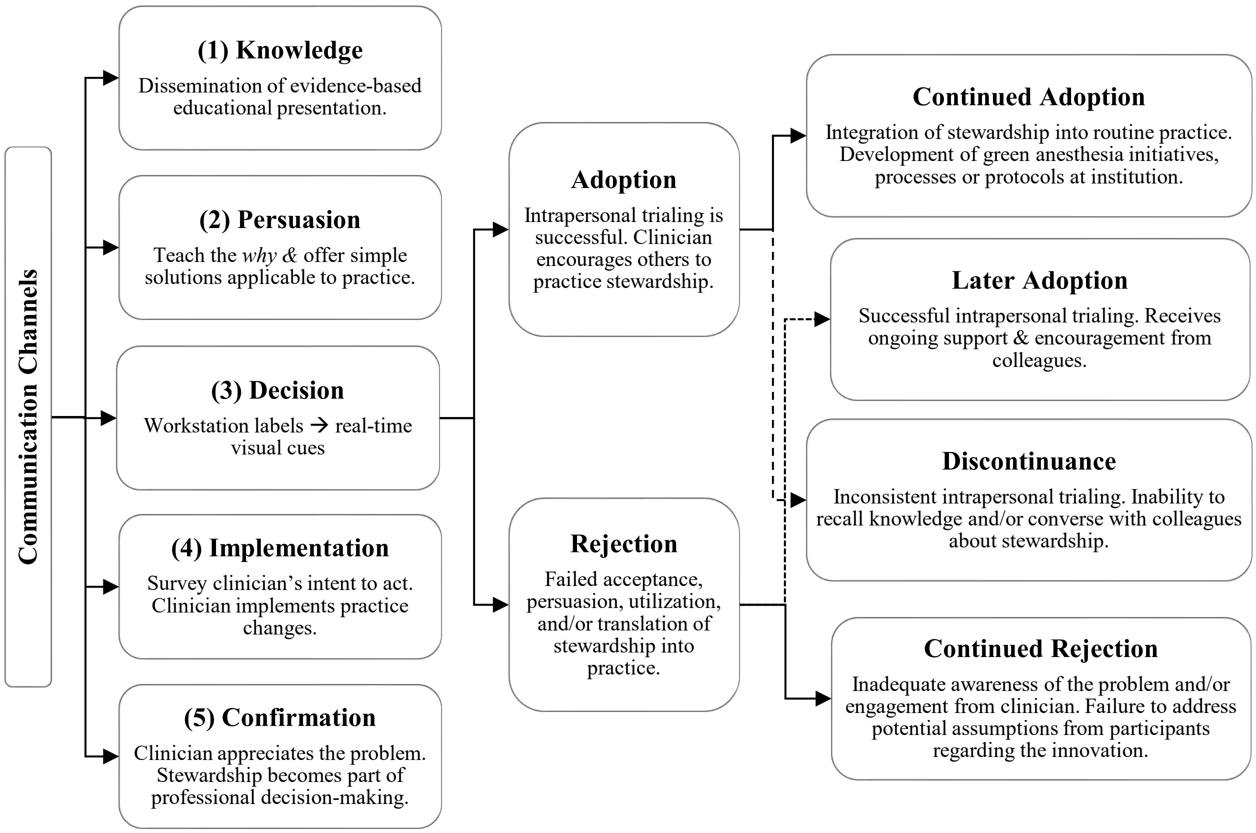
Rogers' Diffusion of Innovations (DOI) theory is a theoretical framework useful for this quality improvement project. Despite technological advancements to mitigate the environmental impact of anesthetic gases, successful adoption of sustainability-related innovations at the institutional level has considerable sociopolitical and financial limitations. Rogers' DOI theory provides a conceptual framework to analyze the diffusion of the educational innovation of this project. The theory also supports project objectives to increase awareness of the environmental impact of inhalational anesthetic agents and encourage environmental stewardship among anesthesia professionals at the implementation site.

Literature supports the use of Rogers' DOI theory to understand and facilitate the process of acceptance and adoption of innovations in clinical settings. For example, findings from Leggott and colleagues' (2016) investigation on the diffusion of peripheral nerve blocks (PNBs) as an adjunct or replacement of general anesthesia for ambulatory orthopedic surgery suggests that innovation adoption is consistent with the DOI theory both quantitatively and qualitatively. The authors reported that the increased acceptance of PNBs among surgeons, anesthesiologists, and nursing staff and use of PNBs at the facility was optional and involved a decision-making process in alignment with the DOI theory. Pashaeypoor and colleagues (2017) also reported value in using the framework to explore the efficacy of evidence-based practice education in teaching nurses to appropriately identify, translate, and apply evidence into practice. Collectively, these findings suggested that the DOI theory was particularly valuable for implementation and acceptance of educational content on environmental stewardship in anesthesia within this quality improvement project.

Everett Rogers' (2003) DOI theory describes the social domains of successful adoption and implementation of healthcare innovations. As shown in Figure 1, the theory explores the pathway of knowledge utilization and translation into practice as a 5-stage orderly process from (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation. This process is a conceptual course of adopting novel practices, programs, policies, or technologies (Allen et al., 2017; Balas, & Chapman, 2018; Dearing & Cox, 2018; Dorr et al., 2018). Indeed, DOI is pertinent to this project considering the demands for improving sustainability of anesthesia within the profession in the setting of ongoing use of inhalational anesthetic agents in modern practice.

Figure 1

Theoretical Framework



Note. Adapted from "Diffusion of Innovations (5th ed.)," by E. M. Rogers. Copyright 2003 by the Free Press.

Important to this innovative project was to explore the fundamental progression of acceptance, utilization, and translation of stewardship into practice as described within the DOI framework. Implementing this educational intervention sought to improve the clinician's awareness of the environmental implications of anesthesia. This task aligned with the initial stages involving knowledge dissemination and fostering engagement among participants and reflect the participant's ability to recall, converse, and accept the messages about the innovation (Rogers, 2003).

To facilitate acceptance of the project, an important aspect of the educational intervention was to address potential assumptions made by participants regarding the project topic. For example, one of the key messages of this project reflected the participant's responsibility to avoid contributing to public health harm through individual decision-making rather than institutional enforcement of a green policy that may impose restrictions on anesthesia providers thereby decreasing workplace satisfaction.

Another DOI theoretical consideration is evaluation of the innovation in terms of engagement and integration into practice (Rogers, 2003). Following the educational presentation, the purpose of implementing simple labels on anesthesia workstations was to support the knowledge, decision, and implementation stages by supporting providers with information recall during periods of real-time decision-making. In addition, retrospective pre-then-post survey responses provided an opportunity to evaluate participants' intent to consider an innovative strategy in their practice. The final stage of confirmation was not evaluated within the timeframe of this project but could be reached when, and if, clinicians integrate environmental stewardship strategies into routine practice and encourage others to improve the sustainability of their practice based on the innovation(s) accepted by the participant.

Although there are important complex considerations inherent to concepts of climate change and "green" practices, analysis of such issues was beyond the scope of this project. Patient-specific, technological, and institutional factors that influence environmental stewardship at the clinical level certainly impact decision-making but were not within the span of this project. Persuading participants to believe in climate change or global warming was also not within the scope of this project; however, any pre-existing appreciation of such phenomena among participants may have favored success within this project. Nevertheless, the intent was to foster stewardship while allowing participants to maintain their personal and political views on climate change within the professional milieu. In doing so, participants may have been more willing to accept knowledge regarding the environmental impact of anesthetic gases.

Furthermore, independent decision-making capacity and professional responsibility to public health were at the forefront of the diffusion process in this project. According to the DOI process, some clinicians will adopt or reject environmental stewardship in practice after implementation of the intervention. However, interpersonal interactions and intrapersonal trialing may contribute to later acceptance or withdrawal from the innovation of environmental stewardship in anesthesia practice.

Literature Synthesis

For this project, the concept of environmental stewardship and use of sustainable anesthetic techniques at the clinician level are defined by the evidence-based recommendations from the American Society of Anesthesiologists (ASA) to assist providers in improving environmental sustainability for anesthesia practice. Although the ASA offers a variety of recommendations for greening the perioperative arena, this quality improvement project focuses on environmentally conscious selection and administration of anesthetic agents. A thorough literature review on environmentally sustainable decision-making in anesthesia is the basis for this educational intervention.

Evidence Search

A focused clinical question was generated in PICO (population, intervention/interest, comparator, outcome) format to identify the primary terms for the literature search. The focus of this search reflects the PICO question, (C) compared to common knowledge, (I) does education on reducing greenhouse gas emissions from anesthesia (O) effectively foster understanding of environmental stewardship in anesthesia (P) among anesthesia providers?

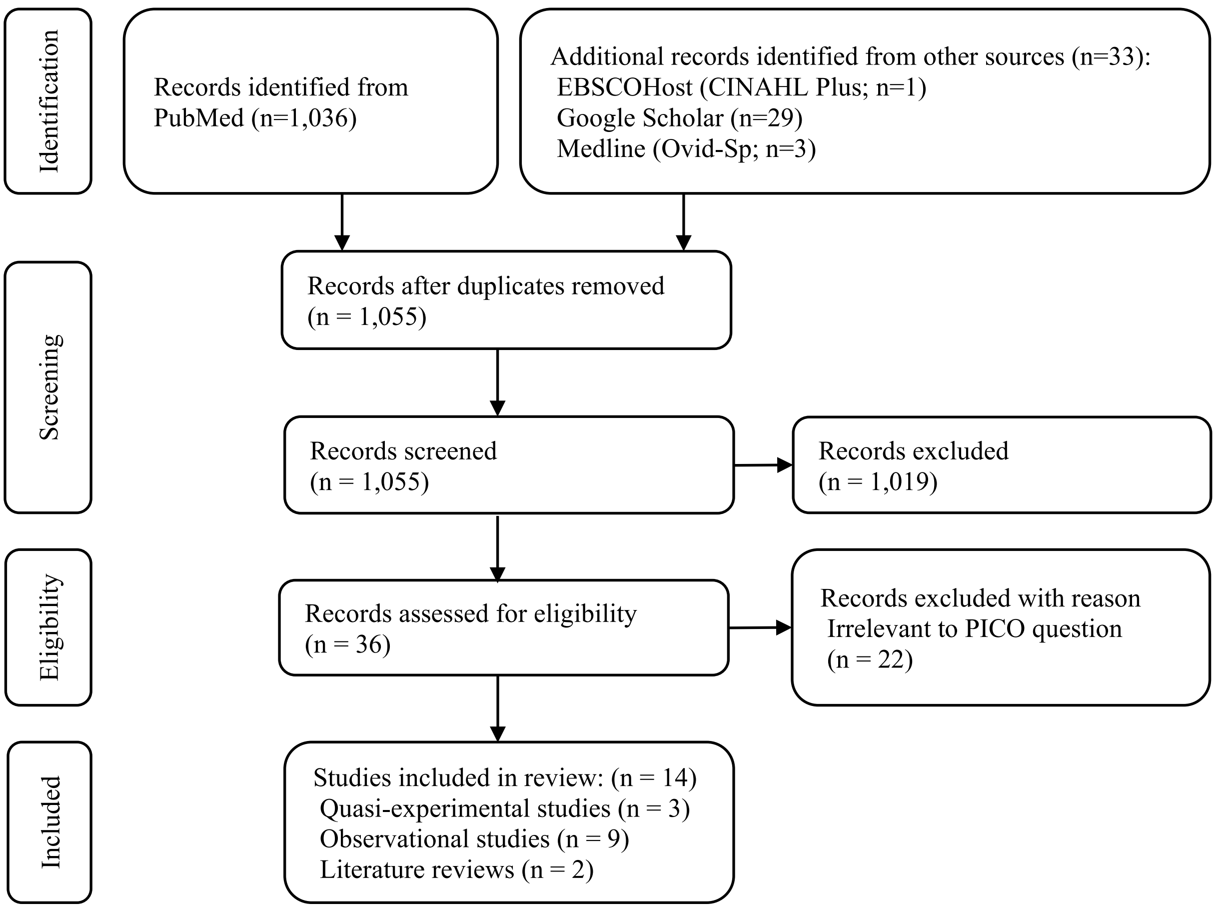
An electronic database search was conducted to identify literature relevant to environmental sustainability in anesthesia. The initial search included relevant papers published between January 2010 and November 2020. Subsequent searches were conducted over the course of project development to include current literature published after November 2020. Electronic databases include PubMed, Medline (Ovid-Sp), Google Scholar, and EBSCOHost (CINAHL Plus). Searches in each database included the following search string: "(*inhalation anesthesia* OR *inhalational anesthetics* OR *anesthetic gases* OR *volatile anesthetics* OR *volatile agents*) AND (*greenhouse gases* OR *greenhouse gas emissions* OR *carbon emissions* OR *global warming* OR *carbon footprint*) AND (*adults* OR *humans*)." The initial search in PubMed using these terms resulted in 1,026 articles; therefore, the search phrase "AND (*fresh gas flow* OR *low flow anesthesia*)" was added to narrow the search.

In addition to the aforementioned search terms, other criteria were set to identify salient articles adequate for analysis of the topic. Criteria included articles available in full text, specific to human species, written in the English language, and published in peer-reviewed scholarly journals. Results of the search across the electronic databases did not produce randomized-control trials, systematic reviews, or meta-analysis, even with an unrestricted timeframe. Therefore, observational studies and other peer-reviewed papers were included in this review. Additional articles were also identified by scanning the reference lists of papers related to the clinical question. The number of articles identified in each database included 10 articles from

PubMed, three from Medline (Ovid-Sp), 29 from Google Scholar, and one from EBSCOHost (CINAHL Plus). After careful review of abstracts and/or summaries of the 43 articles, a total of 14 papers were ultimately included in this review to produce a comprehensive synthesis of literature relevant to the clinical question.

Figure 2

Literature Search Flow Diagram



Comprehensive Appraisal of Evidence

Literature on environmental sustainability in healthcare continues to evolve; however, the development of professional standards for environmentally sustainable anesthesia practice remains in its infancy. The healthcare sector produces a considerable carbon footprint as one of the prominent service industries around the globe, (MacNeill et al., 2017, p. e381). Of the total carbon dioxide (CO_2) emissions from the US, nearly 10% is produced by healthcare systems. For comparison, the percentages in Canada, England, and Australia amount to only 4%, 6%, and 7%, respectively (McGain et al., 2020, p. 683). At the organizational level, operating rooms (and the surgical services associated with them) are disproportionately resource-intensive and waste producing entities (Sherman et al., 2012). Literature suggests that perioperative functions represent more than a third of the hospital waste streams, and of this, anesthetic gases released to the atmosphere contributes the greatest proportion of the total carbon footprint of hospitals (Sherman et al., 2012; MacNeill et al., 2017, p. e385).

Inhaled anesthetic agents are known as greenhouse gases, fluorocarbons specifically, but despite this knowledge, literature indicates that environmentally conscious clinical decision-making currently remains unrealized by practitioners. Desflurane, sevoflurane, and isoflurane undergo minimal, if any, metabolism and degradation before uptake by a gas scavenging system and release into the atmosphere (Sherman & Ryan, 2010). Therefore, currently research generally assumes that the quantity of anesthetic gas consumption is the same quantity that impacts the environment (Sherman & Ryan, 2010; Feldman, 2012; McGain, 2020). Despite these concerns, the growing body of knowledge on environmental anesthesia practice shows promise for future exploration that can lead to sustainable practice transformations. Furthermore, because of multiple call-to-action requests from discipline experts, researchers continue to explore alternative modalities to reduce environmental contamination and the dimensions of individual clinical practice that contribute to GHG emissions. The organization of this narrative on fresh gas flow (FGF) rates and volatile agent selection is by study design, objective, measures, protocols, outcomes, and limitations. Studies are arranged according to study design as follows: three quasi-experimental studies, nine observational studies, and two literature reviews.

The bulk of research in this review are observational studies that explore environmental sustainability of anesthesia practice patterns. The purpose of the longitudinal study by MacNeil et al. (2017) was the direct and indirect scopes of carbon emissions associated with hospital surgical operations in three selected hospital systems of the US, United Kingdom (UK), and Canada. Moving forward, the cross-sectional studies from Ard Jr. et al. (2016) and Karim et al. (2019) observed the practice patterns and knowledge base of anesthesia providers via survey. In comparison, the first study focused on general environmental attitudes while the latter focused on choices of FGF and volatile anesthetic agents specifically. Both studies used electronic modes to deliver their surveys. Conversely, the purpose of the four quality-improvement studies from Kennedy et al. (2019), Zuegge et al. (2019), and Carter et al. (2019) was to influence changes in FGF by providing education to anesthesia providers. Zuegge et al. (2019) implemented visible changes to the anesthetic workstation, including customized vaporizer labels, to facilitate practice changes. The remaining four observational studies were descriptive and aimed to explain the quantity GHG emissions associated with volatile agents. These studies include research by Ryan and Nielsen (2010), Feldman (2012), and Sherman et al. (2012).

The two literature reviews included in this synthesis incorporate numerous original studies and peer-reviewed sources to disseminate information with significant implications on clinical anesthesia practice. McGain et al. (2020) aimed to address the importance of environmental sustainability in both anesthesia and critical care. They also planned to clarify known and unknown knowledge by synthesizing "state-of-the-art" environmental research within the two domains. Comparatively, the narrative review by Wyssusek et al. (2018) focused on the facets of global operating room greening initiatives using electronic database searches according to general academic standards similar to this literature review. All studies included in this review provide meaningful depth to the body of knowledge on the environmental impact of anesthesia practice with practical implications for individual anesthesiologists.

Analysis of samples, measures, and protocols of the specified literature affords insight on the data collection processes of each study design. The experimental studies conducted by Tay et al. (2013) and Skalec et al. (2017) similarly compared manual and automated control of end-tidal anesthetic gas concentrations during general anesthetic cases. The protocols set by Skalec et al. (2017) controlled surgical variance by enrolling lower-risk patients (ASA classifications between 1 & 3) undergoing abdominal and thyroid surgery of greater than 15 minutes duration. They also set parameters of fraction of inspired oxygen, ventilator settings and provided instructions to practitioners for induction and intubation. The protocols set by Tay et al. (2013) was less clear, indicating a divergence of validity among the two studies. Furthermore, Skalec et al. (2017) collected data concomitantly for both groups. This contrasts to the consecutive manner of data collection used by Tay et al. (2013). The data collection process by Tollinche et al. (2018) was also different from these two studies. They collected FGF rates first then subsequently compared sevoflurane and isoflurane use during analysis without prior group allocation. The authors also focused on gas flows during the maintenance phase, as defined by the total anesthesia time less the first and last 30 minutes and eliminated the higher FGF associated with induction and emergence. This was completed over the course of six months at a single facility with all operating rooms equipped with the same machine.

For synthesis of the observational studies in this review, the description of measures and protocols are according to study similarities. Studies by Ard Jr. et al. (2016) and Karim et al. (2019) targeted physician anesthesia providers. Ard Jr. et al. (2016) delivered an email survey to 5,200 ASA members, including anesthesiologists and residents. Of the 24 questions, all were close-ended except the first capturing demographic information. One pertained to the subject matter of this paper which reflected whether providers consider environmental impact in their clinical decisions for anesthetic agent selection. Karim et al. (2019) delivered their questionnaire to anesthesia providers from varying organizations across India. Survey data on isoflurane from all respondents served as the control; however, the allocation process of individuals to the survey on isoflurane plus sevoflurane or isoflurane plus desflurane was unclear.

In contrast to these survey-based studies, MacNeil et al. (2017) segregated operating room functions into three scopes according to a modified version of the Greenhouse Gas Protocol. Much of the extensive data they collected is beyond the focus of this paper; however, the first scope pertained to the pharmaceutical purchase anesthetic agents. During analysis, MacNeil et al. (2017) calculated GHG emissions by converting purchases to volumetric measurements of each anesthetic gas. Studies by Kennedy et al. (2019), Zuegge et al. (2019), and Carter et al. (2019) similarly obtained data on pharmaceutical purchases to analyze FGF and anesthetic agent use trends. Carter et al. (2019) also incorporated spot audits of FGF rates to correlate with purchase trends during analysis. Ryan and Nielsen (2010) and Feldman (2012) used FGF rates and minimum alveolar concentration-hour (MAC-h) of anesthetics to pragmatically analyze GHG emissions. These studies used hypothetical clinical scenarios to determine their results using 100-year or 20-year global warming potential (GWP) as the measurement for comparison. For example, Feldman (2012) compared concentrations of 2.5% and 1% isoflurane delivered via circle system with conditions of a 15-minute induction with a fixed FGF of 8 L/min, followed by 75 minutes of maintenance with a 4 L/min fixed FGF. Alternatively, Sherman et al. (2012) used a unique cradle-to-grave approach to determine the carbon footprint of anesthetic drugs, from synthesis and production to delivery and disposal. The authors used substitutions for drugs or chemicals similar to each volatile agent to determine materials, energy, and emissions. GWP_{100} is a standard measure of GHG emissions across ecological research; however, within anesthesia literature, GWP_{20} is often used by researchers to better reflect the impact of anesthetic agents within their atmospheric lifetime (Sherman & Ryan, 2010).

Strengths of Evidence

Synthesis of outcomes and interpretations will reflect studies related to anesthetic agents first, followed by FGF, and conclude with practice barriers and improvement projects. Research by Ryan and Nielsen (2010), Sherman et al. (2012), and Feldman (2012) confirmed variations in GHG emissions across the three anesthetic gases according to FGF. Feldman (2012) demonstrated decreased efficiency of isoflurane to the patient (increased waste) when a higher drug concentration was administered with a fixed gas flow. Sherman et al. (2012) determined that scavenged anesthetic gases (wasted to the atmosphere) were the single largest contributor of GHG emissions for all three agents, from cradle-to-grave. Moreover, they showed that emissions from desflurane, across its lifecycle, is 15 times and 20 times greater than isoflurane and sevoflurane, respectively, for each MAC-h of delivery (with oxygen and air as carrier gases). Sherman et al. (2012) also identified emissions from volatile agents to be nearly four orders of magnitude greater than propofol. These results have significant anesthesia practice implications.

Several studies use driving equivalents to present an interpretation of their results and in doing so, researchers disseminate information easily recognizable by readers. This is a particularly valuable strategy to illuminate the environmental impact of the individual practitioner's actions when selecting anesthetic gases and FGF. For example, the burden of 1.0 MAC-h of sevoflurane, isoflurane and desflurane delivered at 1 L/min FGF is equivalent to driving four miles, eight miles, and 190 miles, respectively (McGain et al., 2020). Given this understanding, McGain and colleagues (2020) proposed that individual anesthesiologists avoid desflurane, use low gas flows, and consider anesthetic techniques that minimize inhalational agent use. Despite the lack of high-level evidence, these authors offer valuable considerations for decision-making and suggests further studies to quantify the global warming potential of anesthetic practice.

The literature on FGF demonstrate similar outcomes with varying degrees of validity. Analysis by Tollinche et al. (2018) produced statistically significant results that mean FGF patterns were in excess of manufacturer recommendations for sevoflurane and isoflurane-based anesthetic cases alike. The anesthetic simulation performed by Feldman (2012) showed that lower FGF produce less waste. The author posed that a decrease in FGF from 2 L/min to 1 L/min for 500 cases per year for 35 years could prevent 18,900 liters of isoflurane waste into the atmosphere. This result correlates with the conclusions by Sherman et al. (2012) and MacNeill et al. (2017) that atmospheric waste of volatile anesthetics is a modifiable factor within practice that can mitigate global warming. Despite the strong internal validity, one must also consider the external validity of these studies under the pretext of each study's conditions.

Results of the QI and survey-based studies comparably conclude that education is necessary for sustainable practice. Ard Jr. et al. (2016) revealed that only 13.4% of respondents considered sustainability of practice in their clinical decisions. Karim et al. (2018) demonstrated interpersonal and intrapersonal inconsistencies in responses for FGF patterns of isoflurane compared to desflurane and sevoflurane. They similarly conclude the need to address attitudes and behaviors to increase the use of minimal flow anesthesia. This coincides with the favorable reductions in FGF and anesthetic gas use secondary to educational interventions. Zuegge et al. (2019) indicated a 64% reduction in emissions per case after their intervention, including a 55% reduction in desflurane purchases per month. Carter et al. (2019) also observed a trend towards low FGF patterns based on the 18% reduction agent purchases compared to the same timeframe of previous year. Finally, Kennedy et al. (2019) also concluded that education on decreasing flow rates during induction, even with moderate FGF during maintenance, can significantly reduce use of the agents. They note that the effect of FGF reductions during maintenance, however, remains greater than FGF reductions during induction but contribute new information that changes during induction may also meaningfully reduce emissions.

Weaknesses of Evidence

Variations of study objectives and designs within this review imply research novelty on environmental sustainability in anesthesia practice. The aim of the quasi-randomized experimental studies conducted by Tay et al. (2013) and Skalec et al. (2017) was to evaluate FGF fluctuations to maintain a set minimum alveolar concentration (MAC) of anesthetic by comparing automatic versus manually controlled delivery of anesthesia. The primary purpose of the latter study was to evaluate hemodynamic stability in contrast to the environmental and economic interests of the former. Tollinche et al. (2018) sought to assess FGF patterns during the maintenance phase of anesthesia and evaluate the consumption of sevoflurane and isoflurane. This experimental study was also quasi-randomized fashion but only included general anesthetic cases of at least four hours with volatile agents, irrespective of the type of surgical procedure.

Gaps and Limitations

The studies presented in this review afford meaning and purpose to sustainability in anesthesia practice; however, they are not without limitations. Some of these limitations were discussed earlier in the literature review. Quasi-experimental studies offered the highest level of evidence in this review. The study by Kennedy et al. (2019) was in collaboration with, and in the interest of, GE Healthcare. Three authors were employed by the company and two others received speaking fees and honoraria. Furthermore, across the QI projects, conclusions of causality cannot be assumed for any single intervention because of confounders that augmented their interventions (Carter et al., 2019; Kennedy et al., 2019; Zuegge et al., 2019). For example, Zuegge et al. (2019) used multiple outreach modalities and frequencies to encourage practice changes. Carter et al. (2018) optimized engagement by changing outreach modalities throughout the study to capture better results. The researchers also optimized the environment by displacing sevoflurane from anesthetic workstations thereby establishing inconvenience for anesthetic usage by providers. Studies from Karim et al. (2018) and Ard Jr. et al. (2016) also exhibit limitations inherent to their study designs and may not represent true individual practice or beliefs. Finally, the definition of low FGF or appropriate minimum FGF was not standard across studies. FGF below drug manufacturer recommendations was often used as a low FGF rate threshold instead of the more accurate and patient-specific definition of total rebreathing of gases (Feldman, 2012).

The narrative across sustainable anesthesia research highlights the impact of modifying individual practice, notwithstanding the importance of higher-level change. The reviewed studies collectively present the environmental burden of current practice patterns; however, studies suggest that few anesthesiologists consider the environmental implications of their practice. Excessive FGF may correlate with knowledge deficits on the environmental consequences of using anesthetic gases. Multiple studies also confirm the disproportionate contribution of GHG emissions from desflurane. Anesthesiologists are clinically responsible for managing these factors. Therefore, the individual provider has direct control over their contribution of GHG emissions based on clinical decisions. Furthermore, literature suggests future research must evaluate clinical patterns to create interventions that target the knowledge, attitudes, and behaviors of anesthesia providers. This can elicit environmentally conscious clinical decisions, such as minimum FGF, and encourage alternative modalities like regional anesthesia. Discussions across all studies consistently implore researchers to explore areas within anesthesia practice of unknown or unclear ecological burden. Despite the challenges surrounding environmental healthcare research, dissemination of this information can meaningfully influence positive changes in anesthesia practice.

METHODS

Project Design

This DNP quality improvement (QI) project used a retrospective pre-then-post (RPP) survey design to measure knowledge gains and their intent to change among participants following dissemination of the intervention. RPP designs are useful for assessing learner self-reported changes in awareness, attitudes, and knowledge (Howard et al., 1979; Howard, 1980; Little et al., 2019). The RPP favors capturing post-intervention data when time and resource constraints are concerns regarding program evaluation processes (Auld et al., 2017). The design may support internal validity by attenuating the response recalibration effect associated with conventional prospective pretest-posttest designs (Howard et al., 1979; Howard, 1980; Lamb, 2005; Tona et al., 2021). Additionally, RPP can improve participant confidence in recognizing their existing knowledge prior to educational programs and promote self-reflection (Piwowar & Thiel, 2014). This is attributed to the notion that with conventional pretest (pre-intervention) surveys, participants lack sufficient knowledge of a training program to accurately assess their pre-program knowledge (Nimon et al., 2011).

Given this project's broad intent to encourage self-reflection of individual practice, an RPP design was deemed appropriate. Limitations of this design include the risk of a social desirability effect from participants and threats to validity that are inherent to self-reported data (Auld et al., 2017; Hill, 2020). However, prospective pretest-posttest designs are also subject to the same limitations (Lamb, 2005). Administration of a retrospective pre-then-post intervention survey affords the primary investigator (PI) with data to assess utility of the project intervention in terms of improving awareness and fostering environmental stewardship among participants.

The RPP survey included questions of varying structures, some of which captured baseline demographics data. Survey question formats included open-response, Likert-type, and visual analog scaling (VAS) questions. VAS was selected because the format favors capturing data in studies assessing for particularly small changes in comparison to conventional Likert-type scale that limits responses to fixed categories (Chang & Little, 2018).

Model for Implementation

Plan-Do-Study-Act (PDSA)

The Plan-Do-Study-Act (PDSA) process within the Model for Improvement was used to foster improvement within this project. PDSA is a methodical approach involving preparation, implementation, observation, and analysis of a change initiative (Institute for Healthcare Improvement [IHI], n.d.). A PDSA cycle influences the planning phase of the subsequent cycle with progressive improvements in the quality of the change initiative according to observations and data analysis of the previous cycle (IHI, n.d.). Overall, this cyclic process underscores the importance that quality improvement and implementing change are enduring processes. This project utilized a single PDSA cycle given the limited duration for implementation at the clinical site. Project champions and site leadership can improve upon the foundation established by this project by utilizing results to guide subsequent PDSA cycles.

Plan

The plan for this QI project was to improve environmental stewardship among anesthesia providers at the implementation site. Plans included developing an educational presentation to increase provider knowledge and creation of visual cues for the anesthesia workstation. Labels were designed to reinforce the content of the presentation and facilitate practice stewardship by presenting a visual reminder. Two days prior to the intervention, the plan was to email anesthesia providers at the site and present a colorful, attention-grabbing sign in the anesthesia office to facilitate participant recruitment. A list of email addresses for 15 members of the anesthesia team was obtained from the site coordinator for the purposes of project recruitment. The plan also included executing workstation labels on the same day of initial recruitment to provide an additional mode to gain participation interest. The educational presentation recording was planned to be available for 11 days.

Do

Implementation and data collection was planned to take place after the planning phase. The presentation recording was made available to participants two days after initiation of recruitment. After watching the pre-recorded presentation, each voluntary participant would receive access to a quick response (QR) code and link to the single survey for data collection. Implementation plans also included distribution of participation rewards including a certificate of completion, $10.00 gift certificate, and badge pin.

Study

A comparison of results would be made against project aims as part of the data analysis strategy. The intent was to include mean responses before and after the education. Collection and analysis of demographics data was deliberately planned to gather insight into sample population characteristics.

Act

The act phase was structured to involve a review of the data and evaluation of the entire PDSA cycle for effectiveness. Depending on interpretation of results in terms of participant readiness to make the desired change, the plan was to discuss opportunities for site leadership to carry out additional PDSA cycles or repeat the cycle on a larger scale after the conclusion of the project (Perla et al., 2013). However, conducting additional PDSA cycles was not planned given the limited timeframe allotted for this project.

Setting and Stakeholders

Implementation of the project took place at Abrazo West Valley Hospital (AW). AW is in a suburb of the Phoenix metropolitan region within Maricopa County. Participation was targeted to anesthesia providers (certified registered nurse anesthesiologists [CRNAs], physician anesthesiologists, & resident registered nurse anesthesiologists [RRNAs]). However, other stakeholders of this initiative include operating room personnel (perioperative registered nurses & anesthesia technicians), pharmacy staff (pharmacists & pharmacy technicians), department leadership, clinical coordinator, and patients. Furthermore, the greater community was certainly considered the prevailing macro-level stakeholder of sustainability efforts. Indeed, implementation of green initiatives today is in the interest of benefiting successive generations of communities at-large.

The implementation site (AW) utilized an independent anesthesia practice model with CRNAs and physician anesthesiologists. As employees of an anesthesia group, many, if not all, of these licensed practitioners practice at other local hospitals in addition to AW. Physician anesthesiology residents were not present at AW at the time; therefore, anesthesia trainee participants included RRNAs only.

Planning the Intervention

Intervention planning involved communications between the primary investigator (PI) and the AW anesthesia clinical coordinator to proceed with stakeholder buy-in. The PI gleaned valuable insight into identifying stakeholder knowledge deficit, culture of the setting, and interest in the project topic through these discussions. An additional strategy considered was to provide key stakeholders with a brief report on the institution's estimated carbon footprint associated with anesthetic gas consumption in comparison to recent studies from other institutions. Creation of the report would require simple calculations using pharmacy reports of quantity of each inhalational anesthetic agent bottle purchased over a week or month. However, the pharmacy department was unable to provide the PI with such information upon request; therefore, calculated estimations of the institutions carbon footprint was not performed.

Anesthesia workstations in six of the ten main ORs were equipped with both sevoflurane and isoflurane vaporizers. The remaining four main ORs at the institution had sevoflurane vaporizers only. Despite desflurane non-use at this facility, this project could potentially educate providers that work at other facilities that may be equipped with desflurane. Given that providers may encounter other volatile anesthetic agents at other institutions, the impact of this educational intervention had potential to transcend the boundaries of this facility.

Another key component of planning involved the creation of participant interactive materials. The PI created the presentation, vaporizer labels, recruitment signage, and post-education certificate. Visually appealing materials were generated with a uniform design across these items. In addition, a freelance artist created an original design for the badge pin reward using colors consistent with the aforementioned participant materials. For the anesthesia workstation signage, the PI crafted a label with content that emphasized the environmental impact of sevoflurane and regulatory recommendations for fresh gas flow rates. Labels were sized to fit the face of the vaporizers, printed in color, then laminated to allow for normal workstation cleaning processes. All materials were sent to the committee chair for approval prior to implementation.

The implementation phase of the project would involve knowledge dissemination and institution of anesthesia workstation labels. On the first day of implementation, the PI planned to post invitations to participate in the educational intervention in the anesthesia workroom and anesthesia call rooms. The invitation included a QR survey code to the pre-recorded 15 minute lecture to afford all clinicians with an opportunity to participate at their convenience (e.g., meal breaks or at home). At the end of the recording, the PI would ask participants to complete a survey on their personal mobile device. The invitation also included a visually distinct, separate QR code to complete the survey after watching the presentation.

The PI planned to affix agent-specific labels to the vaporizers attached to anesthesia workstations in all the operating rooms on the first day of recruitment. Implementation of the labels at this time was chosen because these visual cues could serve as an additional strategy for gaining participant interest in the project. The plan was to distribute three rewards to providers upon completion of the survey to show appreciation for participation. Rewards included a certificate of completion, badge pin, and $10.00 electronic gift card to their choice of Starbucks or Jimmy John's.

Participants and Recruitment

Project implementation occurred from February 18 through March 2, 2023. Recruitment flyers and emails were distributed as described above on the first day of implementation. Agent-specific anesthesia workstation labels (Appendix E) were affixed to vaporizers in all main operating rooms (ORs) on February 18. Sevoflurane labels were affixed on corresponding vaporizers in all 10 main ORs. Isoflurane labels were affixed on workstations in six of the main ORs where isoflurane vaporizers were present. Figure 3 shows an anesthesia workstation at the implementation site after label deployment. An email reminder was sent to all members of the anesthesia team on the Monday during the last week of implementation on February 27.

Figure 3

Photograph of Anesthesia Workstation After Implementation of Labels

Note. Agent-specific labels were affixed to anesthesia workstations equipped with vaporizers of the corresponding agent.

The primary investigator (PI) began recruitment of voluntary participants at the institution on February 18, 2023. Recruitment flyers and email invitations were sent to anesthesia providers at the implementation site following approval of the project by the project chair, site administrators, and the University of Arizona Institutional Review Board (IRB). The invitation included participant eligibility criteria, expected duration of participation, and a statement affirming survey response anonymity and de-identification of data. This QI project did not fulfill the qualifications of human subjects' research (Appendix A) and a formal letter of determination was obtained prior to implementation.

Recruitment flyers (Appendix C) were posted in the anesthesia office and anesthesia call rooms on the first day of implementation. The recruitment email (Appendix C) with electronic links and QR codes was sent on the first day of implementation. The recruitment email explained the nature of the project, including the presentation topic, eligibility criteria, available dates for participation (February 20 to March 2), expected duration, participation incentives, disclosure and consent statements and contact information. Copies of this email was distributed and made available in the anesthesia office on the same day. Some 15 anesthesia providers (CRNAs & physician anesthesiologists regularly staffed at the implementation site) received the email. An additional five nurse anesthesia residents and eight CRNAs not regularly staffed at the implementation site were invited to participate and given a copy of the email distributed by the site clinical coordinator during the implementation period. A second email to encourage participation and survey completion was sent to the same 15 providers on February 26.

Consent and Ethical Considerations

Participant data protection, privacy, and confidentiality was achieved using Qualtrics, a secure online software platform which allows for data collection and analysis. There was no conflict of interest to report for this QI project. Fidelity was achieved by ensuring the time commitment required from participants and site administration was reasonable and appropriate for the team.

Data Collection

The retrospective survey was constructed in the Qualtrics platform through the University of Arizona with 30 items based on content of the presentation, literature review findings, and consultation with project committee faculty members. Project outcomes were directly measured using Likert scale formatted questions and open-format questions.

The first 10 questions established survey responder demographics including current gender, education level, anesthesia credential, total years of anesthesia practice, years (of practice) at the implementation site, and number of facilities where the responder is employed. Additional demographics questions inquired about each responders' practice in terms of the number of anesthetic cases they perform or supervise in a typical week and the frequency of performing general anesthesia, total intravenous anesthesia (TIVAs), and regional anesthesia in a typical week.

The next 14 questions were close-response retrospective pre-then-post (RPP) survey questions in which responders rated their status on subject knowledge prior to and after viewing the educational presentation. Items were rated on a 4-point scale, with ratings of '1' or '2' representing less than adequate knowledge ("no[ne]" or "very little"), and '3' or '4' indicating moderate (“basic”) to superior knowledge (“very knowledgeable”). Question 24 inquired about the survey responder’s opinion on whether anesthesia providers can be part of the solution for climate change before and after the intervention.

Questions 25 and 26 allowed survey responders to rank the educational presentation in terms of increasing knowledge and the likelihood of sharing the content. The next two questions allowed free text comments on changes they plan to incorporate into practice after watching the presentation and perceived barriers for implementing green anesthesia strategies. The final two survey questions were related to the selection and distribution of participation rewards. At the conclusion of the survey were statements regarding consent, anonymity, and confidentiality.

Voluntary participants completed the survey after viewing the pre-recorded presentation. All survey responses were automatically deidentified in Qualtrics. Deidentified responses to 29 and 30 were designated a numeric code to match gift card preferences with email addresses and names for the distribution of participation rewards compiled independently from survey responses in a secure Excel file. To protect participant privacy, all collected survey data was secured in a password-protected file and encrypted USB drive in a locked office. The PI had exclusive access to the password-protected file, encrypted USB drive, and office and all passwords were only known to the PI. Collected email addresses were not used for any other purpose than for distribution of the $10.00 gift card and certificate of completion. The gift card and certificate were sent to email addresses provided by survey responders on the final day of implementation. At the conclusion of the project, all stored information was deleted, and the USB drive reformatted to ensure security.

Data Analysis

An automated report of deidentified survey data was obtained from Qualtrics and complied into Microsoft Excel. All close-response items were analyzed using descriptive statistics including means, medians, percentages, and standard deviations.

Parametric or nonparametric test analysis was determined based on the assumption of whether the data assumes a normal distribution. Non-parametric testing was chosen under the assumption that normality of the shape or parameters of the population distribution from which the sample was drawn were not normally distributed or not known (Conover & Iman, 1981). Survey data for items 11 to 24 were paired from the same respondents and coded to nominal values and therefore met the prerequisites for analysis using the Wilcoxon signed rank sum test. Incomplete responses for paired survey items were excluded from inferential analysis.

Free text comments from items 27 and 28 were analyzed for practice change and barrier domains, respectively, to illustrate the impact of this activity on the individual learner and future opportunities for diffusion of this innovation.

RESULTS

Responses from 15 CRNAs, one physician anesthesiologist, and three nurse anesthesia residents were received during the implementation period. The invitation was presented to some 28 anesthesia providers (CRNAs, physician anesthesiologists, & nurse anesthesia residents) and a total of 19 surveys were submitted. This recruitment effort yielded a total of 19 participants and resulted in a 68% participation rate. All but 10 survey questions had one or two missing responses. Missing data did not correlate with a specified pattern and were not included in the results.

Survey responders represented all categories of education level, anesthesia practice years, years of practice at the implementation site, and number of practice facilities. The majority of participants were CRNAs with 4-6 years of experience in anesthesiology, practice at more than one facility, and perform over 15 general anesthetics in a normal week. Survey responses indicate that total intravenous general anesthetics and primary regional anesthetics are typically performed two or three times each week. A complete list of demographic results is available in Table 1. Aggregate results of anesthetic technique characteristics are given in Figure 4.

Table 1

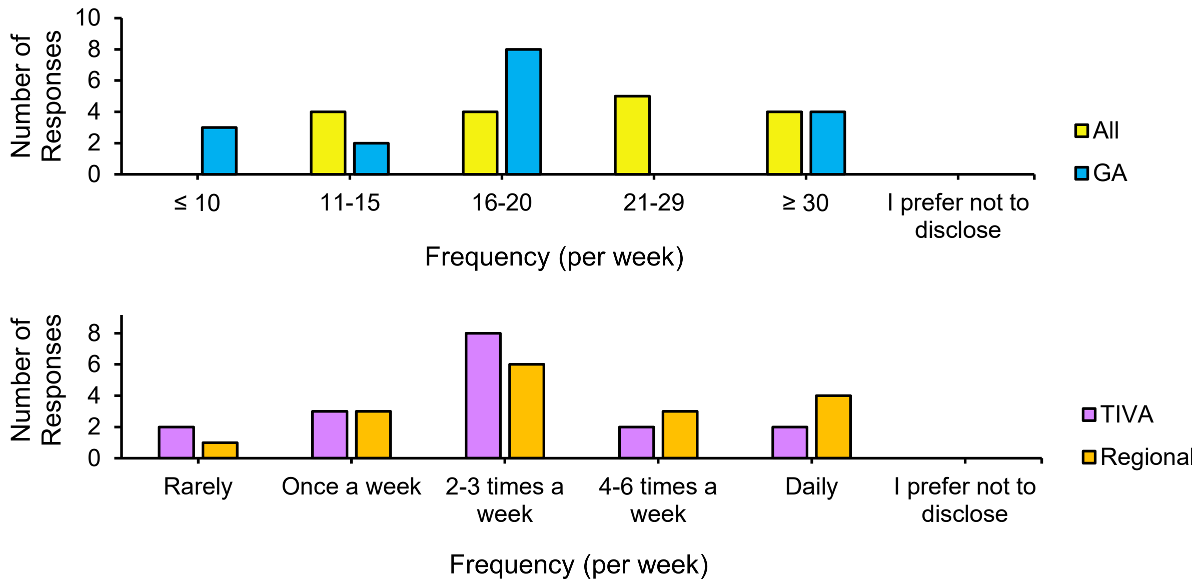
Descriptive Statistics for Participant Demographics

Parameter	Frequency, *n* (%)	Parameter	Frequency, *n* (%)
Gender		Years of Anesthesia Practice	
Man	13 (68.42)	4-6 years	5 (26.32)
Woman	6 (31.58)	< 1 year	3 (15.79)
Transgender	0 (0.00	7-10 years	3 (15.79)
Nonbinary	0 (0.00)	None or in-training	3 (15.79)
I use a different term	0 (0.00)	1-3 years	4 (21.05)
I don't know	0 (0.00)	11-20 years	1 (5.26)
I prefer not to disclose	0 (0.00)	I prefer not to disclose	0 (0.00)
Missing	0 (0.00)	Missing	0 (0.00)
Credential		Years of Practice at the Implementation Site	
CRNA	15 (78.95)	3-5 years	5 (26.32)
Physician	1 (5.26)	< 1 year	4 (21.05)
Resident	3 (15.79)	None or in-training	4 (21.05)
I prefer not to disclose	0 (0.00)	1-2 years	5 (26.32)
Missing	0 (0.00)	I prefer not to disclose	1 (5.26)
Highest Level of Education		Missing	0 (0.00)
Master's degree	10 (52.63)	Number of Practice Facilities	
Doctorate	5 (26.32)	2 sites	5 (26.32)
Bachelor's degree	4 (21.05)	3 sites	2 (10.53)
I prefer not to disclose	0 (0.00)	≥ 5 sites	4 (21.05)
Missing	0 (0.00)	1 site	2 (10.53)
		None or in-training	3 (15.79)
		4 sites	2 (10.53)
		I prefer not to disclose	1 (5.26)
		Missing	0 (0.00)

Note. *n* = 19. CRNA, Certified Registered Nurse Anesthesiologist; percentages may not equal 100% due to rounding errors. Doctorate education examples provided in the survey include Doctor of Philosophy (PhD), Doctor of Nursing Practice (DNP), Doctor of Nurse Anesthesia Practice (DNAP), Doctor of Nursing Science (DNS), Doctor of Osteopathic Medicine (DO), Doctor of Medicine (MD), etc.

Figure 4

Types of Anesthetics Performed or Supervised in a Typical Week



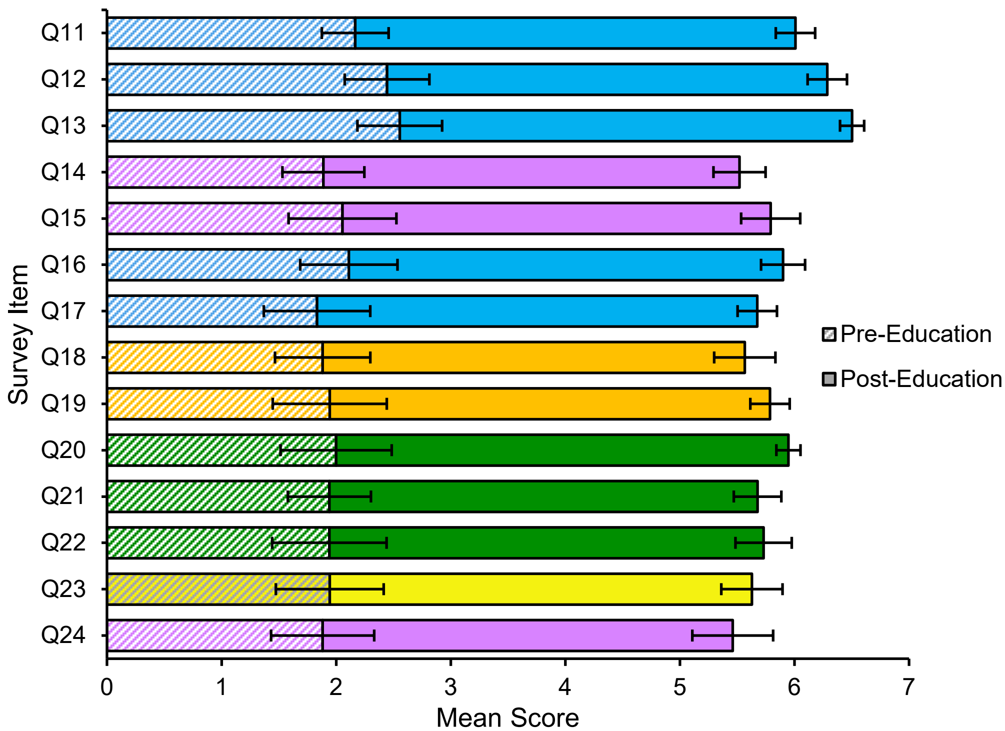
Note. *n* = 19. GA, general anesthesia; TIVA, total intravenous anesthesia. "All" represents the total number of anesthetics (e.g., all techniques). Participants were asked to identify how often they perform (or supervise) a type of anesthetic during a typical week based on results from items 7, 8, 9, and 10 of the evaluation instrument (see Appendix D).

Outcomes

Project outcomes were directly measured using open and closed-response survey items. Close-response questions were used to obtain demographics, practice characteristics, and knowledge assessment measures using a Likert-type scale format. For items 11 through 24, participants were asked to rank their knowledge before and after the intervention on a nominal scale of '1' to '4' with a score of '1' indicating none or the participant had no knowledge; '2,' low or very little knowledge; '3,' moderate or basic knowledge; and '4,' high or very knowledgeable. Mean knowledge scores for paired survey items are illustrated in Figure 5 with 95% confidence intervals. A complete list of descriptive and non-parametric results for paired survey items are provided in Table 2. Comparison of pre-then-post intervention knowledge assessment items were analyzed using Wilcoxon signed rank test. The results of the two-tailed Wilcoxon signed rank test were significant based on an alpha value of .05, $p < 0.001$ indicating that the differences between scores before and after the intervention are not likely due to random variation.

Figure 5

Average Knowledge Scores with 95% CI Error Bars



Note. CI, confidence interval; Q, question. Bar colors for each survey item correspond with an aim of the quality improvement project. The five aims are represented by the following: (1) blue, (2) yellow, (3) orange (4) green, and (5) purple.

Table 2

Descriptive Statistics and Non-parametric Test Results for Survey Assessment Questions

Survey Question	*n*	Missing	Mean	Median	Min	Max	SD	Q_1	Q_3	*Z*-score [c]
Q11: Rate your knowledge of the environmental impact of inhalational anesthetic agents. [a]										
Pre-Education	18	1	2.17	2.00	1	3	0.62	2	2.8	-3.825†
Post-Education	19	0	3.84	4.00	3	4	0.36	4	4	
Q12: I understand that inhalational anesthetic agents can have a big impact on the environmental burden of operating rooms. [a]										
Pre-Education	18	1	2.44	2.00	1	4	0.76	2	3	-3.493†
Post-Education	19	0	3.84	4.00	3	4	0.36	4	4	
Q13: I know that anesthetic gases are greenhouse gases. [a]										
Pre-Education	18	1	2.56	2.50	1	4	0.76	2	3	-3.601†
Post-Education	19	0	3.95	4.00	3	4	0.22	4	4	
Q14: Rate my overall knowledge of the public health consequences of rising global temperatures. [a]										
Pre-Education	18	1	1.89	2.00	1	3	0.74	1	2	-3.561†
Post-Education	19	0	3.63	4.00	3	4	0.48	3	4	
Q15: I understand that low-income communities will likely suffer the greatest morbidity and mortality consequences related to climate change. [a]										
Pre-Education	18	1	2.06	2.00	1	4	0.97	1	2.8	-3.236†
Post-Education	19	0	3.74	4.00	2	4	0.55	4	4	
Q16: I know that nitrous oxide contributes to ozone depletion and ultraviolet radiation exposure. [a]										
Pre-Education	18	1	2.11	2.00	1	4	0.87	1.3	3	-3.564†
Post-Education	19	0	3.79	4.00	3	4	0.41	4	4	
Q17: I understand that nitrous oxide is a greenhouse gas that remains in the atmosphere for over 100 years. [a]										
Pre-Education	18	1	1.83	2.00	1	4	0.96	1	2	-3.589†
Post-Education	19	0	3.84	4.00	3	4	0.36	4	4	
Q18: I can generally compare the emissions produced by sevoflurane, desflurane, and isoflurane. [b]										
Pre-Education	17	2	1.88	2.00	1	4	0.83	1	2	-3.561†
Post-Education	19	0	3.68	4.00	2	4	0.57	3.5	4	
Q19: I know that desflurane has an atmospheric lifespan greater than both sevoflurane and isoflurane. [a]										
Pre-Education	18	1	1.94	2.00	1	4	1.03	1	2.8	-3.464†
Post-Education	19	0	3.84	4.00	3	4	0.36	4	4	
Q20: I understand that delivering one hour of sevoflurane at 1 MAC produces more greenhouse gas emissions than a total intravenous anesthetic with propofol. [a]										
Pre-Education	18	1	2.00	2.00	1	4	1.00	1	2.8	-3.473†
Post-Education	19	0	3.95	4.00	3	4	0.22	4	4	
Q21: Rate my overall knowledge of strategies to minimize anesthetic gas waste. [b]										
Pre-Education	17	2	1.94	2.00	1	3	0.73	1	2	-3.682†
Post-Education	19	0	3.74	4.00	3	4	0.44	3.5	4	
Q22: I understand that I can reduce environmental waste of anesthetic gases by turning off fresh gas flow(s), instead of the vaporizer, prior to breathing circuit disconnections. [b]										
Pre-Education	17	2	1.94	2.00	1	4	1.00	1	2	-3.453†
Post-Education	19	0	3.79	4.00	2	4	0.52	4	4	

Table 2 – Continued

Survey Question	*n*	Missing	Mean	Median	Min	Max	SD	Q_1	Q_3	*Z*-score [c]
Q23: I routinely take steps to make my practice more environmentally sustainable throughout my workday.										
Pre-Label	18	1	1.94	2.00	1	4	0.97	1	2	-3.464†
Post-Label	19	0	3.68	4.00	2	4	0.57	3.5	4	
Q24: Do you think anesthesia professionals can be part of the solution for climate change? [b]										
Pre-Education	17	2	1.88	2.00	3	4	0.90	1	3	-3.223†
Post-Education	19	0	3.58	4.00	4	4	0.75	3	4	

Note. SD, standard deviation; Q_1, first quantile (25th Percentile); Q_3, third quantile (75th Percentile); MAC, minimum alveolar concentration. Missing data did not correlate with a specified pattern and were not included in the results. [a] $n = 18$. [b] $n = 17$. [c] Results analyzed using the Wilcoxon signed rank test.

† Statistical significance based on $\alpha = .05$, $p < 0.001$, two-tailed.

All survey responders reported that they *strongly agreed* (n = 18; 94.74%) or *agreed* (n = 1; 5.26%) the educational session enhanced their knowledge about stewardship (question 26). Questions 11, 12, 13, 16, and 17 inquired about the participants' knowledge of the environmental impact of inhalational anesthetic agents before and after viewing the educational presentation. Knowledge score means across all these items was lower before the education (n = 18; Mean_{Pre} ranged from 1.83 to 2.56) compared to after the education (n = 18; $\text{Mean}_{\text{Post}}$ ranged from 3.79 to 3.95). Wilcoxon signed ranks tests indicated that the median posttest ranks were higher than median pretest ranks ($\alpha = .05$; $p < 0.001$). Knowledge improvement across these items were statistically significant (n = 18; $p < 0.001$ for questions 11, 12, 13, 16, and 17).

Question 23 asked about the impact of the workstation labels on executing green anesthesia strategies in real-time before and after implementation of the visual cues. The median score before implementation was 2.00, indicating little to no knowledge to routinely take steps to green their practice. The median score after the labels were affixed in the main ORs increased to 4.00, which was statistically significant (n = 18; $p < 0.001$) change.

Questions 18 and 19 examined participant's ability to compare the environmental impact of commonly used inhalational anesthetic agents. Participants ranked their ability to compare the emissions produced by volatile anesthetic agents (question 18) with an average score of 1.88 before (n = 17) and 3.68 after viewing the presentation (n = 19). When asked to rank their knowledge of the atmospheric lifespan of desflurane relative to those of sevoflurane and isoflurane (question 19), the mean response before and after viewing the educational presentation was 1.94 (n = 18) and 3.84 (n = 19), respectively. Nonparametric test results indicated that these improvements were statistically significant question 18 ($n = 17$; $Z = -3.561$, $p < 0.001$); question 19 ($n = 18$; $Z = -3.464$, $p < 0.001$).

Questions 20, 21, and 22 inquired about participants' awareness of green anesthesia strategies. Analysis of survey responses to question 21 demonstrated a statistically significant increase in overall knowledge of strategies to minimize anesthetic gas waste ($n = 17$; $Z = -3.453$, $p < 0.001$). Question 22 inquired about a strategy to minimize anesthetic gas waste prior to breathing circuit disconnections. Responders reported a statistically significant increase in knowledge on the technique after the presentation ($n = 18$; $Z = -3.464$, $p < 0.001$). Regarding awareness of greenhouse gas emissions from volatile anesthetics compared to propofol TIVA (question 20), responders reported a lower median score before (2.00; $n = 18$) than after (4.00; $n = 19$) participants viewed the presentation. Nonparametric analysis of responses for question 20 was statistically significant ($n = 17$; $Z = -3.473$, $p < 0.001$).

When asked to describe green strategies that participants plan to incorporate in practice (question 27), 52.9% ($n = 19$) of responders expressed an increased motivation to choose TIVA. A representative comment was "I've always wondered about the environmental impact comparison of TIVA with volatile agents when including manufacturing and waste. I enjoyed that information. I'll be more likely to run TIVA when appropriate." The second most-common change domain related to volatile anesthetic administration (36.8%). One survey responder documented "I now feel more aware of the impact of my use of gases. I am going to try and use less." Other domains described by responders related to nitrous oxide use (10.5%) and regional anesthesia (5.3%). A complete list of change domains with examples are available in Table 3.

Table 3

Commonly Reported Change Domains for Environmental Stewardship

Change Domain	Example quote	Frequency, *n* (%) [a, b]
Q27: Please describe the changes you plan to incorporate into your practice after participating in this educational activity.		
Total intravenous anesthesia	"More conscious in choosing geta vs tiva."	9 (52.9)
	"I guess I'll use more tiva to save Mother Earth."	
	"I've always wondered about the environmental impact comparison of TIVA with volatile agents when including manufacturing and waste. I enjoyed that information. I'll be more likely to run TIVA when appropriate."	
	"I plan to incorporate more TIVAs in my anesthesia delivery because it can reduce greenhouse gas emissions. I didn't realize it could have such an impact on the environment."	
Nitrous oxide	"Continue to use low flows when possible and minimize use of desflurane and nitrous."	2 (10.5)
	"Limit my use of nitrous oxide."	
Volatile anesthetic agent administration	"I now feel more aware of the impact of my use of gases. I am going to try and use less."	7 (36.8)
	"I plan to utilize minimal flows when using volatile anesthetics."	
	"I also plan to turn off FGF during circuit disconnections rather than turning off the vaporizer. I didn't realize it make such a difference in wasting anesthetic gases."	
Regional	"Use minimal flows and advocating for more regional when appropriate."	1 (5.3)
No change	"None."	1 (5.3)
Missing		4 (21.1)
Other	"Yes absolutely."	1 (5.3)

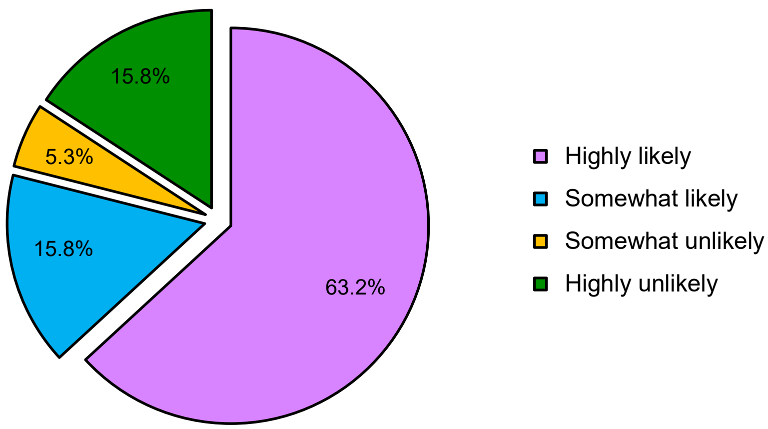
Note. $n = 19$. TIVA, total intravenous anesthesia. [a] Frequency was calculated by the number of responses related to a domain divided by the total number of submitted surveys ($n = 19$). [b] Percentages may not equal 100% due to responses related to more than one domain.

Quantitative analyses were performed on questions 14, 15, 24, 25, and 26 related to identifying barriers for environmental stewardship in practice. The average score for question 14 indicated that responders had *very little* to *no knowledge* of public health consequences of climate change before the educational session ($n = 18$; Mean = 1.89). Knowledge improvement scores on this topic were statistically significant after viewing the presentation ($n = 18$; $Z = -3.561$, $p < 0.001$). On average, results indicate a statistically significant improvement in understanding of the morbidity and mortality impact of climate change on low-income communities (question 15) after the education ($n = 18$; $Z = -3.236$, $p < 0.001$).

Although most survey responders reported *likely* to share learned information with others (63.16% *highly likely* and 15.79% *somewhat likely*), approximately one-fifth of responders indicated that they were *unlikely* to share the content (15.79% *highly unlikely*; 5.26% *somewhat unlikely*) (Figure 6).

Figure 6

'Likelihood to Share Learning with Others' Response Distribution



Note. N = 19. Number of responses are based on results from item 26 of the evaluation instrument (see Appendix D).

Qualitative responses to question 28 was evaluated for domains that responders perceived as potential barriers for incorporating green anesthesia techniques into their practice (Table 5). Out of 19 submitted surveys, the most frequently described practice barrier was related workflow and production pressure (*n* = 8; 42.1%) followed by culture and/or expectations of other providers (e.g., surgeons) or the institution (15.7%). Representative comments were "facility culture, surgeon preference for general over regional," and that "TIVAs take more time to set up than traditional inhaled anesthetics." Although most responders (*n* = 12; 63.16%) reported *highly likely* to sharing the content of the educational activity with others (question 25), few responded *highly unlikely* (*n* = 3; 15.79). Additional examples are presented in Table 4.

Table 4

Commonly Reported Potential Barriers for Environmental Stewardship

Barrier	Example Quote	Frequency, *n* (%) [a, b]
Q28: Please describe potential barriers to incorporating green anesthesia strategies into your practice.		
Cost	"The cost for [*sic*] bottle of propofol is … [more than] a bottle of sevo … here."	1 (5.3)
Workflow and/or production pressure	"Patient care and effective, efficient workflow." "TIVAs take more time to set up than traditional inhaled anesthetics." "OR time management." "Fast paced work areas. Gas is easier to use."	8 (42.1)
Culture and expectations	"Facility culture, surgeon preference for general over regional." "Entrenched ideas of other providers and institutions."	3 (15.7)
Missing		5 (26.3)
Other	"Habit of using sevo and nitrous." "Patient selection."	4 (21.1)

Note. *n* = 19. TIVA, total intravenous anesthesia. [a] Frequency was calculated by the number of responses related to a domain divided by the total number of survey responders (*n* = 19). [b] Percentages may not equal 100% due to responses related to more than one domain.

DISCUSSION

Summary

Outcomes of this quality improvement (QI) project were measured using a combination of open and close-response survey items. Survey data identified participant knowledge inadequacies regarding the impact of climate change on the human health, burden of inhalational anesthetic agents, and green anesthesia strategies. On average, responders reported having little to no previous knowledge of the public health consequences of climate change (n = 18; CI = 1.51, 2.27) especially for low-income communities (n = 18; CI = 1.56, 2.55). Pre-education results also demonstrated that providers were unaware of the overall environmental impact of inhalational anesthetic agents (n = 18; CI = 1.86, 2.47) and the extent by which anesthetic gases contribute to the burden of operating rooms (n = 18; CI = 2.06, 2.83). After participating in the intervention, responders reported a better overall understanding of strategies to minimize environmental waste of anesthetic gases (n = 17; $p < 0.001$) and an increase in practicing stewardship on a routine basis ($n = 18$; $p < 0.001$). However, production pressure and workflow concerns were frequently (42.1%) cited as a practice limitation.

Data analysis revealed considerable improvements in knowledge using a pre-recorded presentation and real-time reminders at anesthesia workstations to complement learning. All except one responder ($n = 19$) *strongly agreed* that the project augmented their knowledge of environmental stewardship in anesthesia. Open-response narratives demonstrates that participants intend to consider more TIVA (52.9%) and/or modify or limit anesthetic gases administration (36.8%). Such findings substantiate the value of informing anesthesia providers about environmental stewardship.

Interpretation

The survey explored multiple dimensions of increasing knowledge to support environmental stewardship in anesthesiology among clinicians. Survey data demonstrated statistically significant improvements in knowledge across all aims of the project following implementation of the study intervention. Observations revealed that survey responders had a better understanding of the general and relative environmental burden of commonly used inhalational anesthetic agents and clinical strategies to minimize their professional carbon footprint after viewing the educational presentation of this project. The knowledge deficit on the topic is consistent with findings from Ard Jr. and colleagues' (2015) large survey study. The authors' findings showed that very few of physician anesthesiologist survey responders reported that they make environmentally conscious anesthetic choices and nearly one-third were unaware of the environmental burden of anesthetic gases.

Furthermore, the information presented on the labels reinforced the content of the educational presentation; therefore, placement of labels on anesthesia workstations supported environmental stewardship awareness in real-time. The benefit of vaporizer labels as visual reminders within this project generally aligns with the findings of Zuegge et al. (2019) who also revealed substantial savings in cost and emissions with their use. Overall, improvements in knowledge after this project's intervention were statistically significant. Thus, findings imply strength in the project to deliver pertinent yet incisive information to participants in an accessible manner. Collective results suggest that dissemination of an educational presentation and workstation labels ameliorated desired outcomes for the project.

Implications

Practice

Survey results produced convincing evidence to suggest that the intervention provided clinicians with sustainability knowledge applicable to their practice. Administrators and leadership at the implementation site should not consider this project as a static endeavor. Ongoing efforts to offer the educational presentation to incoming providers may support a cohesive agenda for sustainable anesthesia practice across the team and facilitate a culture of stewardship. Workstation labels should remain in effect to visually remind clinicians of the environmental implications of volatile anesthetics and encourage these providers to practice environmental stewardship in real-time. Over time, these modalities may foster routine stewardship behaviors and decision-making.

Education

Participants represented providers of all educational levels and years of experience in anesthesiology. Across this comprehensive group was a common lack of education regarding the environmental toll of healthcare and anesthesia, implications of climate change on public health, and strategies to mitigate burden. This suggests a gap in anesthesiology curricula and an opportunity to improve education across professions of the discipline. The educational content was comprehensive yet brief, and the pre-recorded presentation was accessible for clinicians to view at a time of their convenience and across mobile and desktop devices.

Multiple rewards were offered to increase participation for this project, including a certificate of completion. To garner attention from providers, professional education committees and training program developers should consider accompanying a visually appealing and interactive educational module with an incentive, such as continuing education credits or certification.

Research

Findings of this project contribute to the growing body of evidence on anesthesia practice sustainability. This study reveals deficits in knowledge regarding the issue and sheds light on characteristics of practice, including frequency of performing various anesthetic techniques and perceived barriers for stewardship. As suggested by McGain and colleagues (2020), global use of anesthetic gases remains uncertain. However, results of this study uniquely offered insight into the types and frequencies of anesthetics practiced at this facility. Although results are not generalizable across the global anesthesia landscape, this project may afford value to future change agents.

Future projects should also evaluate outcomes by assessing long-term knowledge retention in combination with objective data collection. Indeed, Zuegge and colleagues (2019) notably collected purchasing data for volatile anesthetic agents to demonstrate substantial outcomes after implementing their vaporizer labels. Encouraging findings of this project suggests that vaporizer labels may be an invaluable supplemental resource for supporting stewardship within educational initiatives to improve practice sustainability.

Policy

Reproduction of this quality improvement project at institutions with or without a sustainability agenda can enhance knowledge of the environmental implications of anesthesia and encourage green practice changes across anesthesiology professionals. Despite a lack of national environmental policies to mitigate emissions produced by healthcare, initiatives to educate others on the environmental implications of anesthesia can inform institutional policy for anesthesia practice improvement (Devlin-Hegedus et al., 2022). Therefore, educational projects will continue to be invaluable for facilitating grassroots green anesthesia efforts while awaiting environmental policy development and motion.

Although this project sought to effect individual change, the burden of addressing healthcare-associated greenhouse gas emissions does not lie solely on practitioners. Pursuance of environmental justice mandates critical analysis of the environmental impact of health systems. Macro-level investigations and analyses can certainly guide environmental policies and systems-level changes and produce meaningful, long-term improvements in the sustainability of US healthcare. Opportunities to effect change not only exist across regional hospitals, but also within national programs such as the Veteran's Administration and the Centers for Medicare and Medicaid Services.

Limitations

A potential weakness of this project is whether the survey sample was representative of anesthesiology practitioners and trainees of the institution. For example, results may have been affected by sample bias if participation was limited to a group of providers particularly interested in green initiatives. In addition, multiple rewards were incorporated in this project to attract participation from clinicians less enthusiastic about greening their practice and/or encouraging sustainability in the workplace. Despite knowledge improvements after the intervention, approximately 21% of responders do not anticipate spreading knowledge about stewardship with others, suggesting that nonresponse sample bias is less likely.

Further opportunities to improve this project relate to evaluation instrument operationalization in the setting of sustainability research limitations within anesthesia. The survey was reviewed by a multidisciplinary committee comprised of faculty experts in the field of anesthesiology or environmental sciences and relevant questions were rephrased for content validity according to faculty recommendations. Efforts were made to design project materials to improve the participant's understanding of content by simplifying vocabulary and defining complex concepts. However, operationalizing the evaluation instrument with beta testing might have improved the clarity and ease of understanding of the questionnaire. Nevertheless, Cronbach's alpha coefficient can be used to examine reliability of survey measures. According to George and Mallery (2016), reliability of the scale is considered poor, questionable, acceptable, good, or excellent when the Cronbach's coefficient alpha is greater than 0.500, 0.600, 0.700, 0.800, or 0.900, respectively, or unacceptable when found to be 0.500 or less. The 14 survey items testing stewardship knowledge were found to have a Cronbach's coefficient alpha of 0.93, 95% CI [.88, 0.97] for pre-education scores and 0.93, 95% CI [0.90, 0.97] for post-education scores. Despite the absence of previously validated measures to test aims relevant to this project, the evaluation instrument designed for this project had an excellent degree of consistency across measured responses.

The presence of bias is also an important consideration concerning evaluation of project outcomes. Social desirability and self-inflation bias may influence the accuracy of change responses (scores) and are inherent to self-reported measures of change (Hill, 2020). Retrospective evaluation of project outcomes has the advantage of attenuating errors of pretest score overestimation, a type of response-shift bias often observed with conventional (pre-intervention) testing (Hill, 2020). However, results may be affected by limitations associated with recall, a desire to appear competent (to oneself, leaders, etc.), and/or a tendency to inflate one's actions, attitudes, or behaviors (Hill, 2020). Nevertheless, retrospective pre-then-posttests are recognized as an accessible and trustworthy approach for quantitative evaluations of learning outcomes (Hill, 2020; Hwalek et al., 2022; Little et al., 2020; Nimon & Astakhova, 2015; Young & Kallemeyn, 2019; Watson & Shang, 2021).

DNP Essentials Addressed

Essentials of a Doctor of Nursing Practice (DNP) education are foundational competencies established by the American College of Nurses (AACN) (DNP Essentials Task Force, 2006). The DNP Essentials Task Force (2006) delineate eight competencies to provide an educational framework for graduates to facilitate health advocacy initiatives and transformative practice by exercising leadership, scholarship, and collaborative efforts. DNP Essential III, for example, promotes integration of current research into advanced clinical practice (Zaccagnini & White, 2017). With the scientific foundation and clinical scholarship of DNP Essential III, the DNP-CRNA can certainly incorporate environmental stewardship techniques into clinical practice through critical evaluation and research translation regarding various modern anesthetic agents. Additionally, DNP Essential VII focuses on strategies for improving health through engagement, leadership, interventions, and critical inquiry (Zaccagnini & White, 2017). This project fulfilled this competency by encouraging transformation of anesthesia practice in favor of minimizing climate change contributions and subsequent public health harm. Another competency addressed by this project was DNP Essential VI, which underlines collaboration across disciplines to achieve such goals. (Zaccagnini & White, 2017). Contributions of the multidisciplinary project committee strategically supported the desired goals given the overlap of scientific disciplines regarding the project topic.

Conclusions

Anesthesia practitioners have a commitment to provide safe and comfortable anesthetics. However, considerations for quality, evidence-based anesthesia practice certainly extends beyond the patient-provider encounter. As healthcare providers, clinicians have a duty to provide care with due diligence and in the interest of the public. As demonstrated by project findings of this QI project, anesthesia providers demonstrated a willingness to learn about the environmental implications of their practice and were able to identify evidence-based strategies for providing more sustainable anesthetics. The educational intervention of the project was not only simple and accessible but also effective in achieving desired outcomes. Such results suggest that educational initiatives are fundamental to efforts to transform anesthesia practice in a manner that exhibits and values environmental stewardship. Specifically, initiatives to educate and shift health care practices in favor of environmental stewardship should be at the forefront of today's public health agenda.

Plan for Sustainability

This DNP project enhanced knowledge of environmental stewardship among the providers educated on the environmental implications of anesthetic gases and evidence-based strategies to mitigate the burden of anesthesia practice. Maintaining the presence of vaporizer labels in operating rooms at Abrazo West Valley Hospital will remind these providers to utilize learned strategies in real-time. In addition, anesthesia leadership at the institution will retain access to the pre-recorded educational presentation for distribution to prospective clinicians and residents. In effort to support the environmentally sustainable anesthesia agenda, the presentation will be available to view by any healthcare professional interested in the content.

Plan for Dissemination

A poster presentation was constructed to provide a structural overview of this QI project for dissemination of findings. The poster was presented to CRNAs and RRNAs in attendance at the Arizona Association of Nurse Anesthesiology's state-wide annual Sun and Fun Conference in March 2023. The PI also disseminated project findings with the anesthesia leadership at the implementation site on April 1, 2023, which included insight regarding project efficacy, strengths and weaknesses, and potential strategies to guide future improvements for the quality of the initiative according to analysis of successes and barriers of the DNP project and implications for practice.

Funding

All incentives and materials produced for this quality improvement project were funded exclusively by the PI. No funds, gifts, or reimbursement were accepted by any individual or entity for any portion of this project.

APPENDIX A

SITE AUTHORIZATION LETTER/THE UNIVERSITY OF ARIZONA INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS DETERMINATION LETTER

Abrazo West Valley Hospital
13677 W McDowell Rd
Goodyear, AZ 85395

December 13, 2022

University of Arizona Institutional Review Board
c/o Office of Human Subjects
1618 E Helen St
Tucson, AZ 85721

Please note that Ms. Alexa Dang, UA Doctor of Nursing Practice student, has permission of the Abrazo West Valley Hospital to conduct a quality improvement project at our facility for her project, "Environmental Stewardship in Anesthesia: An Educational Intervention for Clinicians."

Ms. Dang will present an educational presentation, affix labels at the anesthesia workstations, and conduct a survey of health care providers at Abrazo West Valley Hospital. She will recruit providers through email and using print flyers. The email and print flyers will provide a description of the project, what they will be asked to do, the time involved, and links to the presentation and online survey. Ms. Dang's activities will be completed no later than March 30, *2023*.

Ms. Dang has agreed to provide to my office a copy of the University of Arizona Determination before she recruits participants. She will also present aggregate results to the providers at a staff meeting.

If there are any questions, please contact my office.

Signed,

Jared Thirjung, CRNA
Clinical Coordinator

University of Arizona IRB
845 N Park Ave., Suite 537A
Tucson, AZ 85719
Fax: 520-621-9810
VPR-IRB@arizona.edu

NOT HUMAN RESEARCH

February 15, 2023

Alexa Darrow

Dear Alexa Darrow:

On 2/15/2023, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title:	Environmental Stewardship in Anesthesia: An Educational Intervention for Clinicians
Investigator:	Alexa Darrow
IRB Submission ID:	STUDY00002572
Sponsor:	None
Prime Sponsor:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• Advisor Attestation, Category: Other; • Evaluation Instrument, Category: Data Collection Tool; • Participant Materials, Category: Participant Material; • RB Protocol for Determination of Human Research form, Category: IRB Protocol; • Recruitment Materials, Category: Recruitment Materials; • Site Authorization Letter, Category: External Site Authorization;

The IRB determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations.

IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities are research involving humans in which the organization is engaged, please

University of Arizona IRB
845 N Park Ave., Suite 537A
Tucson, AZ 85719
Fax: 520-621-9810
VPR-IRB@arizona.edu

submit a new request to the IRB for a determination. You can create a modification by clicking **Create Modification / CR** within the study.

All Covered Individuals must disclose all sponsored and non-sponsored Research Projects to the Office for Responsible Outside Interests (OROI) prior to Conducting Research if the individual is an Investigator. Please visit the OROI website for more information.

We value your feedback and would appreciate you taking the time to complete our survey about your experience with the IRB staff:
https://uarizona.co1.qualtrics.com/jfe/form/SV_ehQ04WxNA06b42i.

If questions arise at any time during your study, please email the general IRB inbox at VPR-IRB@arizona.edu.

APPENDIX B

CONSENT DOCUMENT (DISCLOSURE FORM FOR CONSENT TO PARTICIPATE)

Environmental Stewardship in Anesthesia: An Educational Intervention for Clinicians

Disclosure Statement for Consent to Participate

Principal Investigator: Alexa G. Darrow, BSN, RN, DNP Candidate

The purpose of this quality improvement project is to provide clinicians with current literature regarding environmental considerations within anesthesia practice and improving professional practice. The goal is to support anesthesia providers at Abrazo West Valley Hospital to consider their individual practice and simple strategies to green their professional footprint.

If you choose to participate in this project, you will be asked to view a fifteen-minute pre-recorded PowerPoint presentation and complete a post-presentation survey. The estimated total time commitment for participation is expected to be 20 minutes. Survey responses are anonymous. Participation in this educational session is voluntary with no known or foreseeable risks associated with participation. You will receive no immediate benefit from participation.

If you choose to participate in the study, participation is voluntary; refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may withdraw at any time from the study. In addition, you may skip any question that you choose not to answer. By participating, you do not give up any personal legal rights you may have as a participant in this study.

If you have any questions, concerns, or complaints regarding this project, please contact Alexa Darrow at alexadang@arizona.edu

APPENDIX C

RECRUITMENT MATERIAL (RECRUITMENT EMAIL AND RECRUITMENT FLYER)

Dear Participant,

You are invited to participate in an educational session on environmental stewardship in anesthesia. The session involves viewing a short (15-minute), pre-recorded slideshow presentation. Following the presentation, you will be asked to complete a brief survey. The total time commitment for participation is expected to be approximately 20 minutes.

This was developed by resident registered nurse anesthesiologist, Alexa Darrow, as part of her Doctor of Nursing Practice project. Educational content of the presentation was developed using current literature and recommendations from the American Society of Anesthesiologists, global professional anesthesia organizations, and field experts. You are being asked to participate based on your scope of practice as anesthesia professionals.

Participant feedback and personal identifiers will remain anonymous, deidentified, and confidential, and all data collected will be stored securely. Your feedback can be used to guide site-specific protocols for environmental stewardship initiatives and future scholarly projects. You will receive a $10 electronic gift card to your choice of Starbucks or Jimmy John's for your time participating in this project.

Participation in this educational session is voluntary with no known or anticipated risks. You have the right to decline or withdraw participation at any time. You may also choose to skip any question in the survey. Your decision to participate or not will be respected and will not have any effect on the relationship with the University of Arizona.

Please use the two links below to access the PowerPoint presentation and survey at your earliest convenience. **Please view the presentation and complete the survey no later than March 1, 2023.**

If you have any questions, concerns, or comments regarding this project, please contact Alexa Darrow at alexadang@arizona.edu.

Thank you for your participation in this project.

Alexa Darrow, BSN, RN, CCRN-CSC, RRNA
DNP-Nurse Anesthesia
The University of Arizona

Slideshow Presentation Link with Audio & Video: https://tiny.cc/ESAedu

Post-Presentation Survey Link: https://tiny.cc/ESAsurvey

Dear Participant,

Last week, you were invited to participate in an educational session on environmental stewardship in anesthesia. If you have already viewed the presentation and completed the survey, your participation is appreciated, and no further action is required.

If you have not watched the presentations and/or completed the survey, please consider taking the time to participate in this doctoral project.

Please use the two links below to access the slideshow presentation and survey at your earliest convenience. **Please view the presentation and complete the survey no later than March 1, 2023.**

If you have any questions, concerns, or comments regarding this project, please contact Alexa Darrow at alexadang@arizona.edu.

Thank you for your participation in this project.

Alexa Darrow, BSN, RN, CCRN-CSC, RRNA
DNP-Nurse Anesthesia
The University of Arizona

Slideshow Presentation Link with Audio & Video: https://tiny.cc/ESAedu

Post-Presentation Survey Link: https://tiny.cc/ESAsurvey


Environmental Stewardship
IN ANESTHESIA
Educational opportunity for all anesthesia providers & residents!
• Watch the brief online presentation
• Check out the new labels at your workstations
Complete the survey
Get rewards!
• Certificate of completion
• Badge pin
• $10 e-Gift card to Starbucks or Jimmy John's
FEBRUARY 20 - MARCH 2
• Check your work email or visit the anesthesia office for more info on voluntary participation.
• Questions? Contact Alexa Darrow, RRNA at alexadang@arizona.edu

APPENDIX D

EVALUATION INSTRUMENTS (POST-PRESENTATION SURVEY)

Environmental Stewardship in Anesthesia Post-Presentation Survey

Demographic Information

1. What is your current gender?
    a. Woman
    b. Man
    c. Transgender
    d. Nonbinary
    e. I use a different term: (please identify)
    f. I don't know
    g. I prefer not to disclose

2. What is your highest level of education?
    a. Bachelor's degree
    b. Master's degree
    c. Doctorate (MD, DO, PhD, DNP, DNAP, DNS, etc.)
    d. I prefer not to disclose

3. Year(s) of practice in anesthesia:
    a. None or in-training
    b. < 1 year
    c. 1-3 years
    d. 4-6 years
    e. 7-10 years
    f. 11-20 years
    g. > 20 years
    h. I prefer not to disclose

4. Please identify your current anesthesia credential.
    a. CRNA
    b. Physician (MD/DO)
    c. Resident
    d. I prefer not to disclose

5. How many years have you worked as an anesthesia provider at Abrazo West Valley Hospital?
    a. None or in training
    b. < 1 year
    c. 1-2 years
    d. 3-5 years
    e. 6-9 years
    f. ≥ 10 years
    g. I prefer not to disclose

6. Select the total number of facilities that you are currently employed at as an anesthesia provider. (Examples: hospitals, clinicals, and/or private practices)
    a. None or in-training
    b. 1 site

   c. 2 sites
   d. 3 sites
   e. 4 sites
   f. ≥ 5 sites
   g. I prefer not to disclose

7. Select the TOTAL number of anesthetics you perform (or supervise) in a typical week.
   a. ≤ 10 anesthetics
   b. 11-15 anesthetics
   c. 16-20 anesthetics
   d. 21-29 anesthetics
   e. ≥ 30 anesthetics
   f. I prefer not to disclose

8. Select the number of GENERAL anesthetics you perform (or supervise) in a typical week.
   a. ≤ 10 general anesthetics
   b. 11-15 general anesthetics
   c. 16-20 general anesthetics
   d. 21-29 general anesthetics
   e. ≥ 30 general anesthetics
   f. I prefer not to disclose

9. In a typical week, how often do you provide a TOTAL INTRAVENOUS general anesthetic (TIVA)? (Example: general anesthesia without anesthetic gases)
   a. Rarely
   b. Once a week
   c. 2-3 times a week
   d. 4-6 times a week
   e. Daily
   f. I prefer not to disclose

10. In a typical week, how often do you perform a REGIONAL block for SURGICAL-LEVEL anesthesia coverage (examples: neuraxial block or peripheral nerve block with motor blockade)?
   a. Rarely
   b. Once a week
   c. 2-3 times a week
   d. 4-6 times a week
   e. Daily
   f. I prefer not to disclose

Assessment

INSTRUCTIONS. Each prompt will have two places to pick an answer.

For your first answer, think about what you knew before listening to the presentation then use the slider to tell us how much knowledge you feel you had on the content *BEFORE* the education.

For your second answer, use the slider to tell us how much knowledge have right now *AFTER* the education.

If you do not wish to respond, please select the option "I choose not to answer".

1 = None – no knowledge
2 = Low – very little knowledge
3 = Moderate – basic knowledge
4 = High – very knowledgeable

11. Rate your knowledge of the environmental impact of inhalational anesthetic agents.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

12. I understand that inhalational anesthetic agents can have a big impact on the environmental burden of operating rooms.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

13. I know that anesthetic gases are greenhouse gases.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

14. Rate my overall knowledge of the public health consequences of rising global temperatures.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

15. I understand that low-income communities will likely suffer the greatest morbidity and mortality consequences related to climate change.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

16. I know that nitrous oxide contributes to ozone depletion and ultraviolet radiation exposure.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

17. I understand that nitrous oxide is a greenhouse gas that remains in the atmosphere for over 100 years.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

18. I can generally compare the emissions produced by sevoflurane, desflurane, and isoflurane.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

19. I know that desflurane has an atmospheric lifespan greater than both sevoflurane and isoflurane.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

20. I understand that delivering one hour of sevoflurane at 1 MAC produces more greenhouse gas emissions than a total intravenous anesthetic with propofol.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

21. Rate my overall knowledge of strategies to minimize anesthetic gas waste.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

22. I understand that I can reduce environmental waste of anesthetic gases by turning off fresh gas flow(s), instead of the vaporizer, prior to breathing circuit disconnections.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

23. I routinely take steps to make my practice more environmentally sustainable throughout my workday.

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Without Vaporizer Labels	☐	☐	☐	☐	☐
With Vaporizer Labels	☐	☐	☐	☐	☐

24. Do you think anesthesia professionals can be part of the solution for climate change?

	1 (None)	2 (Low)	3 (Moderate)	4 (High)	I choose not to answer
Before Education	☐	☐	☐	☐	☐
After Education	☐	☐	☐	☐	☐

25. How likely are you to share the information from this presentation with others?
    a. Highly unlikely
    b. Somewhat unlikely
    c. Somewhat likely
    d. Highly likely
    e. I choose not to answer

26. This educational session enhanced my knowledge about environmental stewardship in anesthesia.
    a. Strongly disagree
    b. Disagree
    c. Agree
    d. Strongly agree
    e. I choose not to answer

27. Please describe the changes you plan to incorporate into your practice after participating in this educational activity in the space below.

28. Please describe potential barriers to incorporating green anesthesia strategies into your practice in the space below.

29. Please make your gift card selection.
    a. Starbucks
    b. Jimmy Johns

30. Please include your name and email address in the space below to receive your electronic gift card and certificate of completion. This information will not be shared or used for any other purpose than to receive your reward.

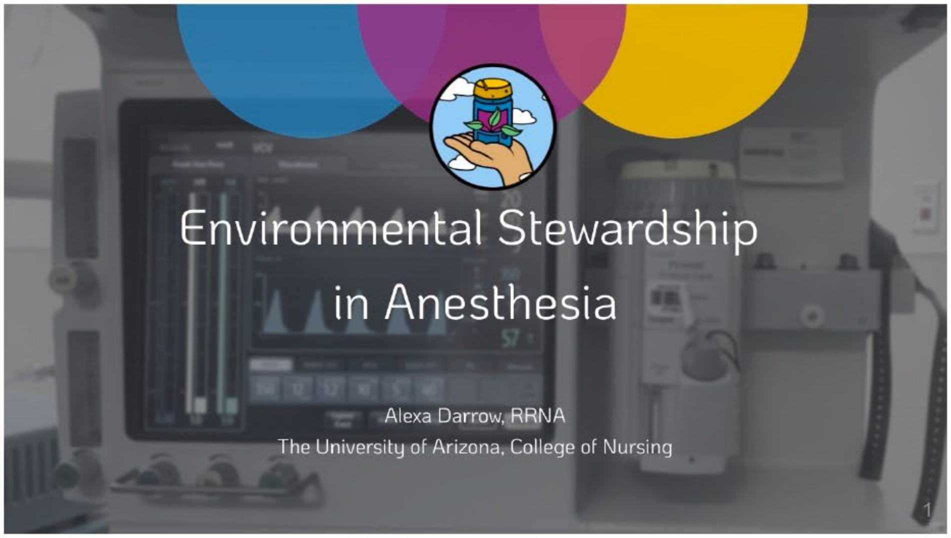
Thank you for participating in this doctoral project.

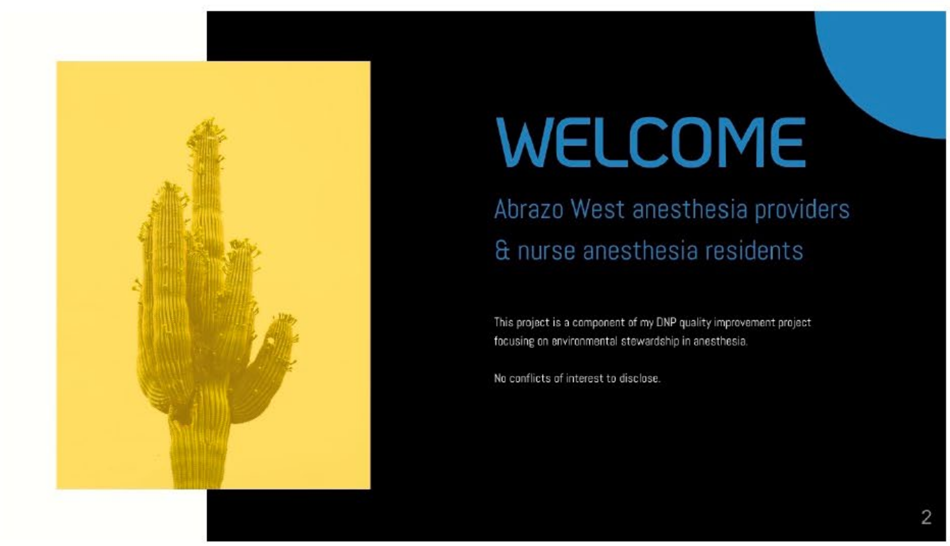
Your response has been recorded.

Completion of this survey implies your consent to participate. Participation in this project is voluntary and you may elect to withdraw participation at any time. Your information and survey responses will remain anonymous and confidential.

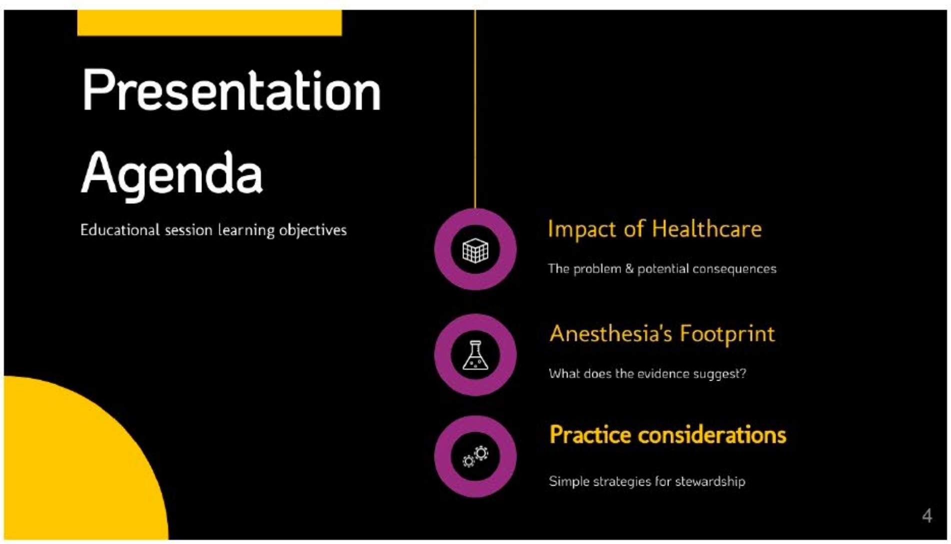
APPENDIX E

PARTICIPANT MATERIAL (SLIDESHOW PRESENTATION, ANESTHESIA WORKSTATION LABELS, PARTICIPATION CERTIFICATE, BADGE PIN, AND POSTER)


Environmental Stewardship
in Anesthesia
Alexa Darrow, RRNA
The University of Arizona, College of Nursing
1

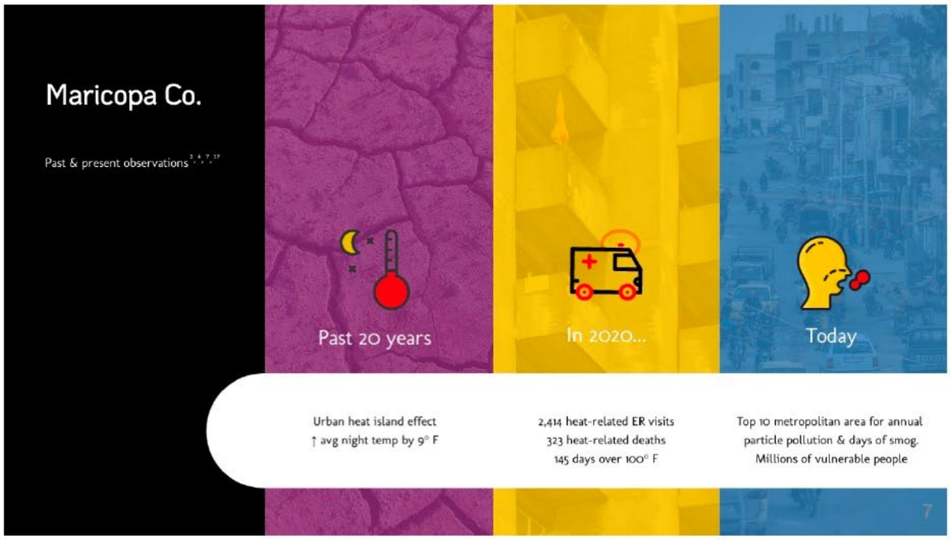

WELCOME
Abrazo West anesthesia providers
& nurse anesthesia residents
This project is a component of my DNP quality improvement project
focusing on environmental stewardship in anesthesia.
No conflicts of interest to disclose.
2

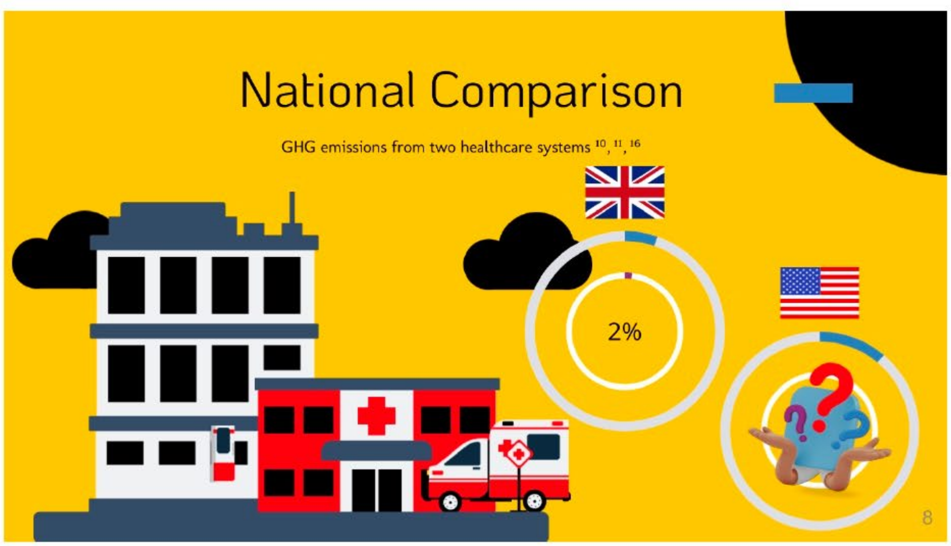

QI Project Activities
Components of this project:
Presentation
Educational Session
Survey
Assessment & Feedback
Rewards!
Thank you for your time!
3

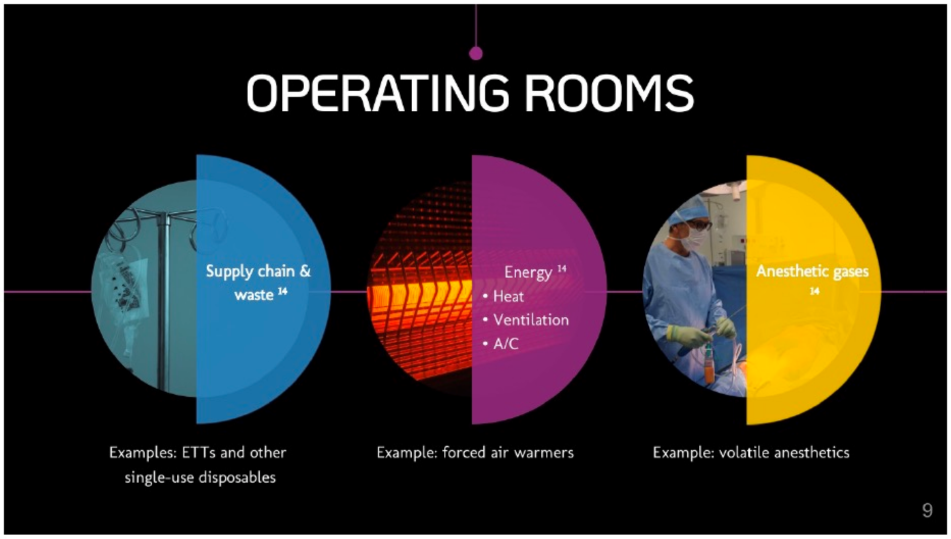

Presentation Agenda
Educational session learning objectives
Impact of Healthcare
The problem & potential consequences
Anesthesia's Footprint
What does the evidence suggest?
Practice considerations
Simple strategies for stewardship
4

Call to Action
Impact of healthcare
Heavy resource demands & utilization[11, 19, 24, 26]
U.S. healthcare burden - global highest per capita[11]
Responsibility to take action[15, 18, 22, 24, 27]
5

Big Picture
Malnutrition [25]
Infectious disease transmission [25]
Physical injury [25]
Systemic inflammation [1, 13, 20]
↑ mortality risk for aging population [8, 9, 25]
6


Maricopa Co.
Past & present observations[2,4,7,17]
Past 20 years
In 2020...
Today
Urban heat island effect
↑ avg night temp by 9° F
2,414 heat-related ER visits
323 heat-related deaths
145 days over 100° F
Top 10 metropolitan area for annual particle pollution & days of smog.
Millions of vulnerable people
7

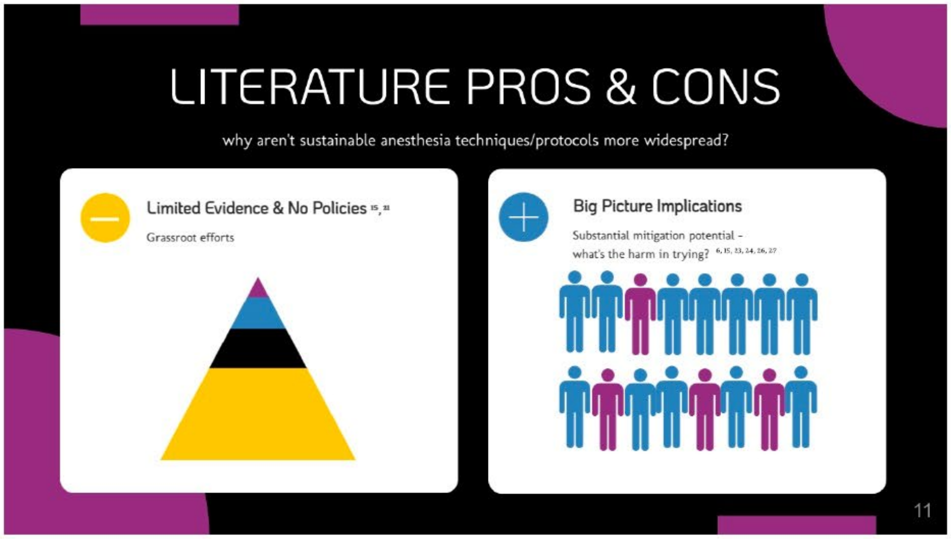

National Comparison
GHG emissions from two healthcare systems[10,11,16]
2%
8

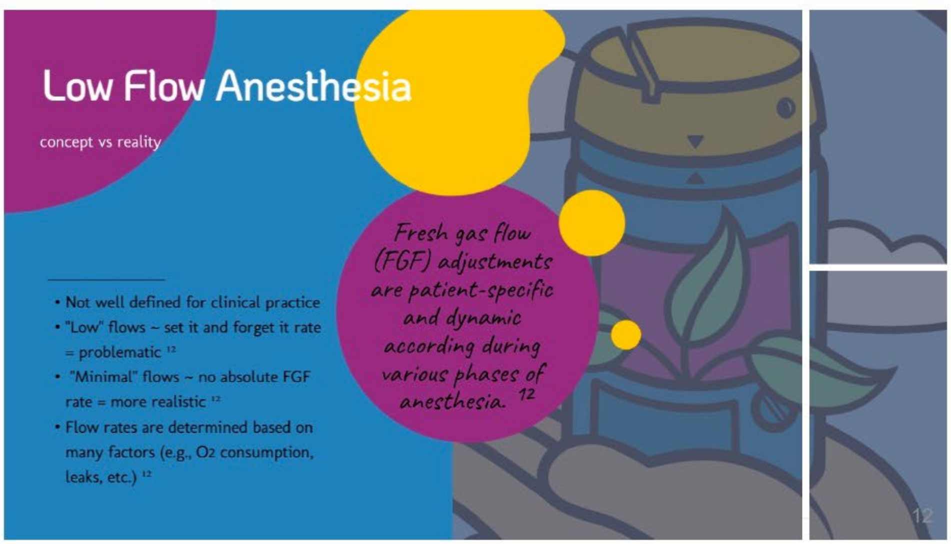


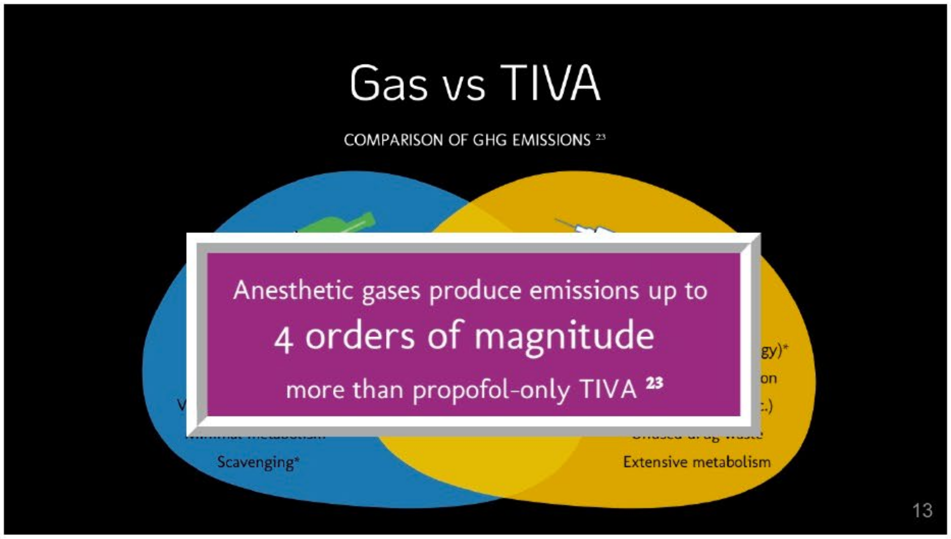
GHG Emissions of Anesthetic Gases

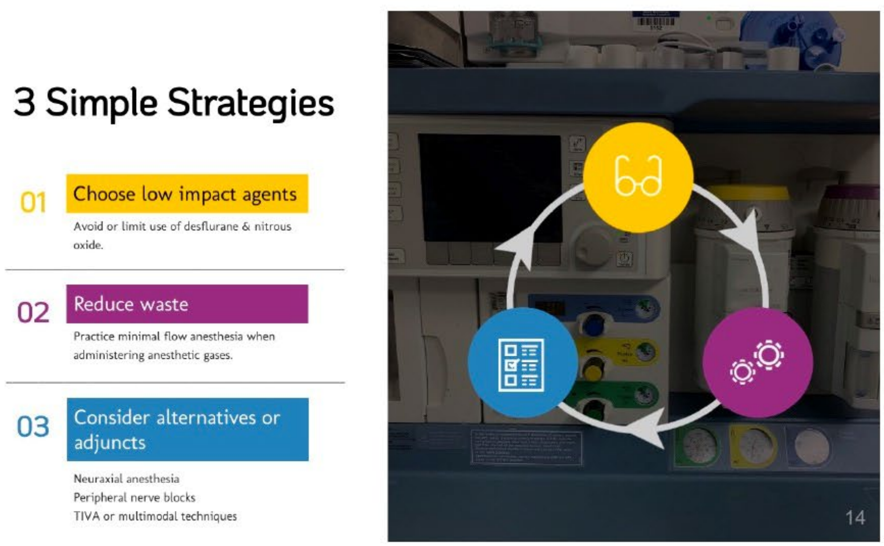
Commonly used agents listed below and their corresponding features: [5]

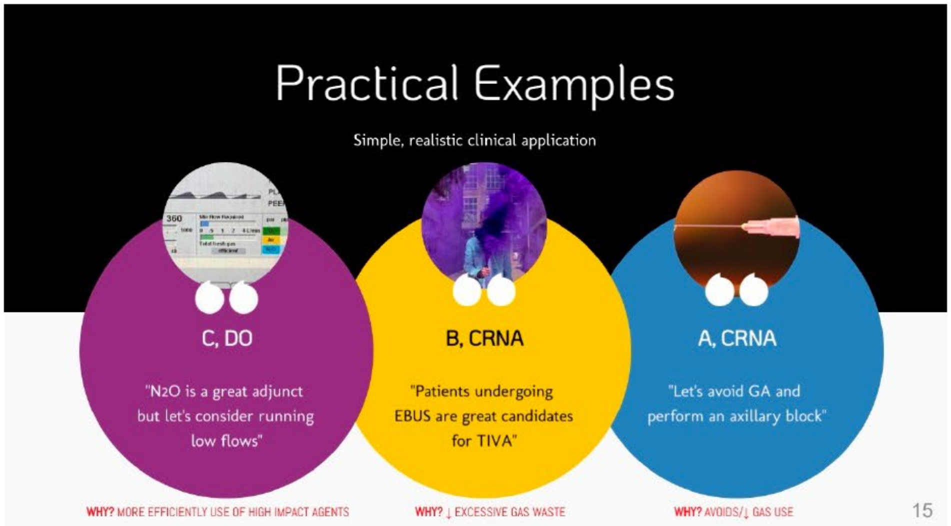
Agent (per hour at 1 MAC)	Sevoflurane (2%)	Isoflurane (1.2%)	Desflurane (6%)	Nitrous Oxide (60%)
Atmospheric Lifetime (years)	1.1	3.2	14	114
100-yr Global Warming Potential (emissions per kg; CO_2 = 1)	130	510	2,540	298
Driving Distance Equivalency (miles per hour of administration)	8	18	400	61

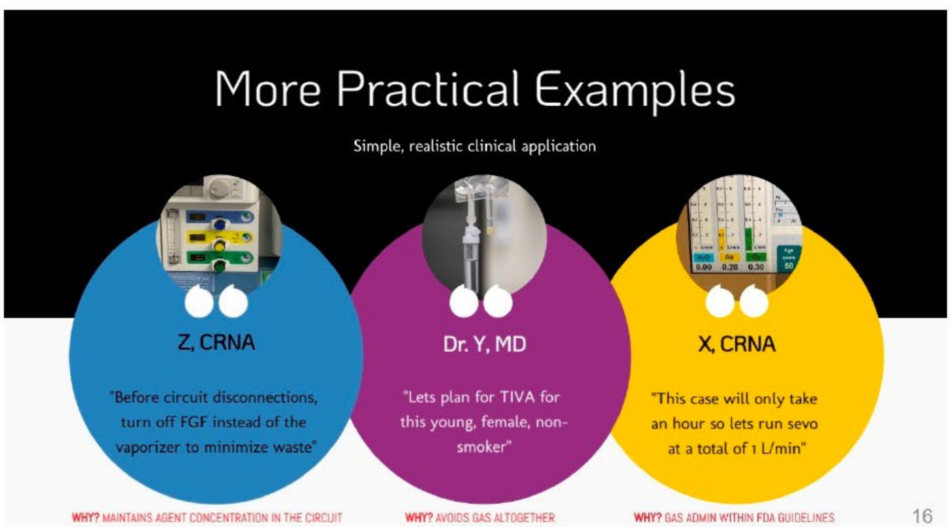

LITERATURE PROS & CONS
why aren't sustainable anesthesia techniques/protocols more widespread?
Limited Evidence & No Policies [15, 21]
Grassroot efforts
Big Picture Implications
Substantial mitigation potential -
what's the harm in trying? [6, 15, 23, 24, 26, 27]
11


Low Flow Anesthesia
concept vs reality
• Not well defined for clinical practice
• "Low" flows ~ set it and forget it rate = problematic [12]
• "Minimal" flows ~ no absolute FGF rate = more realistic [12]
• Flow rates are determined based on many factors (e.g., O2 consumption, leaks, etc.) [12]
Fresh gas flow (FGF) adjustments are patient-specific and dynamic according during various phases of anesthesia. [12]
12

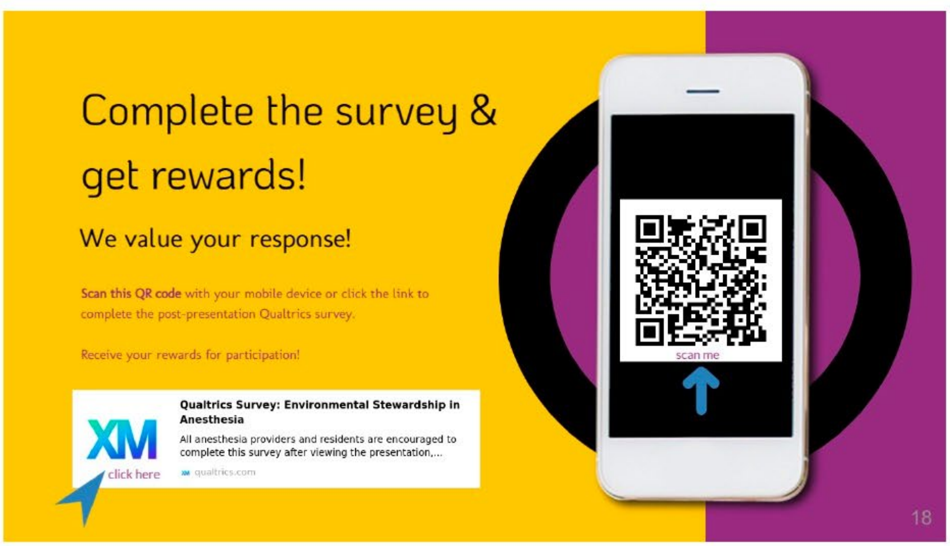

Gas vs TIVA
COMPARISON OF GHG EMISSIONS 23
Anesthetic gases produce emissions up to
4 orders of magnitude
more than propofol-only TIVA 23
Scavenging*
Extensive metabolism
13


3 Simple Strategies
01
Choose low impact agents
Avoid or limit use of desflurane & nitrous oxide.
02
Reduce waste
Practice minimal flow anesthesia when administering anesthetic gases.
03
Consider alternatives or adjuncts
Neuraxial anesthesia
Peripheral nerve blocks
TIVA or multimodal techniques
14


Practical Examples
Simple, realistic clinical application
C, DO
"N2O is a great adjunct but let's consider running low flows"
B, CRNA
"Patients undergoing EBUS are great candidates for TIVA"
A, CRNA
"Let's avoid GA and perform an axillary block"
WHY? MORE EFFICIENTLY USE OF HIGH IMPACT AGENTS
WHY? ↓ EXCESSIVE GAS WASTE
WHY? AVOIDS/↓ GAS USE
15


More Practical Examples
Simple, realistic clinical application
Z, CRNA
"Before circuit disconnections, turn off FGF instead of the vaporizer to minimize waste"
Dr. Y, MD
"Lets plan for TIVA for this young, female, non-smoker"
X, CRNA
"This case will only take an hour so lets run sevo at a total of 1 L/min"
WHY? MAINTAINS AGENT CONCENTRATION IN THE CIRCUIT
WHY? AVOIDS GAS ALTOGETHER
WHY? GAS ADMIN WITHIN FDA GUIDELINES
16


TAKE ACTION!
Check out the new labels at your workstations!
DESFLURANE
ISOFLURANE
SEVOFLURANE
NITROUS OXIDE
114 YEARS
ATMOSPHERIC LIFETIME
298 kg CO₂
EMISSIONS per KG
1 hour 60% N₂O = Driving 61 miles
SCAN QR CODE FOR MORE DETAILS
17


Complete the survey & get rewards!
We value your response!
Scan this QR code with your mobile device or click the link to complete the post-presentation Qualtrics survey.
Receive your rewards for participation!
Qualtrics Survey: Environmental Stewardship in Anesthesia
All anesthesia providers and residents are encouraged to complete this survey after viewing the presentation,...
qualtrics.com
XM
click here
scan me
18


Other resources
Estimate your professional footprint!
Association of Anaesthetists:
https://anaesthetists.org/Home/Resources-publications/Environment/Guide-to-green-anaesthesia/Anaesthetic-gases-calculator
Yale's Gassing Greener Application
Yale's Anesthesia Carbon Calculator:
https://jscalc.io/calc/H7gGXIL4tmDJHOxh
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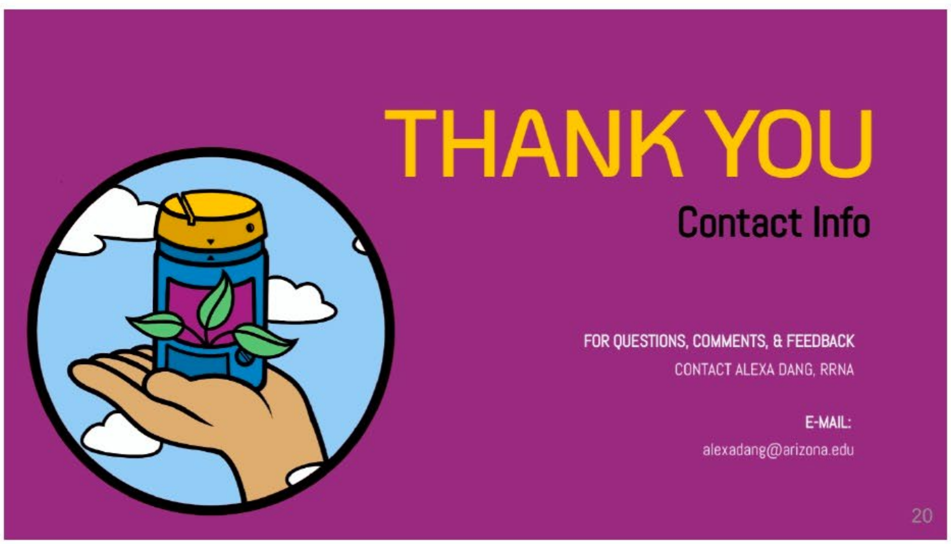
THANK YOU
Contact Info
FOR QUESTIONS, COMMENTS, & FEEDBACK
CONTACT ALEXA DANG, RRNA
E-MAIL:
alexadang@arizona.edu
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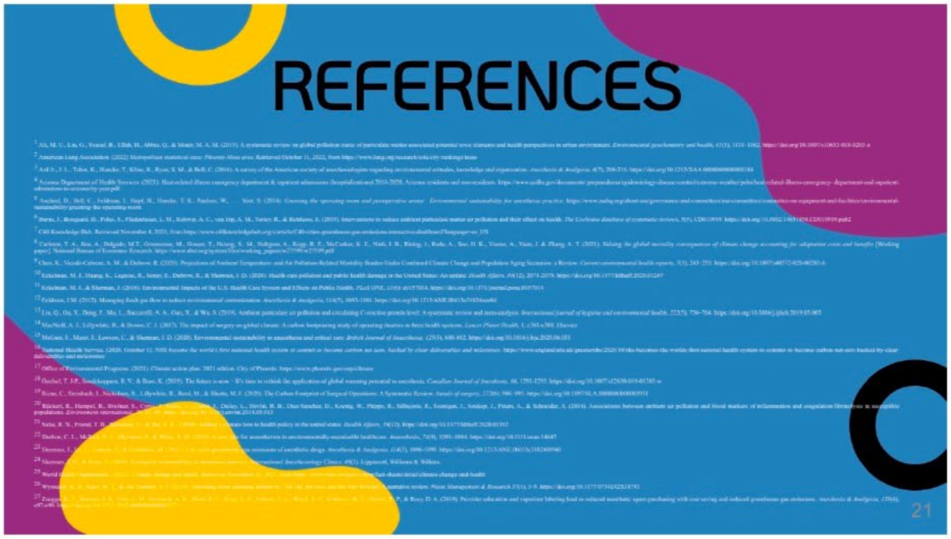
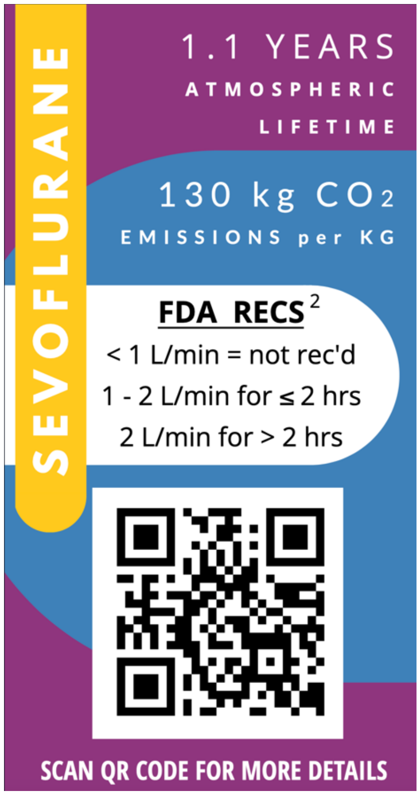

REFERENCES
21


SEVOFLURANE
1.1 YEARS
ATMOSPHERIC
LIFETIME
130 kg CO_2
EMISSIONS per KG
FDA RECS[2]
< 1 L/min = not rec'd
1 - 2 L/min for ≤ 2 hrs
2 L/min for > 2 hrs
SCAN QR CODE FOR MORE DETAILS


ISOFLURANE
3.2 YEARS
ATMOSPHERIC
LIFETIME
510 kg CO_2
EMISSIONS per KG
1 MAC-hour
=
Driving 18 miles
SCAN QR CODE FOR MORE DETAILS

CERTIFICATE OF COMPLETION

This award is presented to

PARTICIPANT NAME

has successfully completed the quality improvement educational session on "Environmental Stewardship in Anesthesia" conducted by Alexa Darrow. on February 20, 2023.

Alexa Darrow, RRNA
DNP Project Leader

THE UNIVERSITY OF ARIZONA
College of Nursing

Environmental Stewardship in Anesthesia: An Educational Intervention For Clinicians

Alexa Darrow, BSN, RN, CCRN-CSC, RRNA, DNP Candidate; Charles Elam, PhD, DNAP, CRNA;
Kristie Hoch, DNP, CRNA, MS, RRT; Mónica Ramírez-Andreotta, MPA, PhD

Purpose

The purpose of this educational quality improvement (QI) project is to increase awareness of the environmental impact of anesthetic gases among anesthesia providers to encourage and support self-driven environmentally sustainable changes to routine practice.

Background/Significance

Operating rooms are remarkably energy intensive. Among numerous resources necessary to perform surgeries, anesthetic gases are responsible for much of the environmental burden of operating rooms (ORs).

- Top three sources of greenhouse gas emissions (GHGs) from ORs: anesthetic gases, supply chain/waste, and energy . [4]
- Anesthetic gases produce emissions up to 4 orders of magnitude greater than propofol. [5]
- Inhalational anesthetic agents in current use have substantial atmospheric lifespans ranging from just over one year to over one hundred years. [2]
- Every hour of desflurane administration at 1 minimum alveolar concentration (MAC) is equivalent to driving 400 miles. [2]
- <15% of anesthesiologists think about the environment when making decisions in practice. [1]
- Institutions have saved thousands of dollars by implementing green anesthesia quality improvement projects. [3, 6]

Methods

Anesthesia providers and nurse anesthesia residents voluntarily participated in an educational QI project conducted at a hospital within Maricopa County.

Pre-recorded, educational slideshow presentation on the following topics:

- Environmental impact of healthcare and anesthesia
- Public health consequences of the climate crisis
- Green anesthesia practice strategies and considerations

Evidence-based visual aids:

- Custom designed labels affixed to workstation vaporizers in all main ORs
- Visual cues to encourage real-time "green" decision-making

Figure 1. Anesthesia workstation vaporizer labels

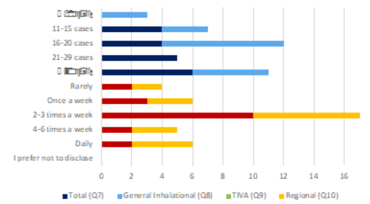
Retrospective pre-post survey to evaluate program effectiveness, characterize baseline participant characteristics, and identify perceived practice barriers.

Participation rewards
- $10 gift certificate
- Certificate of completion
- Bespoke badge pin

Figure 2. Badge pin design

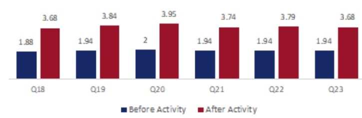
Results

Figure 3. Individual Practice Characteristics



Notes. Abbreviations: Q, question; TIVA, total intravenous anesthesia. Numbers correspond to response counts (n = 19) to survey questions regarding the frequency of cases and anesthetic techniques performed during a typical week. Please refer to the evaluation instrument (see references) for a complete description of survey questions.

Figure 4. Survey Response Mean Scores of Environmental Stewardship Educational Activity



Notes. Abbreviation: Q, question. Q18 – "I can generally compare the emissions produced by sevoflurane, desflurane, and isoflurane". Q19 – "I know that desflurane has an atmospheric lifespan greater than both sevoflurane and isoflurane". Q20 – "I understand that delivering one hour of sevoflurane at 1 MAC produces more greenhouse gas emissions than a total intravenous anesthetic with propofol". Q21 – "Rate my overall knowledge of strategies to minimize anesthetic gas waste". Q22 – "I understand that I can reduce environmental waste of anesthetic gases by turning off fresh gas flow(s), instead of the vaporizer, prior to breathing circuit disconnections". Q23 – "I routinely take steps to make my practice more environmentally sustainable throughout my workday".

Implications and Conclusion

- Greening anesthesia practice is an ongoing important area of interest in the setting of global, multi-industry efforts to mitigate the effects of climate change.
- Findings support the use of an educational presentation and visual reminders to encourage environmental stewardship while supporting translation of research into practice.

References

and copy of the evaluation instrument

Contact Information:
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APPENDIX F

PROJECT TIMELINE

Completion Date	Planning	Pre-implementation	Implementation	Evaluation
8/2022 -12/2022	Creation of participant materials			
10/2022	DNP project proposal submitted to project chair			
12/2022	Implementation site authorization letter obtained			
1/2022	Revised proposal submitted to committee chair			
1/9/2023	DNP project proposed to project committee with approval			
1/2023		Participant materials finalized and approved by project committee chair		
2/20/2023		Human subjects' determination application submitted for review by University of Arizona IRB with approval		
2/20/2023 -3/2/2023			Implemented QI project at site	Collected survey data
3/3/2023			Rewards distributed to participants	
3/2023				Conducted analysis of survey data
3/17-20/2023				Findings disseminated at AZANA Sun & Fun Conference via poster presentation
4/2023				Final defense presentation

APPENDIX G

LITERATURE REVIEW GRID

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
2021; Gaya da Costa et al.	Inhaled anesthetics: Environmental role, occupational risk, and clinical use.	LR	• No globally accepted definition of LFA • Isoflurane is a chloroflurocarbon (contains chlorine atom) which induces ozone destruction • Desflurane and sevoflurane are hydrofluorocarbons (HFCs) • Montreal Protocol adopted control of CFCs in 1987 but amended in 2016 to reduce use of HFCs • Medical relevance of inhaled anesthetics resulted in these agents being excluded from the Montreal Protocol . • Estimated desflurane cost at 1 L/min is $12.96 USD; sevoflurane $6.05; isoflurane $0.52 • Authors suggest providers should be educated and receive continuing education on the impact of inhaled anesthetics.	• Provides a comprehensive view of the considerations of inhaled anesthetics in the U.S. in terms of cost, environmental impact, suggests for practice changes, & procedural considerations based on available evidence.
2021; Edmonds et al.	Evidence-based project: Cost savings and reduction in environmental release with low-flow anesthesia.	Analytic, quasi-experimental, cross-sectional	• Simulated results of environmental and cost savings for the institution extrapolated from actual data from 14, 977 cases at a tertiary medical center in the Pacific Northwest - excluding pediatric procedures (<10 years age) and cases involving use of more than 1 volatile agent in 2017. • Greatest mean FGF rates observed for sevoflurane cases & lowest for desflurane cases (1.8 lpm). • Desflurane most expensive agent per bottle of agent but larger quantities of sevoflurane consumed. • Actual average FGF for	• Vigilance re: fresh gas flow rates administered with volatile anesthetics can potentially reduce institutional spending on anesthetic gases & minimize GHG emissions r/t potential decreases in FGF rate. • Cost savings are simulated estimates & unable to disclose actual costs of volatile agent spent by the institution (contracts) • Does not elaborate or adjust averaged based on the type/complexity of anesthetic cases or the comorbidities associated with cases requiring higher FGF rates. • Does not discuss implications of costs or environmental savings associated with alternative anesthetic techniques.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			sevoflurane cases = 2.5 lpm; simulated savings of ~128 fewer bottles if flow rate decreased to 2 lpm with cost savings of $9,830 for the year. • Simulated savings of 660 bottles if 1 lpm FGF was used for all inhalational agents (total 1,027 bottles of sevo; 93 bottles iso; 113 bottles des) & cost savings of $50,892. • Desflurane cost savings of $5,700 and $10,960 if avg flow decreased from 0.5 and 1 lpm. • Sevo cases < 2 hours duration (FDA req) decreased to avg 1 to 2 lpm FGF could have saved $6,977 to $19,424 • GWP contribution = 48 mtCO2e for des/ 22 mtCO2e for sevo/ 8 mtCO2e iso • Isoflurane & N2O contribute to ozone depletion (referenced) • Desflurane requires 3 to 6x quantity of sevoflurane & isoflurane, respectively • Institution purchase agreement contracts for each agent is proprietary & actual costs were estimated; possible underreported estimates because many cases were excluded; expiratory conc of agents were used to calculate estimates but inspiratory % would be more accurate; average FGF was based on average ET% of volatile agent & total duration with volatile agent expired percent instead of minute-to-minute changes (researchers used a correction factor to avg	

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			tended to be greater than actual fluid volume of agent).	
2021; de Vos & Alexander.	BC anesthesiologists reduce carbon footprint by choosing wisely.		• Anesthesiologists across British Columbia appear to be reducing the use of desflurane (example: Vancouver Island Health Authority observed a 61% drop in CO_2e from 102 kg per case in 2013 to 40 kg per case in 2019). 58% decrease in carbon footprint across 3 participating health institutions = 208 kg CO_2e per case.	• Demonstrated improvements in sustainability/CO_2e results following the purchase of LFA machines (in 2015) and changes to practice patterns to preferentially use sevo over des.
2020; Zhong et al.	Environmental and economic impact of using increased fresh gas flow to reduce carbon dioxide absorbent consumption in the absence of inhaled anaesthetics.	In vitro (laboratory)	• Recorded exhaustion of CO_2 absorbent canister (when inspired PCO_2 > 0.3 kPa) using 1L Draeger test lung insufflated with fixed CO_2 inflow ventilated via circle breathing system & HME filter of Drager Primus (DG) or GE Aisys CS^2 (GE) machine at FGF of 1, 2, 4, or 6 lpm. Test lung ventilation settings programmed at VCV/12bpm/VT 500 mL/I:E 1:1.5. • Calculated economic and environmental cost associated with manufacture of CO_2 absorbent canister and supply of medical air & O_2 (no volatile agents); medical air O_2 (\$0.40) and air (\$0.028) per (1000 L) • Fraction of CO_2 absorber consumption increases linearly per unit of time but mean time to canister exhaustion increases non-linearly with increasing FGF. At 6 lpm FGF, > 5 days for canister exhaustion with GE machine and > 8 days for Dragus machine. • Higher FGFs = canisters lasted longer (DG examples: 205.3 h @ 6	• Life cycle assessment of CO_2 absorbers which adds to knowledge regarding how they contribute to the sustainability & cost efficacy of low-flow anesthesia (without volatile anesthetic agent use) • Low FGF may not be associated with environmental or cost savings when used solely with medical air or O_2. • ?? Higher FGF when inhalational anesthetics may be more cost effective and environmentally friendly…?

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			lpm vs. 10.3 hours @ 1 lpm) and had lower hourly cost (DG examples: \$0.10 per hour @ 6 lpm vs. \$1.46 per hour @ 1 lpm - currency AU\$) • GWP100 slightly differed or same (DG examples: 0.14 kg CO_2e per hour @ 6 lpm vs. 0.13 kg CO_2e per hour @ 1 lpm --- GE examples: 0.14 kg CO_2e per hour @ 6 lpm vs. 0.14 kg CO_2e per hour @ 1 lpm) • Increasing FGF had significant decrease in running cost of CO_2 absorber with minimal net changes to environmental impact • Without CO_2 absorber, FGF required to keep inspiratory CO_2 < 0.3 kPA was 18 lpm for DG & 15 lpm for GE but nearly 20-fold decrease in running cost with absorber but produced almost 2x GWP.	
2020; McGain et al.	Environmental sustainability in anaesthesia and critical care.	Expert opinion (EO), Review article (RA)	<u>*What is known about anesthetic gases/TIVA/regional anesthesia*</u>: • GWP of anesthetics gases are well researched. • Desflurane & nitrous oxide have substantial GWPs compared to sevoflurane and isoflurane. • Automated end-tidal control of anesthesia & low flow anesthesia are existing techniques to limit excessive waste of anesthetic gases. • Research on waste anesthetic gas reclamation technology is emerging but not yet readily available worldwide. • TIVA with propofol has about 1% of the GWP of sevoflurane anesthesia	• Call to action for providers of anesthesia and critical care to "flatten the GHG curve" in alignment with the goals of the Intergovernmnetal Panel on Climate Change (IPCC) to dramatically reduce GHG emissions to prevent global warming to an increase of 1.5 degC and climate change-related public health disasters. • Anesthesia experts that have previously published work related to the environmental impact of anesthesia provide a clear summary on the uncertainties of the environmental implications of various anesthetic techniques based on what is known about anesthetic agents.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			<u>*What is uncertain about anesthetic gases/TIVA/regional anesthesia*</u>: • Worldwide use of anesthetic gases/TIVA & how this is evolving. • Clinical application and research for waste anesthetic gas reclamation technology • Environmental effects of medical use of oxygen/air • Other environmental effects of TIVA • Quantification of water contamination from anesthetic pharmaceuticals • Balance of plastic waste with TIVA vs. GWP of volatiles • Environmental footprint and other environmental effects of regional anesthesia	
2020; Lenzen et al.	The environmental footprint of healthcare: A global assessment.	Descriptive, ecologic	• Healthcare contributes the global environmental impact ranging from 1 to 5 percent of the total global impact (depending on the indicator - e.g., GHGs, particulate matter, NO2, SO2, malaria risk, nitrogen oxides, scarce water) • Of the estimated total global environmental footprint, healthcare contributes 4.4% of GHGs, 2.8% of particular matter, 3.4% of nitrogen oxides, and 3.6% of sulfur oxides • All environmental impact indicators increased from years 2000 to 2015. GHG increases (29%) were in alignment with increasing global expenditure on healthcare ($2.7 trillion or 8.5% of global GDP in 2000 to $5.5 trillion	• Emissions of fluorinated gases is a substantial contributor to GHG emissions on a global scale. • Volatile agents are fluorinated gases, although this authors do not specify anesthetic gases as a driver.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			or 10% of global GDP in 2015). • Healthcare's global GHG footprint = 51% from CO2 (mostly healthcare-related fuel combustion & land use); 22% from nitrous oxides (mostly healthcare-related agriculture); 16% from methane (mostly healthcare-related agriculture & energy transformation); and 11% fluorinated gases ("mainly [from healthcare-related] industrial processes") p. e275 • Authors we unable to determine detailed local drivers of impact or specific recommendations for mitigation.	
2020; Kuvadia et al.	Green-gional' anesthesia: The non-polluting benefits of regional anesthesia to decrease greenhouse gases and attenuate climate change.	EO	• Authors identified the percent of primary hip and knee arthroplasties performed under GA only, neuraxial only, and combined GA/neuraxial across 4 years (2006-2014) in 400 US hospitals using the Premier Healthcare Dataset. • Authors compared these national values to their hospital which performs only 4% of these cases under GA (nationally 75% are performed under GA) and based on the difference • The authors calculated a savings equal to 26,900 lbs of coal burned, 2,750 gallons of gasoline consumed, 60,500 miles driven by an average passenger vehicle, or 3,110,000 smartphones charged based on saving 750 kg of desflurane and 60 kg nitrous oxide (2LPM desflurane, 2LPM of nitrous oxide for a 2 hour surgery).	• Regional anesthesia may have an environmental advantage compared to volatiles but this has not been researched. • The total GWP of regional anesthesia is unknown and hasn't been studied in research as of yet. • Cannot conclude that regional anesthesia is better for the environment than volatiles. • An environmental benefit of regional anesthesia would add to other benefits of regional related to extent of analgesia, PONV, postop recovery, patient satisfaction, and morbidity.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
2019; Zuegge et al.	Provider education and vaporizer labeling lead to reduced anesthetic agent purchasing with cost savings and reduced greenhouse gas emissions.	Quality improvement (QI)	• Purchasing from 2012 to 2015: Desflurane decreased from 252 to 113 bottles per month (55% reduction) = 3025 kg CO2e in fiscal year 2012 to 1354 kg CO2e in FY 2015 • Purchasing from 2012 to 2015: Sevoflurane increased from 262 to 305 bottles per month (16% increase) • Purchasing from 2012 to 2015: Isoflurane remained the same • Cost savings from changes in purchasing per month = $25,000 per month but the cost for sevo was reduced in 2015 • Informal feedback revealed that environmental impact was more motivating to engage in efforts to change their practice than monetary savings. • CO2e per case for fiscal year 2012 was 162 kg vs. 58 kg in FY 2015 = 64% reduction in emissions = annual reduction (based on per case CO2e for a year) ~2,865,430 kg = ~613 passenger vehicles removed from the road each year • Desflurane accounted for 57% of CO2e in FY 2012 vs. 65% in FY 2015	• Provides a foundation for building the format of my QI project using vaporizer labels, provider education, and measuring the outcome of my project that is consistent with existing literature as in this study. • Desflurane represents a large portion of GHG emissions attributed to volatile anesthetics even with reduction in use but reducing use can lead to substantial changes in the total quantity of CO2e overall.
2019; Wyssusek et al.	Operating room greening initiative - the old, the new, and the way forward: A narrative review.	Literature review (LR)	• Identify changing trends in waste production and management from 1992-2018 through a literature search (45 research articles, 30 review articles, 7 editorial/personal reflections, 2 letters-to-the-editor). • ~ 25% OR waste generated by anaesthetists (40 to 60% is recyclable - mostly glass; plastics	• "Rethink" - We must rethink how healthcare is delivered, healthcare personnel and services are responsible for promoting and protecting the wider community & can set examples for other organizations (p. 12). • Greening initiatives & the environment are not at the forefront of staff agendas but basic education and training has the

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			are ~50% to total anaesthetic waste volume - incl. laryngoscope blades, drug ampoules, anesthetic gases) • Anaesthetic gases are poorly recognized as greenhouse gases (GHGs) • Global warming potential (GWP) on an international level in 1 years = ~ 1 million cars • Drugs prepared for "in case of emergency" are unused ~50% time = ephedrine > SCh > lidocaine > dexamethasone > phenylephrine > ondansetron = yearly cost of ~$185,250 USD in a single US academic medical center. • Anaesthetists can take action because they are responsible for the gases that cause an ecological footprint. • Actions include low-gas flow ventilator, low gas flow during maintenance of anaesthsia, and TIVA. • Barriers of greening initiatives - culture of the organization, poor guidance around managing healthcare waste, lack of data/understanding, concern of interrupting/adding to buy OR workflow • Switching to TIVA or regional anesthesia for laparoscopic and robotic hysterectomies could reduce ozone depletion by 3% and 28%, respectively.	potential reduce monthly waste volume produced by institutions; therefore staff engagement is important. • "Research" - success of intervention is determined by benefit to the healthcare system & sustainability over time - this requires ongoing auditing and monitoring of efficacy and success across a set timeline. But there is still a lack of quantity of QI studies and there is still limited information of the environmental effects of healthcare with supporting updated statistical evidence. • Anesthetic gas trapping systems could limit the amount of anesthetic gas vented to the atmosphere and photochemical air purification could remove/destroy all anesthetic gas waste - but unclear as to the cost and availability of this technology. • Implementation strategy - make initiatives the "easier" option - convenient placement of bins, clear signage, celebrate successes via achievement reports/social events to reward safe (i.e., zero-waste BBQ), staff education & re-education are important for reducing waste and can have the greatest effect on improving the ecological footprint of an institution. • Buy-in strategy - requires compliance and flexibility from staff to change current practice. Address staff concerns re: infection control, time constraints, inconvenience, perceived logistical issues, psychosocial barriers re: global warming resulting from human activity.
2019; Kennedy et al.	The effect of fresh gas flow during induction of anaesthesia on sevoflurane usage: A	QI	• 11 month study with data from 4, 371 cases in 4 ORs - analyzed sevo-only cases (78% cases; 3,199 cases)	• Study addresses concerns related to common induction FGF rates and changes seen after education activity but the results does not appear sustained 6 months after

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
	quality improvement study.		• (A) Baseline median (IQR) of mean FGF for entire case = 800 mL/min --> (B) after 2-week intervention = 710 mL/min --> (C) 6 months after = 830 mL/min • FGF during induction for all 3 time periods was statistically different (Kruskal-Wallis statistic 69.01; $P<0.0001$); significant diff between A & B and between A and C ($P < 0.0001$ for both) • As duration of high FGF induction period was shorter, avg FGF for the case tended towards maintenance flows. • 10% reduction in overall FGF (many practitioners at the site already practice LFA)	the intervention.
2019; Carter et al.	Promoting low-flow anaesthesia and volatile anaesthetic agent of choice.	QI	• Goals: achieve total of 90% of all anesthetics conducted using FGF < 1 L/min within 10 min of entering OR & 20% reduction in # of bottles of volatile agents ordered per month. • Project conducted from Sept 2016 to March 2017 • Cycle 1 (Sept - Oct) = awareness phase = 31% increase in # anesthetists practicing low-flow anesthesia (LFA) & during spot audit they saw a 27% increase in isoflurane use. • Cycle 2 (Oct - Nov) = changes via other methods of delivering information = % of ORs with FGF rates < 1 L/min decreased (worsened) after submitting a financial statement to providers "that choices within the theatre had financial repercussions".	• Uses multiple feedback and educational interventions to facilitate goal of encouraging anesthesia providers to participate in LFA but doesn't specify/account for motivational factors influencing engagement of stakeholders.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			• Cycle 3 (Nov - Dec) = "low flow" board implementation & adding isoflurane vaporizers to 2 ORs (so all rooms had an iso vaporizer) = 19% increase in low flow anesthesia compared to previous month; 32% increase in isoflurane use; 13% decrease in sevoflurane use • Cycle 4 (Dec - Jan) = sevoflurane vaporizer removed from machines but kept in the OR = 58% of ORs were achieving target low FGF (remaining % were using FGF rate ≥ 1.2 L/min); desflurane use increased; 34% decrease in inhaled agent expenditure and a 4% increase in activity compared to previous year during same time period. • Cycle 5 (Jan - Feb) = training of new anesthetic trainees at induction = desflurane use was still high (60%) but they observed almost 80% cases with FGF <1L/min • Overall 18% reduction in bottles ordered vs. same period in the previous year = 25% decrease in total expenditure on volatile agents.	
2019; Azouz et al.	Managing barriers to recycling in the operating room.	Descriptive survey study with QI program	• Recycling survey sent to 1082 recruited OR staff of Mayo Clinic (Phoenix, Rochester, Eau Claire, Florida) • Highest response rate from Mayo Clinic Arizona 62% (256/415); 18% anesthesiologists or CRNAs • Greatest barrier to recycling reported: Lack of knowledge of recyclable materials (47.7%) • 89.6% respondents reported that	• Mayo Clinic Phoenix is the clinical site proposed for this DNP project. Indicates that Mayo Clinic Arizona providers may be interested in environmentally friendly changes to their institution and may be more receptive to this project.

Pub. Year; Author’s Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			they were active recyclers at their home	
2018; Tollinche et al.	Analyzing volatile anesthetic gas consumption by auditing fresh gas flow: An observational study at an academic hospital.	Descriptive (observational) study	• Sevo mean FGF = 2.55 L/min (95% CI, 2.45-2.66) - significantly different from null of 2 L/min ($p < 0.0001$) • Iso mean FGF = 2.55 L/min (95% CI, 2.00-2.66) - significantly different from null of 1 L/min ($p < 0.0001$) • Study analyzing Et inhalation agent percentage for all procedures > 4 hours (303 different patients), excluding first and last 30 minutes) • Desflurane was not part of the study	• Institution provides FGF education and ventilators with notifications to limit FGFs but clinicians appear to not consistently practice low-flow anesthesia.
2017; Skalec et al.	Comparison of anaesthetic gas consumption and stability of using automatic and manual control over the course of anaesthesia.	Analytic, observational, cohort study	• Auto ET group results: Less # changes in gas flow (2 vs. 3; $P = <0.0001$) & conc of inhalational anesthetic (2 vs. 4; $P = <0.0001$) required; less # interventions (7 vs. 10; $P = <0.0001$), significantly fewer interventions per total anesthesia minutes ($P = 0.001$), shorter median anesthesia time ($P=0.199$), higher total consumption of oxygen ($P = 0.014$) & sevo ($P = 0.354$), less air consumption ($P = 0.239$) • No significant difference between groups for re: median anesthesia time; time to achieve desired Et level of anesthetic saturation, time to recovery from anesthesia, median time of eye-opening & extubation after cessation of anesthetic delivery, stability of anesthesia, systolic arterial pressure & variability index, BIS measurement, end-expiratory	• Anesthesia machines with automated control of fresh gas flows and end-tidal gas concentrations provided relatively comparable extents of "stability" of anesthetics for each group but does not necessarily contribute to reduced consumption of these agents; possibly because of standardized algorithm of the specific machine. • Does not conclude that manual control of FGF & Et concentrations is better or worse than automated control but may reduce workload of the anesthesia provider. • Environmental sustainability efforts should supplement practice with or without anesthesia machines with automated controls.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			anesthetic conc, frequency of fentanyl boluses.	
2017; MacNeill et al.	The impact of surgery on global climate: A carbon footprinting study of operating theaters in three health systems.	Descriptive, ecologic	• GHG evaluations at 3 institutions (Canada [CA], US, & UK) from Jan 1 to Dec 31, 2011 • Anesthetic gases & energy were the largest sources of GHG emissions at all 3 sites. • Use of desflurane (at the Canada & US hospitals) produced a 10-fold difference in anesthetic gas emissions. • Operating rooms were 3 to 6x more energy intense than hospitals as a hole - mostly from heating, ventilation, and air conditioning requirements. • UK facility had higher case volumes than • CO2e (kg/yr) attributed to volumes of anesthetic agents purchased @ the US hospital (2,129,841 kg/yr) > CA hospital (2,034,277 kg/yr) > UK hospital (211,212 kg/yr) - note: the UK facility did not use desflurane & N2O use was negligible @ all facilities • Per case CO2e (kg/case) attributed to volumes of anesthetic agents purchased @ the US hospital (118.3 kg/case) > CA hospital (92.5 kg/case) > UK hospital (7.0 kg/case) • CO2e (kg/yr) attributed to energy consumption @ the UK hospital (4,344,150 kg/yr) > US hospital (1,515,763 kg/yr) > CA hospital (534,194 kg/yr) -- note: mostly from HVAC demands of the OR	• Operating rooms (ORs) generate substantial quantities of greenhouse gas emissions. • ORs are a substantial contributor to a hospital's overall carbon footprint & therefore should be an important target for greening strategies of a healthcare system, locally and can contribute to national level improvements in sustainability of a country's health system.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
			• Energy performance (MWh/m^2) efficiency @ the UK hospital (3.5 kWh/m^2) > US hospital (2.7 MWh/m^2) > CA hospital (2.0 MWh/m^2) -- note: CA had after hours energy conservation strategy built into their HVAC system & had a newer building	
2017; Axelrod et al.	Greening the operating room and perioperative arena: Environmental sustainability for anesthesia practice.	LR	• End tidal monitoring of inhaled anesthetic agent and oxygen concentration is essential • Minimum fresh gas flow should begin and titrate from the estimated O2 consumption of the patient and account for gas losses from the sidestream gas analyzer and leaks. • Protocol for calculating safe minimum FGF = 5 mL/kg/min + 200 mL/min if sidestream gas analyzer sampler does not return gas to circuit; + 100 mL/min to account for leaks that may not be seen. • Turn FGF off and keep vaporizer on during intubation to maintain desired concentration of the anesthetic in the system (minimizes washout) • Increase anesthetic vapor concentration to achieve desired Et concentration when FGF are reduced • Limit max FGF during maintenance to 1 L/min (can be less for smaller patients & depending on monitoring values)	• Document from a reputable professional organization (American Society of Anesthesiologists [ASA]) that describes environmental differences between agents; importance of avoiding higher FGF; and comparison between anesthetic use and automobile emissions to guide providers and institutions to implement sustainable strategies more consistently across the profession.
2016; Epstein et al.	Economic and environmental considerations during low fresh gas flow	Analytic, observational, cohort study	• Sevoflurane consumption per min decrease by 0.038 mL/min (95% CI, 0.029 to 0.049 mL/min; $p < 0.0001$) after changing from a	• Alternative agent for CO2 absorption decreases risk associated with Sevo and compound A production but institutions may not observe a meaningful cost benefit.

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	volatile agent administration after change to a nonreactive carbon dioxide absorbent.		soda-lime absorbent to non-reactive (Litholyme) absorbent which does not contain a strong alkali and therefore will not produce compound A. • Cost of more expensive non-reactive absorbent was not outweighed by the savings from decreased sevo consumption	• However, using this could support lower fresh gas flows with sevo beyond FDA restrictions related to compound A.
2016; Ard Jr. et al.	A survey of the American Society of Anesthesiologists regarding environmental attitudes, knowledge, and organization.	Descriptive survey study	• Survey conducted by the ASA committee on Equipment and Facilities. • 2,189 ASA-member anesthesiologists/anesthesiology residents responded out of 5,200 sample size (42% response rate) but only 2,036 included for analysis to provide impression of responses from those practicing in the US. • ~94% spent at least a majority if not all their time in an OR setting, most respondents indicated they recycle at home (81.4%) & would like to see recycling of OR waste (80.1%) • Question 9: "Which volatile anesthetic do you use most commonly?" Response choices: Isoflurane (10.5%; n = 192 of 1829; CI, 9.2% - 12%) / Sevoflurane (66.4%; n = 1215 of 1829; CI, 64.2% - 68.6%) / Desflurane (22.3%; n = 408 of 1829; CI, 20.4% - 24.3%) • 5% provided a comment on why they chose a particular drug (out of 1,217 responders that wrote a comment for Q9) • Question 10: "Does the	• Awareness of the environmental implications of anesthetic agents may be minimal but this could also reflect personal beliefs/perceptions of climate change/global warming. • CRNAs should also be addressed in this issue. • Suggests that many providers still use desflurane? • Doesn't specify participation in low-flow anesthesia technique or in relation to alternative agents or techniques.

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			environmental impact (global-warming potential and ozone depleting effect) of inhalational agents affect your choice of anesthetic?" Response choices: Yes (13.4%; n = 244 of 1816; CI, 11.9%-15.1%) / No / "I am unaware of the environmental impact of these agents" (30.3%)	
2013; Tay et al.	Financial and environmental costs of manual versus automated control of end-tidal gas concentrations.	Analytic, quasi-experimental, cohort study	• 2010 - hospital with 6 ORs in an Australian replaced all anesthesia machines with a GE Aisys Care station which allows for both manual and automated control of FGF and end-tidal (Et) concentrations of O2, N2O, & volatile agents. • 12-weeks of manual phase (control data) --> 2 months of preparation and education --> 12-weeks of Et phase (intervention data which also required voluntary case report of whether Et control was used & reasons for not using Et control) • No statistical differences in case-load mix between different phases, for age, gender, ASA physical status, surgical specialties, and pediatric GA cases; acquisition costs for volatile agents or CO2 absorber did not change, no statistical or significant difference in CO2 absorber use or consumption savings of medical gases. • 1835 GA cases during manual phase (178 hours/week); 1810 GA cases (160 hours/week) during automated phase; 65% of voluntary	• Vigilance is required to administer volatile anesthetic agents in an optimal manner (environmentally-speaking) • Manual titration of FGFs and inhaled gas concentrations may not be the most efficient in terms of minimizing waste. • Requires a hospital to invest in costly replacements of anesthesia machines with this function - which may not be available in all countries.

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			case reports during Et phase were submitted • Manual vs. automated differences: volatile agent cost per hour decreased from $18.87 to $13.82; rate of GHG emissions 23.2 kg/hr to 13.0 kg/hr (decrease of 10.2 kg/hr = 44% decrease); % of each agent used out of total bottles 17.6% des, 82% sevo, 0.4% iso vs. 11.8% des, 87.6% sevo, 0.4% iso. • Cost difference based on 12-week phase 1 year prior = 153 hours/week of GA; volatile agent cost per hour was $1.54 less than manual phase • Overall automated Et control produced a 25% decrease in volatile agent cost per hour & rate of GHG emissions decreased more than 40%, cost savings ~$40K & 80 tons of CO2e per year at the hospital.	
2012; Sherman et al.	Life cycle greenhouse gas emissions of anesthetic drugs.	Descriptive, ecologic	• Cradle-to-grave GHG emission analyses of common anesthetic agents: desflurane, isoflurane, sevoflurane, and propofol. • Modeling of drug synthesis data, transportation of drugs to Yale-New Haven Hospital via US diesel trucks from US production sites, energy & material requirements during drug delivery (e.g., plastic syringes/tubing, energy for IV pump/des vaporizer), elimination of unmetabolized drug, disposal of accessory waste and unused drug. • Desflurane = largest life cycle GHG emissions (waste & other	• Provides comprehensive quantitative emissions data that compares inhalational anesthetics to another agent that can be used for an alternative anesthetic technique (e.g., TIVA) • Important to the growth of research regarding environmental implications of anesthetic agents but not necessarily generalizable (agents may come from different manufacturers, locations, and agents are not administered at fixed rates but rather fluid depending on patient condition and anesthetic requirements for the patient/surgery)

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			lifecycle stages) • Isoflurane & sevoflurane had similar GHG emissions profiles (greatest emissions from waste) • Propofol almost 4 orders of magnitude lower than desflurane or N2O (greatest emissions from energy to operate syringe pump) - even assuming 50% waste from plastics and energy reqs. • If hydroelectric power is main source of energy (e.g., Pacific NW) then GHG emissions with electricity for drug delivery are nearly nil. • Emissions from transportation, waste management of accessory materials negligible. • Emissions from packaging usually < 5% • Discussion - charcoal absorbers do not effectively eliminate but will absorb volatile anesthetic	
2012; Feldman.	Managing fresh gas flow to reduce environmental contamination.	EO, RA	• Closed circuit is the most efficient use of fresh gas because only enough gas and anesthetic drug are introduced into the circuit to replace what the patient consumes. • GASman simulations to estimate anesthetic vapor use during typical inhaled anesthetic with isoflurane (circle system - induction 15 min/2% iso @ 8 lpm FGF; maintenance 75 min @ 2 lpm FGF & 1 lpm FGF maintaining similar MAC) • Efficacy of vapor delivery = amount of vapor uptake by the patient ÷ total amount delivered to patient - @ 1 lpm maintenance,	• True closed circuit technique will come closest to goal of eliminating environmental contamination but problem with injecting liquid anesthetic vapors, tightly controlling FGF, & assessing volume of circuit = impractical for daily practice, especially during induction & emergence. • Technique recommendations to minimize environmental contamination of anesthetic agents with consideration of how to determine sufficient fresh gas flow necessary & advantages • Disadvantages of minimal flow anesthesia = environmental impact of using more CO2 absorbents; accumulation small amounts of toxic byproducts in the system (e.g.,

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			efficiency increased from 24% to 29% x 500 cases per year for 35 year career = savings of 18,900 L of isoflurane from entering atmosphere. • 1.12 L of isoflurane wasted @ 2 lpm flow per case multiplied by # similar cases annually = millions of liters of anesthetic vapor contaminating the atmosphere • Without a true closed circuit, even 1 lpm flow technique still wastes 52,850 L of isoflurane over the course of a career. • **"Minimum flow anesthesia"** preferred by author because indicates the FGF required to manage anesthetic effectively is not constant but that there is a minimum possible flow at any given time. • Maintenance is the best opportunity to reduce flows but lack of literature available on how to practice minimal flow anesthesia during critical phases of anesthesia (induction & emergence). • Higher FGF required to effect rapid changes in circuit conc of anesthetic but how much flow is sufficient? • <u>Recommendation for induction:</u> <u>I</u>ncreasing the FGF further once there is an open circuit only pushes more gas out of the scavenging system without any benefit to induction process - no benefit to increasing FGF beyond the amount required to eliminate rebreathing. --> requires FGF to be slightly >	nitrogen, carbon monoxide, methane, acetone, compound A) - to address this can consider using absorbents with minimal to no strong alkali (best strategy to avoid toxic gas accumulation), avoiding dessication of absorbents caused by running FGF when not using machine, diverting sampling gas to the scavenging system instead of via breathing circuit, using high FGF q30 min to flush the circuit

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			minute ventilation to eliminate rebreathing; once the set & measured inspired conc approach each other, there is minimal benefit to increasing FGF because additional fresh gas is wasted thru scavenging system; overpressure system, with or without a semic-losed system if provider is comfortable, and use a high exhaled anesthetic concentration alarm to alert of excess levels of anesthetic accumulated in the system. • <u>Recommendation for intubation</u>: Turn off FGF during intubation while leaving the vaporizer on instead of turning off vaporizer and keeping FGF on (preserves anesthetic gas conc in the circuit, facilitates restoring alveolar conc of anesthetic when intubation achieved, & prevents inadvertent release of gas into the OR room -- BUT this requires practitioner to decide comfort with airway management in light of anticipated airway difficulty). • After induction --> FGF can be reduced at the point that anesthetic uptake in the lungs slows down & changes in the vapor conc in the circuit is minimal/steady using the inspiratory/expiratory conc monitoring. Set a low exhaled anesthetic gas alarm to indicate when FGF is too low to sustain anesthetic gas conc desired as a result of uptake. FGF with desflurane can be decreased sooner	

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			because low solubility compared to isoflurane but isoflurane may be the best drug from pure environmental standpoint (& bc sevo minimum flow reqs). • Recommendation for maintenance: Adequate FGF to replace needs from patient's O2 consumption, and leaks from a circuit &/or via a sidestream gas analyzer; add 100 mL/min FGF to target FGF rate to compensate for any immeasurable system leaks (no system is perfect) = Match O2 flow to match patient consumption --> must O2 concentration monitor/analyzer to safely minimize FGF -- determine absolute minimum flow by progressively reducing FGF of O2 and N2O by observing the inspired monitored O2 conc over several mins. • Recommendation for emergence: Impossible to avoid environmental contamination but optimal with experience - estimate surgical duration, managing vaporizer & FGF settings & minute ventilation in relation to duration of procedure --> increase FGF toward end of procedure to gradually reduce vaporizer setting. • Selection of agent: comply with sevoflurane requirements set by FDA = 1 lpm FGF up to 2 MAC hours.	
2011; Dexter et al.	Observational study of anaesthetists' fresh gas flow rates during	Descriptive (observational) study	• Anesthetists more likely than random to choose FGF of multiples of 1 L/min and 0.5 L/min but	• FGF rates vary among providers and may require small titration of rates that may be less convenient that increments of 0.5 or 1

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	anaesthesia with desflurane, isoflurane and sevoflurane.		differences minor re: "economic or psychological importance" • Mean desflurane FGF averaged 26% less than sevoflurane FGF (t=-25.7, P <0.0001); isoflurane FGF averaged 24% less than sevoflurane FGF (t = -17.7, P < 0.0001); des & iso FGF were not statistically significant. • For des & iso: FGF > 1 L/min but less than 3 L/min were observed in 75% of the total FGF = most reductions in FGF are small for FGF for many cases with < 3 L/min • Comparing two studies with different wording of target FGF ('FGF greater than 1 l/minute should not be required" vs. "to reduce FGF to 1 l/minute") but successful at reducing FGF, authors suggest that the precise wording of the target FGF is likely to be irrelevant.	L/min. • Verbiage re: suggested FGF rates is a consideration but may not affect stakeholder understanding of the suggestion.
2010; Sherman & Ryan.	Ecological responsibility in anesthesia practice.	EO	• "'**Ecological footprint**' [definition:] measure of how much land & water area a human population requires to produce the resources it consumes and to absorb its wastes under prevailing technology" (p. 140) • "'**Eco-health footprint**' [definition:] recognizes 6 major impact categories - GHGs (incl. anesthetic gases), water (incl. process & potable), waste (incl. municipal solid, regulated medical, hazardous waste, electronics,	• Ecological responsibility aligns with DNP essential VII by encouraging efforts to temporize hospital manufacturing (upstream) and waste (downstream) sources of toxic chemical agents. • No standardized measure exists to compare environmental harm of pharmaceuticals. • Broadens the understanding of the environmental considerations and potential implications related to anesthesia practice. • Authors end with "an urgent call to action" in medical practice to reduce ecological footprint of the perioperative

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			construction/demolition, recyclable waste), toxic chemicals, air pollutants, and built land." There are areas for improving environmental stewardship that is unique to the healthcare sector. (p. 140) • U.S. EPA recognizes link between public health and greenhouse gases. Healthcare is leading consumer of fossil fuels representing 17% of U.S. GDP. • Anesthetic gases impacts environment via (1) unregulated direct release into atmosphere, (2) undergo minimal in vivo metabolism in clinical use - exhaled and scavenged by anesthetic machines with little to no additional degradation. • AGs remain for a long time in the troposphere (lowest layer of the atmosphere in which the greenhouse effect occurs) & where the AGs can act as GHGs. • What is GWP? Atmospheric lifetimes & infrared absorption patterns help determine GWP of each AG based on a kilogram per kilogram basis compared with CO_2. GWP of desflurane (3714) > isoflurane (1401) > sevoflurane (349) > N_2O (289) > CO_2 (1). US average per mile driven = 398g CO_2. • Adding N_2O worsens impact of sevoflurane by 6-fold and isoflurane by 3-fold but remains the same for desflurane. N_2O; however, is directly destructive to	area is low FGF, use & selection of low-impact agents, institution of pre-packaged syringes.

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			the ozone layer. - clinicians shouldn't automatically add N2O to limit volatile agent use. • Prepackaged syringes can be ecological and economic because sterile preparation are similar to unopened drug vials = reduces waste.	

REFERENCES

Allen, J. D., Towne Jr., S. D., Maxwell, A. E., DiMartino, L., Leyva, B., Bowen, D. J., Linnan, L., & Weiner, B. J. (2017). Measures of organizational characteristics associated with adoption and/or implementation of innovations: A systematic review. *BMC Health Services Research, 17*(1). https://doi.org/10.1186/s12913-017-2459-x

American Association of Nurse Anesthesiology. (n.d.). (AANA). *Management of waste anesthetic gases: Policy considerations*. https://www.aana.com/docs/default-source/practice-aana-com-web-documents-(all)/professional-practice-manual/management-of-waste-anesthetic-gas.pdf?sfvrsn=600049b1_6

American Lung Association. (ALA). (2022-a.). *Report card: Arizona*. https://www.lung.org/research/sota/city-rankings/states/arizona

American Lung Association. (ALA). (2022-b.). *State of the air: Health impact of air pollution*. https://www.lung.org/research/sota/health-risks#peopleatrisk

American Lung Association. (ALA). (2022-c.) *Metropolitan statistical area: Phoenix-Mesa area*. https://www.lung.org/research/sota/city-rankings/msas

American Lung Association. (ALA). (2022-d.). *Understanding grades and tables*. https://www.lung.org/research/sota/about-the-report/understanding-the-grades

Anesthetic Gas Reclamation Incorporation. (n.d.). *Our key products*. https://www.gasrecycler.com/products/

Aranake, A., Mashour, G. A., & Avidan, M. S. (2013). Minimum alveolar concentration: Ongoing relevance and utility. *Anaesthesia, 68*, 512-522. https://doi.org/anae.12168

Ard Jr., J. L., Tobin, K., Huncke, T., Kline, R., Ryan, S. M., & Bell, C. (2016). A survey of the American society of anesthesiologists regarding environmental attitudes, knowledge and organization. *Anesthesia & Analgesia, 6*(7), 208-216. https://doi.org/10.1213/XAA.0000000000000184

Arizona Commerce Authority. (2018). *County profile for Maricopa County*. https://www.azcommerce.com/a/profiles/ViewProfile/9/Maricopa+County/

Arizona Department of Health Services. (ADHS). (2021). *Heat-related illness emergency department & inpatient admissions (hospitalizations) 2016-2020, Arizona residents and non-residents*. https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/heat-related-illness-emergency-department-and-inpatient-admissions-in-arizona-by-year.pdf

Arora, K., Swami, A., Puppala, P., & Rai, A. (2020). Comparative study of automated end tidal control versus manula fresh gas flow adjustment with respect to gas usage and delivery during low flow anesthesia. *Anesthesia and Critical Care 2*, 039-051. https://fortuneonline.org/articles/comparative-study-of-automated-end-tidal-control-versus-manual-fresh-gas-flow-adjustment-with-respect-to-gas-usage-and-delivery-du.html

Associated Press. (2018, July 26). 'Urban island' heat tests Phoenix, other large cities. US News & World Report. https://www.usnews.com/news/healthiest-communities/articles/2018-07-26/urban-island-heat-tests-phoenix-other-large-cities

Auld, G., Baker, S., McGirr, K., Osborn, K. S., & Skaff, P. (2017). Confirming the reliability and validity of others' evaluation tools before adopting for your programs. *Journal of Nutrition Education and Behavior, 49*(5), 441–450.e1. https://doi.org/10.1016/j.jneb.2017.02.006

Axelrod, D., Bell, C., Feldman, J., Hopf, H., Huncke, T. K., Paulsen, W., . . . Yost, S. (2014). *Greening the operating room and perioperative arena: Environmental sustainability for anesthesia practice*. https://www.asahq.org/about-asa/governance-and-committees/asa-committees/committee-on-equipment-and-facilities/environmental-sustainability/greening-the-operating-room

Azouz, S., Boyll, P., Swanson, M., Castel, N., Maffi, T., & Rebecca, A. M. (2019). Managing barriers to recycling in the operating room. *Am J Surg*, *217*(4), 634-638. https://doi.org/10.1016/j.amjsurg.2018.06.020

Balas, E. A., Chapman, & W. W. (2018). Road map for diffusion of innovation in health care. *Health Affairs, 37*(2). https://doi.org/10.1377/hlthaff.2017.1155

Blue-Zone Technologies. (n.d.). *Blue-zone technologies awarded additional US patent for central collection of anesthetic gas, securing their leading position in the sector*. https://www.blue-zone.ca/Central-collection-of-anaesthetic-gas-US-Patent

Buslov, Carroll, M., & Desai, M. S. (2018). Frozen in time: A history of the synthesis of nitrous oxide and how the process remained unchanged for over 2 centuries. *Anesthesia and Analgesia*, *127*(1), 65–70. https://doi.org/10.1213/ANE.0000000000003423

Braz, M. G., Carvalho, L., Chen, C. O., Blumberg, J. B., Souza, K. M., Arruda, N. M., Filho, D., Resende, L. O., Faria, R., Canário, C. D., de Carvalho, L. R., Corrêa, C. R., Braz, J., & Braz, L. G. (2020). High concentrations of waste anesthetic gases induce genetic damage and inflammation in physicians exposed for three years: A cross-sectional study. *Indoor Air*, *30*(3), 512–520. https://doi.org/10.1111/ina.12643

C40 Cities Climate Leadership Group. (2021a). Statement by the C40 cities steering committee on the organization's new leadership standards. https://www.c40.org/news/statement-by-the-c40-cities-steering-committee/

C40 Cities Climate Leadership Group. (2021b). *Data insights: Greenhouse gas emissions interactive dashboard [Data set]*. C40 Knowledge Hub. https://www.c40knowledgehub.org/s/article/C40-cities-greenhouse-gas-emissions-interactive-dashboard?language=en_US

Carleton, T. A., Jina, A., Delgado, M.T., Greenstone, M., Houser, T., Hsiang, S.. M., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I. B., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J. & Zhang, A. T. (2021). *Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits* [Working paper]. National Bureau of Economic Research. https://www.nber.org/system/files/working_papers/w27599/w27599.pdf

Carter, L. A., Oyewole, M., Bates, E., & Sherratt, K. (2019). Promoting low-flow anaesthesia and volatile anaesthetic agent choice. *BMJ Open Qual*, *8*(3), e000479. https://doi.org/10.1136/bmjoq-2018-000479

Centers for Disease Control and Prevention. (CDC). (n.d.). *Climate effects on health.* https://www.cdc.gov/climateandhealth/effects/default.htm

Chang, R., & Little, T. D. (2018). Innovations for evaluation research: Multiform protocols, visual analog scaling, and the retrospective pretest–posttest design. *Evaluation & the Health Professions, 41*(2), 246-269. https://doi.org/10.1177/0163278718759396

Conover, W. J., & Iman, R. L. (1981). Rank transformations as a bridge between parametric and nonparametric statistics. *The American Statistician, 35*(3), 124-129. https://doi.org/10.1080/00031305.1981.10479327

Dearing, J. W., & Cox, J. G. (2018). Diffusion of innovations theory, principles, and practice. *Health Affairs, 37*(2). https://doi.org/10.1377/hlthaff.2017.1104

Devlin-Hegedus, J. A., McGain, F., Harris, R. D., & Sherman, J. D. (2022). Action guidance for addressing pollution from inhalational anaesthetics. *Anaesthesia.* https://doi.org/10.1111/anae.15785

Dialesandro, J., Brazil, N., Wheeler, S., & Abunnasr, Y. (2021). Dimensions of thermal inequity: Neighborhood social demographics and urban heat in the Southwestern US. *International Journal of Environmental Research and Public Health, 18*(3), 941. https://doi.org/10.3390/ijerph18030941

DNP Essentials Task Force. (2006). *The essentials of doctoral education for advanced nursing practice*. American Association of Colleges of Nursing. https://www.aacnnursing.org/DNP/DNP-Essentials

Dorr, D. A., Cohen, D. J., & Adler-Milstein, J. (2018). Data-driven diffusion of innovations: Successes and challenges in 3 large-scale innovative delivery models. *Health Affairs, 37*(2). https://doi.org/10.1377/hlthaff.2017.1133

Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public health damage in the United States: An update. *Health Affairs, 39*(12), 2071-2079. https://doi.org/10.1377/hlthaff.2020.01247

Edmonds, A., Stambaugh, H., Pettey, S., & Daratha, K. B. (2021). Evidence-based project: Cost savings and reduction in environmental release with low-flow anesthesia. *AANA Journal, 89*(1), 27-33.

Epstein, R. H., Dexter, F., Maguire, D. P., Agarwalla, N. K., & Gratch, D. M. (2016). Economic and environmental considerations during low fresh gas flow volatile agent administration after change to a nonreactive carbon dioxide absorbent. *Anesthesia Analgesia, 122*(4), 996-1006.

Feldman, J. M. (2012). Managing fresh gas flow to reduce environmental contamination. *Anesthesia & Analgesia*, 114(5), 1093-1101. https://doi.org/10.1213/ANE.0b013e31824eee0d

Freund, P. (2022, April 2). *GE Healthcare receives FDA approval of first-ever software to help automate anesthesia delivery and reduce greenhouse gas emissions during surgery.* Business Wire. https://www.businesswire.com/news/home/20220404005215/en/GE-Healthcare-Receives-FDA-Approval-of-First-Ever-Software-to-Help-Automate-Anesthesia-Delivery-and-Reduce-Greenhouse-Gas-Emissions-During-Surgery

Gaya da Costa, M., Kalmar, A. F., & Struys, M. (2021). Inhaled anesthetics: Environmental role, occupational risk, and clinical use. *Journal of Clinical Medicine 10*(6). https://doi.org/10.3390/jcm10061306

George, D., & Mallery, P. (2016). *IBM SPSS statistics 23 step by step: A simple guide and reference*. Routledge.

Guetter, C. R., Williams, B. J., Slama, E., Arrington, A., Henry, M. C., Möller, M. G., Tuttle-Newhall, J. E., Stein, S., & Crandall, M. (2018). Greening the operating room. *American Journal of Surgery*, *216*(4), 683–688. https://doi.org/10.1016/j.amjsurg.2018.07.021

Hill, L. G. (2020). Back to the future: Considerations in use and reporting of the retrospective pretest. *International Journal of Behavioral Development, 44*(2), 184-191. https://doi.org/10.1177/0165025419870245

Hiller, K. N., Altamirano, A. V., Cai, C., Tran, S. F., & Williams, G. W. (2015). Evaluation of waste anesthetic gas in the post anesthesia care unit within the patient breathing zone. *Anesthesiology Research and Practice,* 354184. https://doi.org/10.1155/2015/354184

Howard, G. S. (1980). Response-shift bias. *Evaluation Review*, *4*(1), 93–106. https://doi.org/10.1177/0193841X8000400105

Howard, G. S., Ralph, K. M., Gulanick, N. A., Maxwell, S. E., Nance, D. W., & Gerber, S. K. (1979). Internal invalidity in pretest-posttest self-report evaluations and a re-evaluation of retrospective pretests. *Applied Psychological Measurement*, *3*(1), 1–23. https://doi.org/10.1177/014662167900300101

Hwalek, M., Solomon-Filer, C., & Wasserman, D. (2022). Retrospective pretests: Recent use in visitor studies research and ways to make them more informative. *Visitor Studies, 25*(1), 1-21. https://doi.org/10.1080/10645578.2021.1977084

Institute for Healthcare Improvement. (IHI). (n.d.). *Science of improvement: How to improve*. https://www.ihi.org/resources/Pages/HowtoImprove/ScienceofImprovementHowtoImprove.aspx

James, I. (2021, March 15). Low-income and Latino neighborhoods endure more extreme heat in the Southwest, study shows. *AZ Central.* https://www.azcentral.com/story/news/local/arizona-environment/2021/03/15/poor-and-latino-neighborhoods-endure-hotter-temperatures-study-finds/6920826002/

Kandeel, A., Emorshedi, M., Abdalla, U., Abouelela, M., Elsarraf, W., Sultan, A., Abdelwahab, M., & Yassen, A. M. (2017). Automated control of end-tidal sevoflurane in living donor hepatectomy, a prospective, randomized, controlled study. *Egyptian Journal of Anaesthesia, 33*(3), 233-237. https://doi.org/10.1016/j.egja.2017.05.007

Karim, H. M. R., Sinha, M., Kumar, M., Khetrapal, M., & Dubey, R. (2018). An observation from an online survey: Is fresh gas flow used for sevoflurane and desflurane different from isoflurane based anesthesia? *Medical Gas Research, 9*(1), 13-17. https://doi.org/10.4103/2045-9912.254637

Karliner, J., Slotterback, S., Boyd, R., Ashby, B., & Steele, K. (2019). *Health care's climate footprint: How the health sector contributes to the global climate crisis and opportunities for action*. Health Care Without Harm, & Arup. https://noharm-global.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf

Kennedy, R. R., French, R.A., Vesto, G., Hanrahan, J., & Page, J. (2019). The effect of fresh gas flow during induction of anaesthesia on sevoflurane usage: A quality improvement study. *Anaesthesia, 74*, 875-882. https://doi.org/10.1111/anae.14669

Kim, D. D., Kimura, A., Jr, Pontes, D., Oliveira, M., & Cumino, D. O. (2018). Evaluation of anesthesiologists' knowledge about occupational health: Pilot study. *BMC Anesthesiology*, *18*(1), 193. https://doi.org/10.1186/s12871-018-0661-y

Kuhlman, C. J., Korkmaz, G., Ravi, S. S., & Vega-Redondo, F. (2020). Effect of interaction mechanisms on Facebook dynamics using a common knowledge model. In R. M. Benito, C. Cherifi, H. Cherifi, E. Moro, L. M. Rocha, M. Sales-Pardo (Eds.), *Complex networks & their applications IX* (Vol. 943, pp. 395–407). Springer International Publishing AG. https://doi.org/10.1007/978-3-030-65347-7_33

Leggott, K. T., Martin, M., Sklar, D., Helitzer, D., Rosett, R., Crandall, C., Vagh, F., & Mercer, D. (2016). Transformation of anesthesia for ambulatory orthopedic surgery: A mixed-methods study of a diffusion of innovation in healthcare. *Healthcare, 4*, 181-187. https://doi.org/10.1016/j.hjdsi.2015.09.003

Lenzen, M., Malik, A., Li, M., Fry, J., Weisz, H., Pichler, P.-P., Chaves, L. S., Capon, A., & Pencheon, D. (2020), The environmental footprint of healthcare: A global assessment. *Lancet Planet Health, 4*(7), e271-e279. https://doi.org/10.1016/S2542-5196(20)30121-2

Li, J. F., & Chiu, S. (2019). *Evaluation of waste anesthetic gas exposure and miscarriages at a veterinary hospital: Health hazard evaluation report 2017-0077-3336*. United States Department of Health and Human Services, Centers for Disease Control and Prevention, & National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/2017-0077-3336.pdf

Little, T. D., Chang, R., Gorrall, B., Waggenspack, L., Fukuda, E., Noam, G., & Allen, P. (2020). The retrospective pretest-posttest design redux: On its validity as an alternative to traditional pretest-posttest measurement. *International Journal of Behavioral Development, 44*(2), 175–183. https://doi.org/10.1177/0165025419877973

MacNeill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., Hernandez, L., McGain, F., Simonsen, K., Thiel, C., Young, S., Lagasse, R., & Sherman, J. D. (2020). Transforming the medical device industry: Road map to a circular economy. *Health Affairs, 39*(12), 2088–2097. https://doi.org/10.1377/hlthaff.2020.01118

MacNeill, A. J., Lillywhite, R., & Brown, C. J. (2017). The impact of surgery on global climate: A carbon footprinting study of operating theatres in three health systems. *Lancet Planet Health,* 1, e381-e388. Elsevier.

Maricopa Association of Governments. (n.d.). Heat relief network: Frequently asked questions. https://azmag.gov/Portals/0/Heat-Relief/2022/HRN-FAQ_2022.pdf

McGain, F., Ma, S. C., Burrell, R. H., Percival, V. G., Roessler, P., Weatherall, A. D., Weber, I. A., & Kayak, E. A. (2019). Why be sustainable? The Australian and New Zealand college of anaesthetists professional document ps64: Statement on environmental sustainability in anaesthesia and pain medicine practice and its accompanying background paper. *Anaesthesia and Intensive Care*, *47*(5), 413–422. https://doi.org/10.1177/0310057X19884075

McGain, F., Muret, J., Lawson, C., & Sherman, J. D. (2020). Environmental sustainability in anaesthesia and critical care. *British Journal of Anaesthesia, 125*(5), 680-692. https://doi.org/10.1016/j.bja.2020.06.055

Mohajerani, A., Bakaric, J., Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management, 197*, 522-538. https://doi.org/10.1016/j.jenvman.2017.03.095

Moran, P., Barr, D., Holmes, C. (2019). Saving sevoflurane: Automated gas control can reduce consumption of anesthetic vapor by one-third in pediatric anesthesia. *Pediatric Anesthesia, 29*(4), 310-314. https://doi.org/10.1111/pan.13587

National Institute for Occupational Safety and Health. (2007). Waste anesthetic gases: Occupational hazards in hospitals. Department of Health and Hyman Services Centers for Disease Control and Prevention. https://www.cdc.gov/niosh/docs/2007-151/pdfs/2007-151.pdf

Nimon, & Astakhova, M. (2015). Improving the rigor of quantitative HRD research: Four recommendations in support of the general hierarchy of evidence. *Human Resource Development Quarterly, 26*(3), 231–247. https://doi.org/10.1002/hrdq.21219

Nimon, K., Zigarmi, D., & Allen, J. (2011). Measures of program effectiveness based on retrospective pretest data: Are all created equal? *American Journal of Evaluation, 32*(1), 8-28. https://doi.org/10.1177/1098214010378354

Occupational Safety and Health Administration. (OSHA). (2000). *Anesthetic gases: Guidelines for workplace exposures*. United States Department of Labor. https://www.osha.gov/waste-anesthetic-gases/workplace-exposures-guidelines

Office of Environmental Programs. (2021). *Climate action plan: 2021 edition. City of Phoenix*. https://www.phoenix.gov/oep/climate

Pashaeypoor, S., Ashktorab, T., Rassouli, M., & Alavi-Majd, H. (2017). Experiences of nursing students of evidence-based practice education according to Rogers' diffusion of innovation model: A directed content analysis. *Journal of Advances in Medical Educaiton & Professionalism, 5*(4), 203-208.

Pichler, P.-P., Jaccard, I. S., Weisz, U., & Weisz, H. (2019). International comparison of health care carbon footprints. *Environmental Research Letters, 14*(6), 64004. https://doi.org/10.1088/1748-9326/ab19e1

Piwowar, V., & Thiel, F. (2014). Evaluating response shift in training evaluation: Comparing the retrospective pretest with an adapted measurement invariance approach in a classroom management training program. *Evaluation Review, 38*(5), 420-448. https://doi.org/10.1177/0193841X14546932

Potdar, M. P., Kamat, L. L., & Save, M. P. (2014). Cost efficiency of target-controlled inhalational anesthesia. *Journal of Anaesthesiology Clinical Pharmacology*, *30*(2), 222-227. https://doi.org/10.4103/0970-9185.130026

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Ryan, S. M. & Nielsen, C. J. (2010). Global warming potential of inhaled anaesthetics: Application to clinical use. *Anesthesia & Analgesia, 111*(1), 92-98. https://doi.org/10.1213/ANE.0b013e3181e058d7

Salas, R. N., Friend, T. H., Bernstein, A., & Jha, A. K., (2020). Adding a climate lens to health policy in the United States. *Health Affairs, 39*(12). https://doi.org/10.1377/hlthaff.2020.01352

Sherman, J., Feldman, J., Berry, J. M. (2017). Reducing inhaled anesthetic waste and pollution [Commentary]. *Anesthesiology News*, 12-14.

Sherman, J. D., Lagasse, R. (2018). How healthy is health care [Commentary]? *JAMA Network Open, 1*(4), e18,1000. https://doi.org/10.1001/jamanetworkopen.2018.1000

Sherman, J., Le, C., Lamers, V., & Eckelman, M. (2012). Life cycle greenhouse gas emissions of anesthetic drugs. *Anesthesia & Analgesia, 114*(5), 1086-1090. https://doi.org/10.1213/ANE.0b013e31824f6940

Sherman, J. D., & Ryan, S. (2010). Ecological responsibility in anesthesia practice. *International Anesthesiology Clinics, 48*(3). Lippincott, Williams & Wilkins.

Shine, K. P. (2010). Climate effect of inhaled anaesthetics [Editorial]. *British Journal of Anaesthesia, 105*(6), 731-733. https://doi.org/10.1093/bja/aeq313

Singaravelu, S., & Barclay, P. (2013). Automated control of end-tidal inhalation anaesthetic concentration using the GE Aisys Carestation. *British Journal of Anaesthesia, 110*(4), 561-566. https://doi.org/10.1093/bja/aes464

Skalec, T., Gorecka-Dolny, A., Zielinski, S., Gibek, M., Strozecki, L., & Kubler, A. (2017). Comparison of anaesthetic gas consumption and stability of anaesthesia using automatic and manual control over the course of anaesthesia. *Anaesthesiology Intensive Therapy, 49*(1), 34-39.

Souza, K. M., Braz, L. G., Nogueira, F. R., Souza, M. B., Bincoleto, L. F., Aun, A. G., Corrente, J. E., Carvalho, L. R., Braz, J., & Braz, M. G. (2016). Occupational exposure to anesthetics leads to genomic instability, cytotoxicity and proliferative changes. *Mutation Research*, *791-792*, 42–48. https://doi.org/10.1016/j.mrfmmm.2016.09.002

Sulbaek Andersen, M. P., Nielsen, O. J., Wallington, T. J., Karpichev, B., & Sander, S. P. (2012). Medical intelligence article: Assessing the impact on global climate from general anesthetic gases. *Anesthesia and Analgesia*, *114*(5), 1081–1085. https://doi.org/10.1213/ANE.0b013e31824d6150

Sulbaek Anderson, M. P., Sander, S. P., Nielsen, O. J., Wagner, D. S., Sanford, T. J., & Wallington, T. J. (2010). Inhalation anaesthetics and climate change. *British Journal of Anaesthesia, 105*(6), 760-766. https://doi.org/10.1093/bja/aeq259

Suttner, S. & Boldt, J. (2000). Low-flow anaesthesia: Does it have potential pharmacoeconomic consequences? *PharmacoEconomics*, *17*(6), 585–590. https://doi.org/10.2165/00019053-200017060-00004

Tay, S., Weinberg, L., Peyton, P., Story, D., & Briedis, J. (2013). Financial and environmental costs of manual versus automated control of end-tidal gas concentrations. *Anaesthesia Intensive Care, 41*(1), 95-101

Tollinche, L., Tan, K., Han, A., Ojea, L., & Yeoh, C. (2018). Analyzing volatile anesthetic consumption by auditing fresh gas flow: An observational study at an academic hospital. *International Journal of Anesthetics and Anesthesiology, 5*(1), 1-4. https://doi.org/10.23937/2377-4630/1410064

Tona, J., Kruger, J., Jacobsen, L. J., Krzyzanowicz, R., Towle-Miller, L. M., Wilding, G. E., & Ohtake, P. J. (2021). Assessing the assessment: A comparison of the IPASS and ICCAS to measure change in interprofessional competencies following a large-scale interprofessional forum. *Journal of Interprofessional Care*, *35*(5), 726–735. https://doi.org/10.1080/13561820.2020.1806219

United States Environmental Protection Agency. (USEPA). (2021a). *Basic ozone layer science*. https://www.epa.gov/ozone-layer-protection/basic-ozone-layer-science

United States Environmental Protection Agency. (USEPA). (2021b). *Climate change indicators: US and global temperature*. https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature

United States Environmental Protection Agency. (USEPA). (2021c). *Climate change indicators: Weather and climate*. https://www.epa.gov/climate-indicators/weather-climate

United States Food and Drug Administration. (USFDA). (n.d.-a.). *Ultane*. https://www.accessdata.fda.gov/drugsatfda_docs/label/2017/020478s030lbl.pdf

United States Food and Drug Administration. (USFDA). (n.d.-b.). *Summary of safety and effectiveness data: Et control*. https://www.accessdata.fda.gov/cdrh_docs/pdf21/P210018B.pdf

Upadya, M. & Saneesh, P. (2018). Low-flow anaesthesia - Underused mode towards "sustainable anaesthesia." *Indian Journal of Anaesthesia*, *62*(3), 166–172. https://doi.org/10.4103/ija.IJA_413_17

Varughese, S., & Ahmed, R. (2021). Environmental and occupational considerations of anesthesia: A narrative review and update. *Anesthesia & Analgesia, 133*(4), 826-835. https://doi.org/10.1213/ANE.0000000000005504

Varughese, S., & Bacher, H. P. (2020). Validation of waste anaesthetic gas exposure limits when using a closed vaporizer filling system: A laboratory-based study. *Advances in Therapy*, *37*(1), 450–456. https://doi.org/10.1007/s12325-019-01159-2

Visme. (n.d.). *About Visme*. https://www.visme.co/about/

Watson, & Zhang, Y. (2021). A retrospective pre-post survey to analyze course revisions, perceived learning, and learning outcomes in an agricultural structures course. *Transactions of the ASABE, 64*(5), 1415–1423. https://doi.org/10.13031/trans.14578

Whalen, F. X., Bacon, D. R., & Smith, H. M. (2005). Inhaled anesthetics: An historical overview. *Best Practice & research. Clinical Anaesthesiology*, *19*(3), 323–330. https://doi.org/10.1016/j.bpa.2005.02.001

World Health Organization. (WHO). (2021). *Climate change and health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

Wyssusek, K. H., Keys, M. T., & van Zundert, A. J. (2018). Operating room greening initiatives - the old, the new, and the way forward: A narrative review. *Waste Management & Research 37*(1), 3-9. https://doi.org/10.1177/0734242X18793

Young, J., & Kallemeyn, L. (2019). Testing the retrospective pretest with high school youth in out-of-school time programs. *Journal of Youth Development, 14*(1). https://doi.org/10.5195/jyd.2019.635

Zaccagnini, M., & White, K. (2017). *The doctor of nursing practice essentials: A new model for advanced practice nursing*. Jones & Bartlett Learning.

Zuegge, K. L., Bunsen, S. K., Volz, L. M., Stromich, A. K., Ward, R. C., King, A. R., Sobeck, S. A., Wood, R. E., Schliewe, B. E., Steiner, R. P., & Rusy, D. A. (2019). Provider education and vaporizer labeling lead to reduced anesthetic agent purchasing with cost saving and reduced greenhouse gas emissions. *Anesthesia & Analgesia, 128*(6), e97-e99. https://doi.org/10.1213/ANE.0000000000003771