THE IMPACT OF ANESTHETIC CHOICE ON CARBON EMISSIONS AND COST

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Dedication and Acknowledgements

To my family who provided endless support and encouragement over this three-year journey. To my professors, Dr. Nancy Shedlick, Dr. Linda Stone, Dr. Terry Wicks, and Dr. Vadim Korogoda for believing in me and pushing me to succeed. To the committee members for their help with this monumental task. To the hospital anesthesia department, for encouraging and supporting my creative vision and for making me feel like a part of the team. Thank you.

Abstract

Background: The environmental impact and cost of anesthetic agents are easily overlooked aspects of anesthesia practice. Nearly the entire volume of inhaled anesthetics are released into the atmosphere where they act as greenhouse gases (GHGs). Intravenous (IV) anesthesia exerts a fraction of the environmental impact and provides a more favorable patient experience. **Purpose:** The purpose of this project was to educate anesthesia providers about the environmental effects and relative cost of commonly used anesthetic agents. **Methods:** A mixed-methods design was used to evaluate and educate anesthesia providers at a level 1 trauma center in North Carolina. Baseline anesthetic usage was collected from the electronic medical record (EMR) for a fourteen-day period. A presentation to anesthesia providers during a morning staff meeting discussed those results, environmental impact, and cost of volatile anesthetics. Participants were asked to complete pre and post-surveys. Educational flyers were distributed in the break room and a sticker was placed on each anesthesia machine in the operating rooms that provided information on carbon footprint and the cost of volatile anesthetics. Anesthetic usage was collected for a fourteen-day period after the educational intervention. **Results:** Estimated carbon footprint ($KgCO_2e$) of the measured inhaled anesthetics (isoflurane, sevoflurane, desflurane, and nitrous oxide) saw a 28% decrease. Estimated cost incurred decreased by 11%. The use of total intravenous anesthesia (TIVA) or balanced anesthesia technique with IV and inhaled agents saw virtually no change between the two data collection periods. **Conclusion:** A statistically significant decrease in carbon footprint may be attributed solely to inhaled anesthetic agent choice.

Keywords: anesthesia, carbon, footprint, environment, inhalational, desflurane, isoflurane, sevoflurane, intravenous, propofol, emission, volatile, gas, cost, waste, green, and climate.

Background and Significance

Qualified professionals in the operating room administer anesthetic agents to produce a reversible depression of the central nervous system and optimize the working conditions for each surgical procedure. This may be achieved with inhaled or intravenous (IV) anesthetics and requires careful titration to minimize undesirable physiologic responses. Throughout anesthesia education, attention is focused on the use of anesthetic agents with minimal discussion of the disposal of volatile anesthetics and their impact on the environment.

Three halogenated ethers: isoflurane, sevoflurane, and desflurane, along with nitrous oxide, are commonplace inhaled anesthetics found in facilities throughout the United States.. The pharmacokinetic profiles show little metabolism, with 95-99% of inhaled agents exhaled from the body chemically unchanged. The agents leave the operating room (OR) via active scavenging and passive ventilation systems (Ehrenwerth et al., 1993, p.133-134). While a handful of facilities in the U.S. employ waste anesthetic gas (WAG) reclaiming devices, the vast majority do not; therefore, the anesthetics go from the facility straight into the atmosphere.

Once in the atmosphere, all inhaled anesthetic agents act as greenhouse gases (GHG), contributing to global climate change radiative forcing. Inhaled anesthetics are exempt from multinational treaties on chemical production/regulation based on medical necessity. The global impact of inhaled anesthetics each year may be comparable to one coal-fired power plant or one million passenger cars (Sulbaek Anderson et al., 2010). Nitrous oxide is widely known as one of the most environmentally damaging gases in the atmosphere, and 40% of global emissions are attributed to human activities. Beyond its capacity as a GHG, nitrous oxide also contributes to ozone depletion (Lew et al., 2018). An alternative to inhaled anesthesia is a total intravenous anesthetic (TIVA) technique with propofol. TIVA provides an equally safe anesthetic with less postoperative nausea and vomiting, post-operative pain, postoperative delirium, shorter recovery unit stay, and increased patient satisfaction (Elbakry et al., 2018; Schraag et al., 2018). A cradle-to-grave assessment of GHG emissions estimated the use of propofol produces roughly 4 orders of magnitude fewer carbon emissions than desflurane (Sherman et al., 2012). TIVA techniques produce significantly lower environmental impact and can improve the postoperative course for patients when compared to inhaled anesthetic agents.

Purpose

The purpose of this project was to educate anesthesia providers about the environmental effects and relative cost of commonly used anesthetic agents. New or reinforced awareness empowered providers with knowledge to make clinically sound and environmentally responsible decisions about their choice of anesthetic agent.

Review of Current Evidence

A review of recent literature on climate change, pharmacology, and chemistry was done to understand the current state of the science. The University of North Carolina Greensboro (UNCG) online library advanced search tool was used to search PubMed, CINAHL Complete, and ProQuest Central databases. Keywords “carbon”, “carbon footprint”, “environment”, “inhalational”, “emission”, “volatile”, and “climate” were used alone or in combination with “AND” as the Boolean operator. The searches were limited to full text articles published within the past ten years. Fifteen articles met the criteria, and others were excluded based on publication language, article type, or year of publication. To gauge coverage of the topic by students, the keywords “carbon”, “environment”, “anesthetic”, “inhalational”, and “emission” were entered individually to search DNP repositories from Vanderbilt University, University at Buffalo, Northshore University, and the University of Massachusetts. The same keywords were entered into the UNCG online library advanced search tool with the Boolean operator "AND" to limit search results to those with journal source "International Student Journal of Nurse Anesthesia." No available student literature met these criteria.

Modern volatile anesthetics are chemical compounds known as chlorofluorocarbon (CFC) or hydrofluorocarbon (HFC) chemical structures. Such compounds have been predominantly phased out worldwide due to their impact on the atmosphere, but anesthetics are exempt based on medical necessity. These are classified as GHGs because they accumulate in the atmosphere, where they absorb and re-emit infrared (IR) radiation back towards the earth's surface. Additionally, isoflurane and nitrous oxide destroy ozone. This ozone-depleting effect is relatively small for isoflurane, but the long atmospheric lifetime of nitrous oxide leads to a more-considerable impact (Campbell & Pierce, 2015; Revell et al., 2015). Atmospheric measurements of isoflurane, sevoflurane, and desflurane suggest roughly 80% of the collective carbon footprint may be attributed to desflurane (Vollmer et al., 2015). Simply avoiding desflurane may empower providers to decrease their carbon footprint without having to omit volatile agents altogether.

Inhaled anesthetics can be delivered to, recycled within, and discarded from the body at different rates based on the fresh gas flow rate (FGF) dialed in the anesthesia machine by the provider. When the agent leaves the circuit, it is considered WAG, routed outside the building, and released into the atmosphere chemically unchanged. There is no regulation against this practice nor are there widely used mechanisms to capture WAGs. Adjusting FGF is one way providers may alter the amount of WAG. Isoflurane, desflurane, and nitrous oxide may be used safely at FGF 0.5 L/min. Sevoflurane is most commonly used at a FGF 2.0 L/min based on manufacturer recommendations. The manufacturer does not recommend sevoflurane usage at FGF less than 1 L/min or 1-2 L/min for longer than 2 hours at the MAC level (Ultane, 2003).

The impact of these agents may be quantified using Global Warming Potential over 100 years (GWP). GWP is an internationally accepted metric used to gauge environmental impact compared to carbon dioxide (CO_2), which has a GWP of 1. The GWP for isoflurane, sevoflurane, desflurane, and nitrous oxide is 510, 130, 2540, and 298 for the same mass unit as CO_2 (Sulbaek Andersen et al., 2012). The relative volume administered should also be taken into consideration, as these agents are supplied in varying concentrations. The minimum alveolar concentration at 1 atm of pressure which prevents movement in response to surgical stimulation in 50% of patients (MAC) is established as the benchmark of surgical-level anesthesia for inhaled agents. The estimated MAC value for isoflurane is 1.15% (Stevens et al., 1975), sevoflurane is 2% (Katoh & Ikeda, 1987), desflurane is 6% (Rampil et al., 1991), and nitrous oxide is 104% (Hornbein et al., 1982). A combination of GWP, MAC, molecular weight, and fresh gas flow per hour (FGF) can be used to estimate the CO_2-equivalent carbon footprint ($KgCO_2e$) over time. Though the GWP differs by four times, isoflurane and sevoflurane may ultimately produce comparable carbon footprints when isoflurane is administered using low FGF (Vollmer et al., 2015). This is attributed to the higher concentration (lower MAC) of isoflurane. The $KgCO_2e$ of desflurane remains the greatest even at the lowest practically usable FGF (Vollmer et al., 2015). Desflurane's low potency means that it must be used in volumes roughly three times greater than sevoflurane and six times greater than isoflurane to achieve a similar therapeutic effect. The combination of more volume with a GWP five to twenty times greater than the other two options positions desflurane to have an exceedingly high carbon footprint.

Nitrous oxide is the primary anthropogenic ozone-depleting gas in the atmosphere (Campbell & Pierce, 2015). Although the volume used is much greater than other inhaled anesthetics, anesthesia as a whole does not represent a large contributor to atmospheric concentrations of nitrous oxide (Revell et al., 2015). Anesthesia use does not contribute a large percentage of total nitrous oxide to the atmosphere but remains an important consideration to the overall carbon footprint of inhaled anesthetics.

Propofol is a commonly used IV anesthetic without a directly measurable atmospheric impact. Propofol does exert a carbon footprint from manufacturing, transport, use, and waste. The most significant impact stems from the energy used to power the IV pump as most healthcare facilities are powered by fossil-fuel-based energy plants (Sherman et al., 2012). A low carbon footprint makes propofol the most environmentally-friendly agent to maintain general anesthesia.

TIVA or balanced anesthesia with propofol and volatile anesthetics may also improve patient outcomes. TIVA's utility extends from minor procedures to major operations, including coronary artery bypass grafting (CABG) with no significant difference in outcome (Landoni et al., 2019). A systematic review and meta-analysis of randomized controlled trials (RCTs) found a significantly lower risk of postoperative nausea and vomiting (PONV), post-operative pain, post-operative delirium, and time spent in the recovery unit by patients who received TIVA (Schraag et al., 2018). The authors also noted a significant increase in patient-reported satisfaction (Schraag et al., 2018). Beyond the direct benefit to patients and perceived benefit to the wellbeing of anesthesia providers, patient-reported satisfaction has increasing importance for hospital reimbursement and future revenue stream. Healthcare quality measures are readily available to the public and reported patient satisfaction, particularly with surgical procedures, may be a deciding factor when patients select a facility to have their procedure.

Climate change has been named the biggest threat to global health in the 21st century (Watts et al., 2018). Atmospheric changes from GHGs and aerosols increase the incidence of temperature-dependent health and well-being effects on humans (Lelieveld et al., 2019). If GHG emissions stopped completely, the global climate might stabilize, but the temperature would not decrease for centuries (Matthews & Zickfeld, 2012). The US health care system alone is responsible for around 25% of global health care GHG emissions and 8-10% of total US GHG emissions (Eckelman et al., 2020; Pichler et al., 2019). Inhaled anesthetics are estimated to contribute around 1% to US health care GHG emissions (Sherman et al., 2014). The commensurate impact on public health by GHG emissions from the US health sector is associated with 388,000 disability-adjusted life-years lost (DALYs) without accounting for WAGs (Eckelman et al., 2020). The scale and varying nature of global climate make it difficult to predict the impact moving forward but the current understanding is that it will only worsen. An international report with over 6,000 scientific references discussed the importance of reducing GHG emissions to “net-zero” by 2050 to avoid the worst predicted harms to global health (IPCC, 2018).

Forgoing the use of inhalational anesthetics altogether may produce the lowest carbon footprint incurred by anesthesia providers. However, an impactful middle-ground may be found by simply avoiding the use of desflurane and nitrous oxide. Compounding adverse effects to air quality and climate change will influence the lives of many generations. It remains our responsibility as, “The nurse’s primary commitment is to the patient, whether an individual, family, group, community, or population.” (ANA, 2015, Provision 2). In this unique instance, anesthesia providers are positioned to make a choice that not only impacts the patient at hand but impacts the population as a whole.

Theoretical Framework

Lewin's Change Theory was used as a framework. Lewin's approach to change management initiates by spreading awareness of a problem to disrupt the established equilibrium and unfreeze habits in practice (Manchester et al., 2014). This was accomplished by presenting information to anesthesia providers about relative carbon emissions and the cost of anesthetics used. Once the equilibrium is disrupted, an opportunity for change appears. Awareness of environmental impact and financial burden led providers to modify the anesthetics they choose. The change may then be solidified as a new habit so long as the change mechanism was effective enough to reestablish equilibrium (Cummings et al., 2016). Information was reinforced using educational material organized in a high-yield format on single sheets of paper placed in the breakroom and on stickers adhered to the anesthesia machines. A survey was distributed pre- and post-presentation to assess knowledge, understanding, habits, and willingness to change. The post-survey provided insight into barriers that can be modified to promote permanent change. Once providers adopt a new approach, their equilibrium resolidifies and resists change.

Methods

Design

This DNP project aimed to provide information to anesthesia providers about the impact of commonly used anesthetics on carbon emissions and cost. A mixed-methods design was used to assess, measure, and educate anesthesia providers at an urban level 1 trauma center in North Carolina. Qualitative data was collected with a pre and post-survey. Quantitative data from twenty GE Healthcare Aisys CS^2 Anesthesia Delivery Systems was recorded in the electronic medical record (EMR). Data was collected for a fourteen-day period before a PowerPoint presentation and was compared to data collected for a fourteen-day period after the presentation.

Translational Framework

The Promoting Action on Research Implementation in Health Services (PARiHS) framework underscored the implementation of this quality improvement (QI) project. This model relies on a strong connection between three elements: evidence, context, and facilitation (Rycroft-Malone, 2004). The evidence incorporated research on climate change, human health, environmental chemistry, and pharmacodynamics. It also included clinician experiences and facility pricing data for the volatile anesthetics studied. The context included the internal culture present at the facility and was revealed by the outcomes of this DNP project. The facilitation of this project was dependent on disseminating information to clinicians to promote change. This was accomplished with a presentation to anesthesia providers, placing stickers on individual anesthesia machines during the measurement period, and sharing informational flyers. These three elements promoted the change in behavior of anesthesia providers.

Population

The study consisted of a convenience sample of licensed anesthesia providers practicing during the data collection period. The sample size for qualitative data was limited by the number of providers who voluntarily completed the surveys. Participants may have included certified registered nurse anesthetists (CRNA), anesthesiologist assistants (AA), Doctors of Osteopathic Medicine in anesthesia (DO), and medical doctors of anesthesia (MD). Participants were recruited with a recruitment email sent to anesthesia providers at the facility. The email included disclosures and information intended to protect the project participants from harms that might result from their participation in the project – physical, psychological/emotional, social, and economic risks. No identifying information was collected, and results were congregated.

Data from anesthesia machines in twenty operating rooms were collected over two fourteen-day periods before and after the educational presentation. The first and second data collection periods included 686 and 721 cases, respectively, for a total of 1,407 cases. Anesthesia machines were the same model with isoflurane, sevoflurane, and desflurane cassettes readily available to choose from. Bottles of isoflurane, sevoflurane, and desflurane were accessible to anesthesia providers both in the operating rooms and in the centrally located medication room. Nitrous oxide was available on all machines via pipeline connection. Propofol supply in every room was maintained by pharmacy team members. Syringes and IV pump tubing were stocked by anesthesia and support staff making them available to use.

Setting

The project took place at an urban level 1 trauma center in North Carolina. Twenty main operating rooms were the focus for gathering data. Educational information was distributed in the anesthesia breakroom and the twenty operating rooms.

Project Implementation

Actions taken and what support/resources were used to implement the plan

Permission to conduct the project was granted by a clinical coordinator and the assistant chief CRNA at the facility. The APP & Medical Student Research Committee at the facility approved the project and multimedia before implementation. Exemption from the Institutional review board (IRB) approval process was granted through UNCG on the basis that it did not constitute human subjects research.

Instruments

The primary outcome of this study was to determine the impact of an educational intervention on inhaled anesthetic usage. Secondary outcomes included determining which barriers arose to prevent or dissuade providers from changing practice. Prior to the intervention, the participants were directed to an online pre-intervention survey via email or scannable QR code (Appendix A). Throughout the intervention period, participants were directed to a similar online post-presentation survey via scannable QR code (Appendix A). A five-point Likert-style survey was used to assess provider knowledge of volatile anesthetic impact on the environment, provider willingness to change current practice, and potential barriers to change. The Likert-style survey consisted of the options: strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, and strongly disagree. Data were compiled in Microsoft Excel for organization and statistical analysis.

Timeline and critical milestones

February 21, 2021: Project site support letter

June 21, 2021: Project approved by university IRB

July 12, 2021: Project approved by site APP & Medical Student Research Committee

July 18, 2021 – July 31, 2021: Data collection period

July 29, 2021: Stickers printed

August 6, 2021: PowerPoint presentation

August 8, 2021: Educational flyers and stickers distributed

August 9, 2021 – August 22, 2021: Data collection period

August 23, 2021: Educational flyers and stickers removed

Data Collection

Records for surgeries occurring in the main twenty operating rooms fourteen days pre and post-intervention were retrospectively and remotely accessed through the EMR. Data measured included: surgery type (vascular, extrathoracic, intrathoracic, extracranial, intracranial, spinal, orthopedic, oropharyngeal, endocrine, intraabdominal, skin, or perineal), surgery length, anesthetic type, anesthetic length, age, and body mass index (<18.5, 18.50-24.99, 25.00-29.99, 30.00-34.99, 35.00-39.99, and >39.99). The data were recorded in Microsoft Excel, included in the educational intervention, and distributed with the educational materials (Appendix D). Anesthetic type was linked with $KgCO_2e$, cost, BMI, age, and procedure type.

A twenty-minute PowerPoint presentation on the environmental effects and relative costs of commonly used anesthetic agents was provided to the anesthesia department during a scheduled morning staff meeting (Appendix B). Data from the first collection period was displayed to illustrate current anesthetic usage, comparative cost, and comparative carbon footprint. Survey data was collected via a Qualtrics XM survey link emailed to the anesthesia department 1 week prior to the presentation. The same survey was made accessible on the day of the presentation using a scannable QR code. Follow-up survey data was collected via a Qualtrics XM survey QR code on informational flyers that were distributed in the anesthesia breakroom and on educational stickers placed on the anesthesia machines (Appendix E). The educational flyers and stickers remained in place for fourteen days.

Anesthetic usage data was collected from a total of 1,407 cases. Cases were excluded by date range and if they were procedures for organ procurement. Anesthetic time was calculated to include the minutes between when an agent was initially administered to when either the agent was stopped or the patient was extubated, whichever came first. Anesthetic agent start/stop time may have been entered by the provider or recorded automatically in the EMR. Inhalational induction is frequently used in pediatric cases. This typically involves the use of nitrous oxide for the beginning of the case. If a provider used the inhaled induction technique and did not use nitrous oxide for any other part of the procedure, it was categorized by the type of anesthetic used after the nitrous oxide induction, not a combination of the two agents. If a provider chose to use nitrous oxide for only the end of a procedure (pediatric or adult), it was categorized by the type of anesthetic used prior to the nitrous oxide, not a mixture of the two agents. Cases that involved cardio-pulmonary bypass machines (CPB) only recorded the anesthetic agent used by the anesthesia machine in the record. The perfusionist operating the CPB titrates the anesthetic agent when a patient's blood is being circulated through the bypass pump. For cases using CPB, the anesthetic agent on the chart was recorded as being administered for the entire duration of the anesthetic.

Data Analysis

Survey Data

Survey data was analyzed using descriptive statistics. Twenty respondents completed the pre-test questionnaire. Seven respondents completed the post-test questionnaire. Ordinal categorical variables were organized in histograms for analysis. Four of the questions on the pre- and post-test questionnaire were identical and thus were the only questions analyzed using t-Test: Two-Sample.

The post-evaluation survey contained multiple open-ended questions. These were compared to the overall analysis of both questionnaires and used to highlight common themes.

Machine Data

Data was organized in Excel with each row representing a surgical case and each column representing the surgery type (by previously outlined categories), surgery length (published in the EMR), anesthetic agent/technique, anesthetic length (calculated by agent start/stop times in the EMR), body mass index (BMI), and age. Each 24-hour period was separated by sheet within the excel spreadsheet file. In the instance that a case bridged between 24-hour periods, it was recorded on the day it started. Separate excel spreadsheet files were created for pre- and post-presentation periods (14 days each). Data from each collection period was consolidated and graphed in a separate sheet.

Anesthetic length was used to estimate carbon footprint and cost of volatile anesthetics. In the instance that a volatile anesthetic was used as the primary means of anesthesia, cost and carbon footprint ($KgCO_2e$) were calculated with the assumption of a 2 liter per minute (L) fresh gas flow (FGF) and 1.0 minimum alveolar concentration at 1atm of pressure (MAC) for the entire duration. In the instance that a volatile anesthetic was used alongside nitrous oxide (N_2O) as the primary means of anesthesia, cost and $KgCO_2e$ were calculated with the assumption of a 3 L FGF and 1.0 MAC for the entire duration. In the instance that a volatile anesthetic was used alongside a propofol infusion, cost and $KgCO_2e$ were calculated under the assumption of a 2 L FGF and 0.5 MAC for the entire duration.

The ideal gas law was used to determine that 1 mole of a gas at 1 atm and 21 °C (69.8 °F) will occupy 24.14 L. The volume of volatile agent, as calculated using the FGF and MAC values, was divided by 24.14 L to determine the molar volume of volatile agent delivered per minute. This molar volume was multiplied by molecular weight and converted from grams (g) to kilograms (Kg) to determine the mass of volatile agent delivered per minute. This was multiplied by 60 to determine the mass delivered per hour. The GWP for each volatile agent was used as a conversion factor to calculate KgCO2e per hour from the mass. The KgCO2e was used to determine the carbon footprint, delivered at each respective concentration over a given period.

Purchasing data for each of the volatile anesthetics was obtained from the hospital: 250 mL of sevoflurane at $74.4100, 250 mL of isoflurane at $25.5383, and 240 mL of desflurane at $149.1067. The calculated mass for each agent was divided by the respective density (Kg/cm^3) to determine the volume of liquid used per hour. This volume was divided by the unit volume in which each agent was supplied to determine the fraction of the bottle used per hour. The fraction of the bottle used was multiplied by the purchasing price to determine the cost per hour. This was applied to the length of each surgical case to determine the cost, delivered at each respective concentration over a given period.

The surgical cases were organized by data collection period and grouped side by side into two categories: D1 and D2. Anesthetic length for each case was organized in the respective column. Estimated volatile anesthetic cost and estimated volatile anesthetic $KgCO_2e$ were organized into columns corresponding with the anesthetic length. The data was further separated by anesthetic type and grouped into separate Excel sheets based on 5 categories: desflurane, sevoflurane, isoflurane, balanced (volatile agent with propofol, local anesthetic), and TIVA (propofol as the primary anesthetic). F-Test T-Sample for Variances was performed to determine variance between collection periods for anesthetic length, volatile anesthetic estimated cost, and volatile anesthetic estimated $KgCO_2e$. The two datasets as a whole were analyzed using a t-Test: Two-Sample with respective variance used based on the results of the f-Test. Alpha was set at 0.05. The categories: desflurane, sevoflurane, isoflurane, and balanced were analyzed using a t-Test: Two-Sample with respective variance used based on the results of the f-Test. Alpha was set at 0.05. Analysis of cost and $KgCO_2e$ was not performed for TIVA due to a lack of purchasing data from the hospital and a lack of reliable $KgCO_2e$ for propofol.

Results

Survey Data

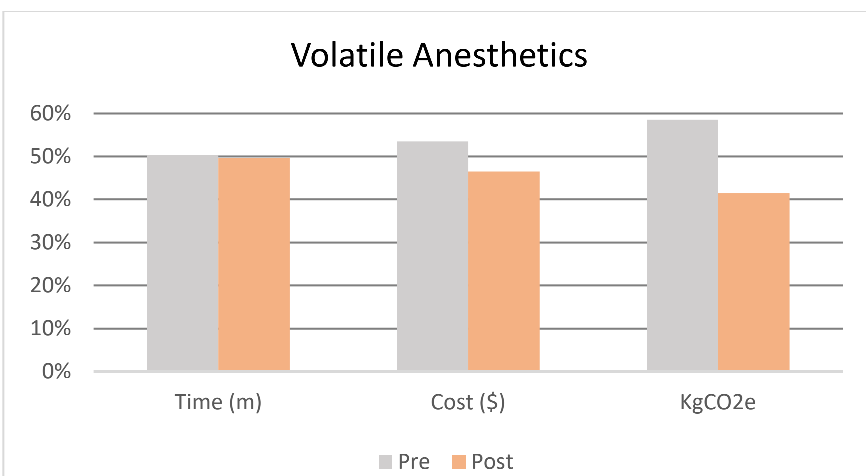
Four of the survey questions were analyzed to show that questions two and three produced statistically significant increases ($p\text{-value} < 0.05$) from pre- to post-presentation groups.

Question two evaluated whether providers understood how anesthetics have an environmental impact. On the pretest, 25% strongly agreed and 70% somewhat agreed. On the posttest, 71% strongly agreed and 29% somewhat agreed. Question three asked whether providers considered the cost of their anesthetic. On the pretest, 25% strongly agreed and 45% somewhat agreed. On the posttest, 29% strongly agreed and 71% somewhat agreed. Question four asked whether providers considered the carbon footprint of their anesthetic. On the pretest, 5% strongly agreed and 35% somewhat agreed. On the posttest, 43% strongly agreed and 29% somewhat agreed. Question five asked whether providers tended to modify their anesthetic plan to minimize carbon footprint or cost. On the pretest, 5% strongly agreed and 35% somewhat agreed. On the posttest, 14% strongly agreed and 43% somewhat agreed.

Machine Data

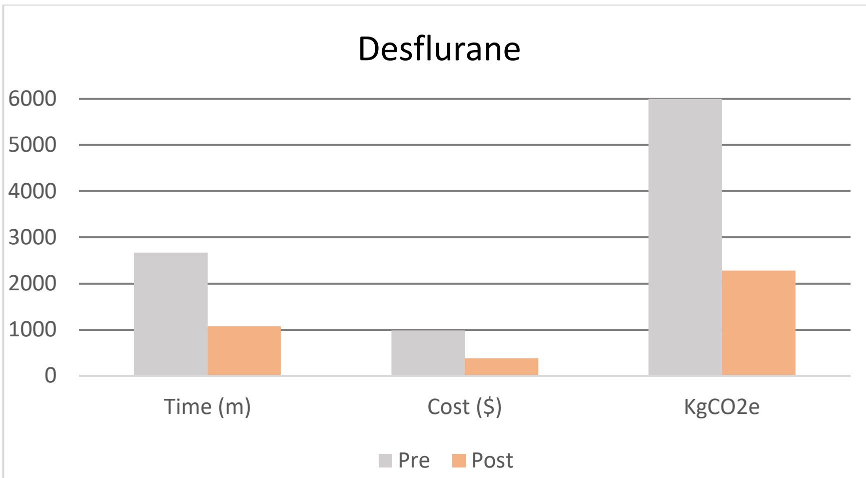
Overall analysis of estimated cost and $KgCO_2e$ for inhaled anesthetics found a statistically significant decrease (p-value<0.05) from pre- to post-presentation groups in $KgCO_2e$ but not cost (Figure 1).

Figure 1 *Volatile anesthetics pre- and post-presentation*



The desflurane group showed a statistically significant decrease from pre- to post-presentation groups in all 3 of the variables analyzed: time used, cost, and $KgCO_2e$ (Figure 2). The sevoflurane, isoflurane, and balanced groups did not show a statistically significant change from pre- to post-presentation groups in any of the 3 variables analyzed. The TIVA group did not show a statistically significant change from pre- to post-presentation group in time used (the only variable analyzed for this group).

Figure 2 *Desflurane pre- and post-presentation*



Discussion

Overall, the educational intervention resulted in a 28% decrease in carbon footprint and an 11% decrease in cost associated with volatile anesthetics administered in the main operating rooms. The use of desflurane as the primary anesthetic decreased by 59% which produced a 39% decrease in carbon footprint and a 50% cost savings for this category alone. Instead of desflurane, providers chose sevoflurane, which increased by 21% while isoflurane decreased by 8%. Sevoflurane is roughly 3x the cost of isoflurane but exerts less of a carbon footprint when administered at 2 L FGF (Sulbaek Anderson et al., 2012). Additionally, 3 cases during the second data collection period were anesthetized using a balanced technique with desflurane and propofol for a total of 506 minutes. These lengthy cases contributed to a 203% increase in carbon footprint and 103% increase in cost for the balanced technique group even though the total time of balanced technique usage was practically unchanged. This takes on greater significance, as the overall decreased cost and carbon footprint came with virtually no increase in the use of TIVA (1.3%) or balanced anesthetic techniques (0.6%). The improvements are a direct result of anesthesia providers modifying their choice of volatile anesthetic to include ones that decrease carbon emissions.

Survey data showed a statistically significant increase in providers' understanding of how anesthetics have an environmental impact and their consideration for the cost of the anesthetic they provide. This aligns with data taken from the anesthesia machines. After providers gained a greater understanding of the cost and environmental impact of volatile anesthetics, they incorporated the knowledge into practice by using less desflurane, the most expensive and environmentally harmful volatile anesthetic. Because the stickers placed on the anesthesia machines were removed after the two-week data collection period, the original usage trends may return. The stickers would have served as a visual cue to reinforce change behavior, allowing it to refreeze as the new normal. If the changes made by providers were applied to a calendar year, this intervention could save $9,125.62 and 104,630 $KgCO_2e$. This carbon footprint savings is equivalent to 22.8 average passenger vehicles or 262,956 miles driven by one passenger vehicle (EPA, 2021). Sharing this information could lead to greater savings once providers are made aware of the impact of their choices.

Strengths and Limitations

Limitations imposed by a convenience sample and a one-time educational intervention produced a small sample size of survey respondents. Educational material was posted in the anesthesia break room and on stickers placed on the anesthesia machines to increase the number of participants. Passive recruitment for the post-survey contributed to a small pool of respondents. Adding additional dates and times for an educational intervention and emailing participants with reminders to complete the post-survey may increase sample size.

The project was designed to coincide with an update to the EMR. The update would have provided volumetric data for the volatile anesthetics. The update did not work as intended and no case-specific volumetric data was available for the measured inhalational anesthetics. Carbon footprint and cost of the measured anesthetics were estimated from manual data collected.

Climate change is a polarizing topic in the United States and may be associated with a political party, providing a barrier to change. Pairing carbon emissions data with price data provides a multi-faceted approach demonstrating how a more expensive anesthetic may also be worse for the environment.

Anesthesia providers may be partial to using modalities they feel most comfortable with thereby resisting change. Education about the pharmacokinetic profiles of anesthetics they may not frequently use prepares those providers for successful implementation of change and increases comfort levels with new modalities.

Access to volatile anesthetic supply in the operating room often depends on the stock available. Ensuring that operating rooms are adequately stocked with volatile anesthetics will provide availability of all options and ensure choice of any anesthetic.

Estimated GWP for these agents is based on our current understanding of carbon dioxide's lifespan in the atmosphere. Improvements in data collection and calculations may lead to changes in these values. This may result in differing GWP values between studies, based on the state of science at the time.

Recommendations for Future Study

It will be important to the permanence of this change that providers are informed of the results from this project and permanent reminders are placed on anesthesia machines. Follow-up studies may be performed to assess staying power. While there was a decrease in the use of desflurane, a further decrease in the environmental impact can be achieved with the use of TIVA. Educational interventions on the benefits of TIVA usage may improve the adoption of this technique. A small number of healthcare facilities in the area have decreased the use of desflurane by limiting the availability of desflurane cassettes. It would be helpful to assess whether this is an appropriate intervention for an urban level 1 trauma center and whether anesthesia providers are amenable to such a change. Volumetric data for inhaled anesthetics is accessible on anesthesia machines. If this data can be included as a part of the EMR, it will increase the precision of cost and carbon footprint estimates and enable thorough analysis by surgical case. Similar initiatives to this one should be taken at other facilities. The greatest decrease in cost and environmental impact can only occur if these changes grow to a large scale in the anesthesia community.

Conclusion

This project sought to educate anesthesia providers about the environmental impact and cost of commonly used anesthetics and led to practice change to decrease both. The survey reported an increase in knowledge after the educational intervention. Additionally, there was a decrease in cost and carbon footprint of anesthetics post-intervention. A simple intervention to improve providers' knowledge of the carbon footprint and cost related to the anesthetics they use led to impactful results. Additional education to increase the number of participants could further decrease cost and environmental impact from anesthesia.

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Appendix A: Surveys

Pre-Intervention Survey

1. What is your mother's birthday? (This question is used for matching purposes only)
2. I understand how anesthetics have an environmental impact.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
3. I think about the cost of anesthesia I provide.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
4. I think about the carbon emissions of anesthesia I provide.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
5. I modify my anesthetic plan to minimize carbon emissions or cost of anesthetics more than 50% of the time.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

6. I prefer to use TIVA over inhaled anesthesia
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
7. Rank the volatile anesthetics by the frequency that you use them
    - __ Desflurane
    - __ Sevoflurane
    - __ Isoflurane
8. My volatile anesthetic of choice has not changed since I graduated and became an anesthesia provider
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
9. Years of experience ______

10. I use recycle bins when available.

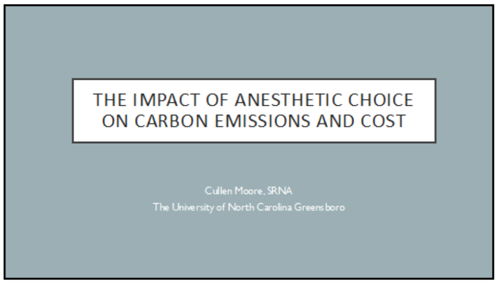
    - Yes
    - No

Post-Intervention Survey

1. What is your mother's birthday? (This question is used for matching purposes only)
2. I understand how anesthetics have an environmental impact.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
3. I think about the cost of anesthesia I provide.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
4. I think about the carbon emissions of anesthesia I provide.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree

5. I modify my anesthetic plan to minimize carbon emissions or cost of anesthetics more than 50% of the time.
    - Strongly agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Strongly disagree
6. Rank the volatile anesthetics by the frequency that you use them since learning about their environmental impact and cost via this DNP project
    - __ Desflurane
    - __ Sevoflurane
    - __ Isoflurane
7. Years of experience _______
8. I use recycle bins when available.
    - Yes
    - No
9. If you have not and don't plan to adjust how you provide anesthesia, why?
    - __ I already do those things
    - __ (free text)
10. If you encountered any barriers to adjusting how you provide anesthesia, what were they?
    - (free text)
11. Other comments or concerns that you would like to share.
    - (free text)

Appendix B: PowerPoint Presentation



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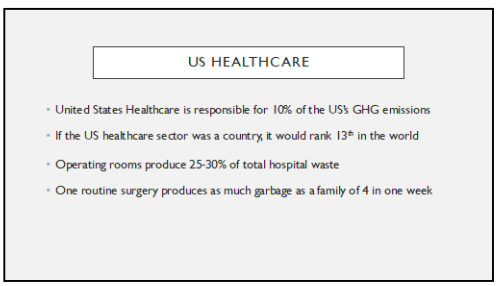

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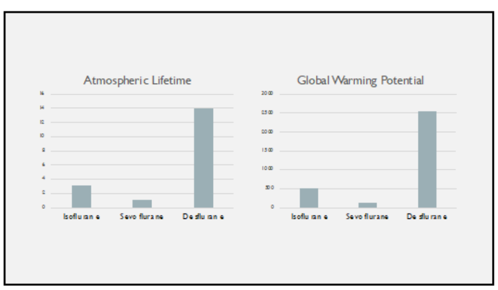

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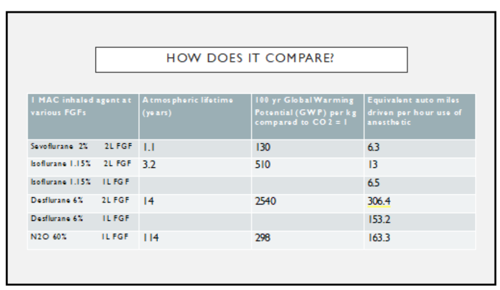
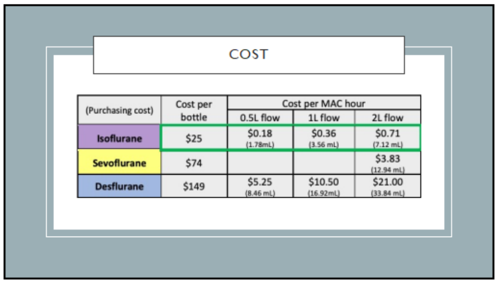
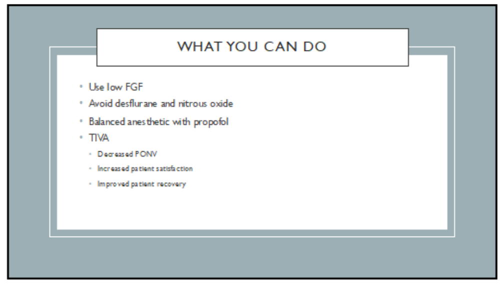


1 MAC inhaled agent at various FGFs	Atmospheric lifetime (years)	100 yr Global Warming Potential (GWP) per kg compared to CO2 = 1	Equivalent auto miles driven per hour use of anesthetic
Sevoflurane 2% 2L FGF	1.1	130	6.3
Isoflurane 1.15% 2L FGF	3.2	510	13
Isoflurane 1.15% 1L FGF			6.5
Desflurane 6% 2L FGF	14	2540	306.4
Desflurane 6% 1L FGF			153.2
N2O 60% 1L FGF	114	298	163.3

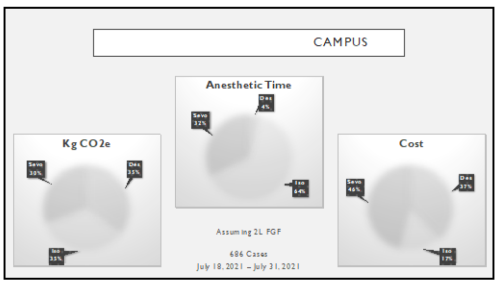
6


COST
(Purchasing cost)
Cost per bottle
Cost per MAC hour
0.5L flow
1L flow
2L flow
Isoflurane
$25
$0.18 (1.78mL)
$0.36 (3.56 mL)
$0.71 (7.12 mL)
Sevoflurane
$74
$3.83 (12.94 mL)
Desflurane
$149
$5.25 (8.46 mL)
$10.50 (16.92mL)
$21.00 (33.84 mL)

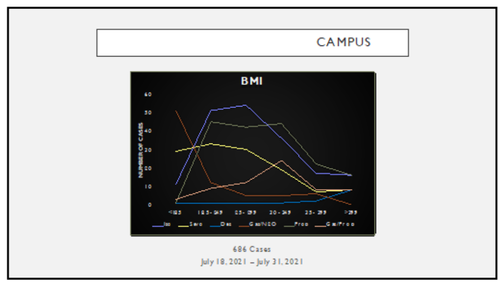
7


WHAT YOU CAN DO
Use low FGF
Avoid desflurane and nitrous oxide
Balanced anesthetic with propofol
TIVA
Decreased PONV
Increased patient satisfaction
Improved patient recovery

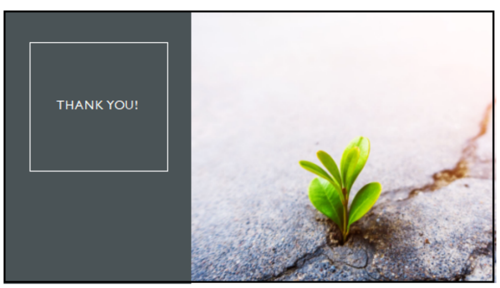
8


CAMPUS
Kg CO2e
Sevo 30%
Des 35%
Iso 35%
Anesthetic Time
Des 4%
Sevo 32%
Iso 64%
Cost
Sevo 46%
Des 37%
Iso 17%
Assuming 2L FGF
686 Cases
July 18, 2021 – July 31, 2021

9


CAMPUS
BMI
686 Cases
July 18, 2021 – July 31, 2021

10


THANK YOU!

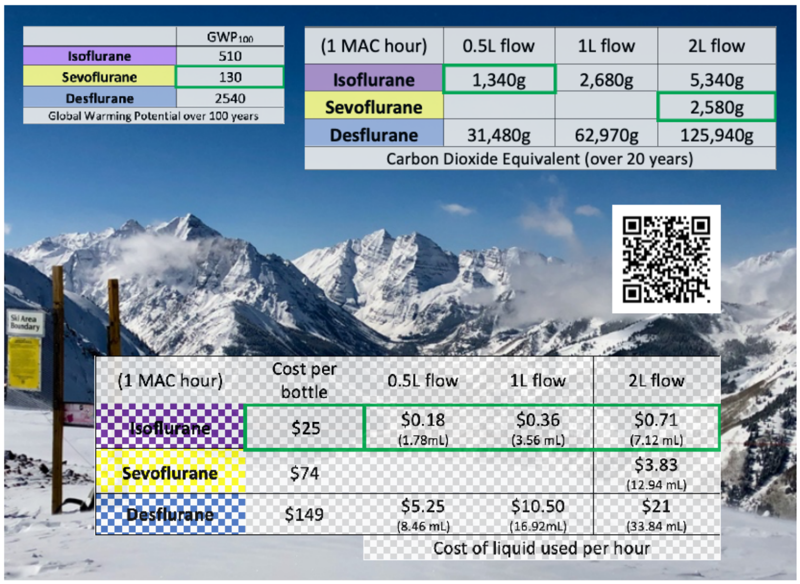
11

Appendix C: Educational Handout

The Impact of Anesthetic Choice on Carbon Emissions and Cost

Cullen Moore, SRNA

In case you missed my presentation, I have provided some helpful information below. Some of this information can also be found on stickers on the anesthesia machines.
I greatly appreciate your help and support with my DNP project.



	GWP_{100}
Isoflurane	510
Sevoflurane	130
Desflurane	2540

Global Warming Potential over 100 years

(1 MAC hour)	0.5L flow	1L flow	2L flow
Isoflurane	1,340g	2,680g	5,340g
Sevoflurane			2,580g
Desflurane	31,480g	62,970g	125,940g

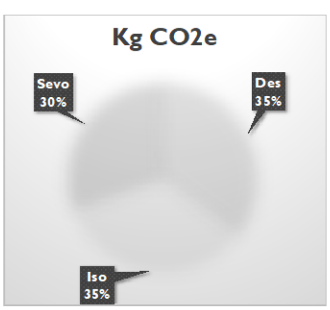
Carbon Dioxide Equivalent (over 20 years)

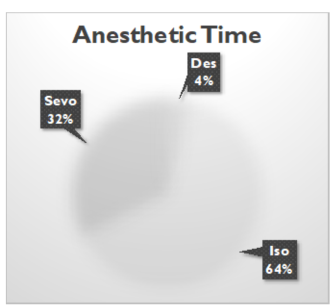
(1 MAC hour)	Cost per bottle	0.5L flow	1L flow	2L flow
Isoflurane	$25	$0.18 (1.78mL)	$0.36 (3.56 mL)	$0.71 (7.12 mL)
Sevoflurane	$74			$3.83 (12.94 mL)
Desflurane	$149	$5.25 (8.46 mL)	$10.50 (16.92mL)	$21 (33.84 mL)

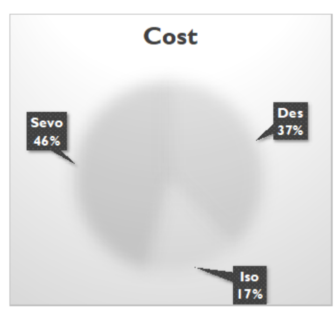
Cost of liquid used per hour

- Use low Fresh Gas Flow
- Avoid desflurane and nitrous oxide (not just a harmless carrier gas)
- Balance anesthetic with propofol
- TIVA (decreases PONV & increases patient satisfaction)

Volatile Usage at   – July 18 to July 31 (686 cases)



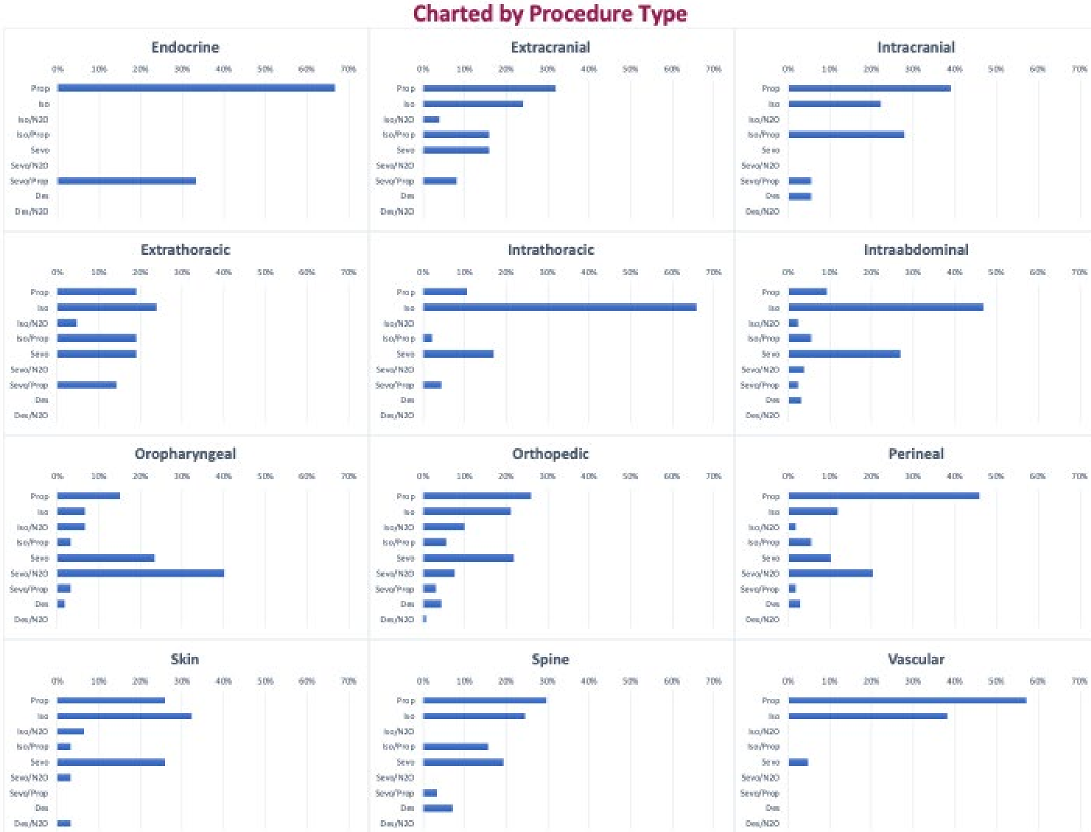




Feel free to email me with any questions or concerns: cbmoore3@uncg.edu

July 18 – July 31 Charted by Anesthetic Type

Charted by Procedure Type



Appendix E: Stickers

(Purchasing cost)	Cost per bottle	Cost per MAC hour		
		0.5L flow	1L flow	2L flow
Isoflurane	$25	$0.18 (1.78mL)	$0.36 (3.56 mL)	$0.71 (7.12 mL)
Sevoflurane	$74			$3.83 (12.94 mL)
Desflurane	$149	$5.25 (8.46 mL)	$10.50 (16.92mL)	$21.00 (33.84 mL)

Scan Me

Survey

(1 MAC hour)	0.5L flow	1L flow	2L flow
Isoflurane	1.3 kg	2.68 kg	5.34 kg
Sevoflurane			2.58 kg
Desflurane	31 kg	63 kg	126 kg
Carbon Dioxide Equivalent (over 20 years)