Assessing the Current State of Surgical Smoke Evacuation Device Use: A Quality Improvement Project at Doernbecher Children's Hospital

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NURS 703: DNP Project

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August 1, 2021

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Abstract

Exposure to surgical smoke (SS) in the operating room (OR) is an occupational hazard and may harm patients. Smoke evacuation devices (SEDs) are available, but not uniformly utilized, at Doernbecher Children's Hospital (DCH). By assessing and describing the current state of SED use at DCH, a comprehensive understanding of its underutilization may allow for future local interventions that more effectively and consistently protect patients and staff from the hazards of SS. This quality improvement (QI) project evaluated OR personnel's adoption or rejection of SEDs through survey questions informed by Roger's Diffusion of Innovation (DOI) theory. Survey methodology, targeted interviews, and record review were employed to describe the current state of SED use and identify perceived benefits and barriers to their use in DCH ORs. Report data revealed only 3.2% of annual SS-generating cases at DCH utilized SEDs. Survey and targeted interview data highlighted opposing views regarding their use. Perceived benefits of SED use include patient and OR personnel safety and perceived barriers include inconvenience or interference with the procedure (including bulkiness of the device), impaired surgical field visualization, and surgeon preference. OR personnel across specialties indicated a need for mandatory institutional policy, legislative change, or a significant change in the culture surrounding SED use at DCH. Future work should focus on standardizing education regarding the hazards of SS to all DCH OR personnel and improving communication surrounding this topic among staff members.

Keywords: surgical smoke, operating room, occupational hazard, smoke evacuation device, pediatric hospital, quality improvement, survey

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Problem Description

Exposure to surgical smoke (SS) in the operating room (OR) is an occupational hazard and may be harmful to patients. SS is the result of energy-generating surgical devices heating bodily tissues, subsequently producing a "plume" that may consist of particulate matter (PM), carcinogens, mutagens, and infectious agents (Hill et al., 2012; Limchantra et al., 2019; Michaelis et al., 2020; O'Brien et al., 2020). OR personnel are routinely exposed to this plume, and pediatric patients may be uniquely vulnerable to the effects of inhaled PM (Grigg, 2009; Wild & Kleinjans, 2003). Given the current state of evidence, several professional and governmental organizations, including the National Institute for Occupational Safety and Health (NIOSH) and the Association of periOperative Registered Nurses (AORN), recommend the use of smoke evacuation devices (SEDs) during SS-generating procedures (Association of periOperative Registered Nurses [AORN], 2017; Carr et al., 2020; Steege et al., 2016). These devices are present in nearly every OR at Doernbecher Children's Hospital (DCH), but they are not uniformly utilized. Due to the associated risks of SS exposure for OR personnel and pediatric patients, this quality improvement (QI) project aims to describe the current state of SED use, and identify perceived benefits and barriers to their use at DCH.

Available Knowledge

Every year, SS affects the health and safety of over 500,000 OR staff members in the United States (National Institute for Occupational Safety and Health [NIOSH], 2017). SS is released during surgical procedures utilizing diathermy devices, such as electrosurgical units (ESUs), lasers, and ultrasonic scalpels (Limchantra et al., 2019). Common pediatric procedures, such as appendectomies and tonsillectomies, routinely utilize monopolar electrocautery (O'Brien et al., 2020; Sømme et al.,

2013). Widespread use of ESUs in pediatric procedures exposes OR personnel to the acute and chronic adverse effects of SS following inhalation of PM, mutagens, carcinogens and infectious agents.

PM is a mixture of solid particles and liquid droplets aerosolized in SS and varies in size depending on the surgical device used (Environmental Protection Agency, 2020). ESUs produce particles <0.1um in size, lasers create particles ~0.3um, and ultrasonic scalpels generate the largest particles (0.35-6.5um) (Alp et al., 2006). Inhaled particles of 10um may lead to long-term cardiopulmonary complications and ultrafine particulate matter (UFPM) (<0.1um) travels deep into the bronchoalveolar tree, penetrates the circulatory system, and causes oxidative stress (Limchantra et al., 2019; Ling & van Eeden, 2009). Epidemiologic studies examining air pollution suggest that PM <10um impairs normal lung development and increases a child's risk of developing a respiratory disease later in life (Grigg, 2009).

In addition to hazards associated with PM inhalation, chronic inhalation of SS produces mutagenic and potentially carcinogenic changes. The mutagenic potential of SS varies with its chemical composition, depending upon the diathermy source, tissue type ablated, and length of ablation (Liu et al., 2019). Approximately 150 potentially harmful volatile organic compounds (VOCs) exist in SS after tissue ablation, but the true number may exceed 600 (Pierce et al., 2011; Weber & Spleiss, 1995). Chronic childhood exposure to certain VOCs contained in SS may relate to the genesis of tumors later in life, and the World Health Organization (WHO) states that children are "uniquely vulnerable" to the effects of chemical, biological, and physical agents (Wild & Kleinjans, 2003).

Equally concerning, SS may transmit active biological elements, such as bacteria and viruses (Swerdlow, 2020a). Mycobacteria (including Mycobacterium tuberculosis), Staphylococcus aureus, intact virions or viral deoxyribonucleic acids (DNA) of poliovirus, hepatitis B virus, and human immunodeficiency virus (HIV) have all been recovered in SS (Pollock, 2007; Swerdlow, 2020a). Most notably, intact HPV from certain types of warts and condylomas detected in SS represents a pathogen linked to nosocomial disease in humans (Hallmo & Naess, 1991). Several case reports describe laryngeal

papillomatosis and tonsillar carcinomas in OR personnel chronically exposed to HPV ablated tissue with no other identifiable risk factors for these diseases (Hallmo & Naess, 1991; Rioux et al., 2013). Similarly, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) may remain viable in SS aerosol and transmit disease accordingly (Swerdlow, 2020b).

These physical, chemical and biological hazards provide ample reason to implement effective SS-mitigating measures. Common methods to address SS, such as wall suction, standard surgical masks and filters (including the N95 respirator and "laser" high-efficiency particulate air (HEPA) filter masks), are inadequate (Limchantra et al., 2019; Swerdlow, 2020a). Wall suction (designed for removal of liquids) only generates five cubic feet per minute (CFM) of suction, while SED vacuum systems generate 35-50 CFM (Swerdlow, 2020a). Unlike wall suction, SEDs utilize HEPA filters that capture particles with a maximum diameter of 0.3um with 99.97% efficiency (Pollock, 2007). Therefore, the NIOSH and the AORN recommend the use of SEDs during any SS-generating procedure (AORN, 2017; NIOSH, 1996).

Despite these recommendations, SEDs are underutilized in most ORs (Edwards & Reiman, 2008). A survey conducted by the NIOSH found only 14% of respondents always used a SED during electrosurgery (Steege et al., 2016). In a survey of 623 AORN members, surgeon resistance or refusal ranked highest as the most common obstacle to SED use (Edwards & Reiman, 2008). Additional reported obstacles include impaired visualization of the surgical field due to bulkiness of the device, excessive noise, inadequate facility support, and lack of surgeon recognition of SS as a hazard (Edwards & Reiman, 2008). SEDs are more frequently utilized with implementation of employer standard procedures and employee training addressing hazards of SS (Steege et al., 2016). By assessing and describing the current state of SED use at DCH, a comprehensive understanding of SED underutilization may allow for future local interventions that effectively and consistently protect OR personnel from the hazards of SS.

Rationale

This project sought to understand why DCH providers adopt or reject the use of SEDs by using Roger's Diffusion of Innovation (DOI) Theory as a framework. This theory explains how adoption, or lack thereof, of an innovation is explained by three sets of variables: each innovation's attributes, characteristics of the adopters, and the larger sociocultural context (Dearing & Cox, 2018). At the individual level, DOI is based on five stages of the adoption process: awareness, persuasion, decision, implementation, and continuation (Dearing, 2009). Depending on their readiness for change, an individual can be an innovator, early adopter, early majority, late majority, or laggard (Dearing & Cox, 2018). Roger's DOI Theory guided survey question development to better evaluate the characteristics of DCH OR personnel, their respective adoption process stage, and the overarching sociocultural environment. The Model for Improvement (developed by the Institute for Healthcare Improvement [IHI]) served as this project's methodological framework. The central feature of this model is the Plan-Do-Study-Act (PDSA) cycle: an iterative, four-stage, problem solving action plan (Institute for Healthcare Improvement, 2020). Utilization of the PDSA cycle informed the length, format, and distribution of the final survey.

Specific Aims

This QI project aimed to describe the current state of SED use and identify perceived benefits and barriers to their use in DCH ORs. Primary objectives included distributing surveys to various OR personnel, analyzing survey results, conducting targeted interviews, and completing report data review by May 31, 2021 to achieve these aims.

Methods

Context

DCH is an 80-bed pediatric academic teaching hospital associated with Oregon Health & Science University (OHSU) located in Portland, Oregon. With nine ORs and over six thousand cases per year, DCH

employs approximately 45 OR Registered Nurses (RNs), 12 Certified Surgical Technologists (CSTs), 29 anesthesia providers, and 42 surgical attendings. Currently, smoke evacuation is recommended (not required) during SS-generating procedures at DCH. OHSU policy dictates that the surgical team identifies whether SED use is necessary for each case using "reasonable judgement." While SS is a hazard to all OR personnel, SED use is currently determined by surgeon preference, as indicated on procedure cards. Despite SED availability in every OR (with the exception of the iMRI room, dental room, and GI suite) and three additional portable systems, SEDs are not utilized consistently at DCH. In contrast, the Center for Health and Healing (CHH) is OHSU's only site to receive the Go Clear Award™, which is a national SS-free recognition program from the AORN. CHH successfully transformed SED-use culture by creating a local leadership team to champion this movement, ultimately leading to CHH's SS-free status.

In an effort to improve SS evacuation at DCH, stand-alone Buffalo Filter® SEDs replaced previous SEDs inconveniently stationed in the bottom of surgical equipment booms. Despite these efforts, SED utilization did not improve. According to OR Management Team members (see Appendix A), surgeon buy-in appears to be the largest barrier to SED use at DCH. Surgeons cite impaired surgical field visualization with PlumePens® (as well as other available electrosurgical pencil attachment devices) as a primary deterrent. As a result, DCH recently purchased a smaller cautery headpiece. In response to excessive noise complaints, OHSU plans to implement VisiClear® SEDs in DCH ORs in the future. However, it seems equipment upgrades will not result in standardization of SED use until the culture surrounding SS evacuation at DCH changes. Currently, some OR personnel tend to favor SED use (RNs), while others tend to oppose it (surgeons). However, in the setting of the COVID-19 pandemic, certain surgical specialties (general surgery and otolaryngology) are increasing SED use, representing a potential opportunity for cultural change. In addition, service coordinators are partnering with surgeons to increase SED utilization. By assessing the current state of opinion regarding SED use among DCH stakeholders, this QI project could lead to a future cultural shift similar to that of CHH.

Interventions

An anonymous, online, Qualtrics survey (Appendix D) distributed to DCH surgeons, OR RNs, CSTs, and anesthesia providers served as the primary method of data collection. Survey design included Likert scale and multiple-choice questions with free-text comments, allowing for quantitative and qualitative interpretation of survey data. Surveys were distributed as open, anonymous links via electronic mailing lists to ensure survey distribution to all OR personnel. To reduce survey fatigue and optimize survey response rate, the survey required no more than 13 minutes to complete and two email reminders were sent one week apart (Cho et al., 2013; Van Mol, 2015). This QI project included two PDSA cycles. Prior to PDSA Cycle One, survey questions were first submitted to OHSU's Executive Management Group (EMG) for feedback regarding survey question content. The first PDSA cycle involved survey distribution to a small sample of OR providers (two surgeons, OR nurses, surgical techs, and anesthesia providers) in order to assess appropriateness of survey design. Feedback regarding survey length and content was elicited anonymously through a free-text response section at the end of the initial survey. OR Management guided selection of PDSA Cycle One participants. The second PDSA cycle followed, with widespread distribution of the survey to all OR personnel.

Next, targeted interviews with 13 key individuals (two surgeons [known SED user and known SED non-user], six OR Management Team members, two RNs, two CSTs, and one anesthesia provider) were conducted virtually utilizing Cisco WebEx Meeting software. OR Management also guided selection of individuals for targeted interviews. Targeted interview questions (Appendix E) were developed for each provider type; however, the conversation was not limited to pre-written questions during the allotted 30-minute interviews. Additional data collection methods included evaluation of surgeon procedure card reports, supply utilization reports, and case volume reports for SED use, compiled by OR Management Team members. All report data was taken from November 1, 2019 – October 31, 2020. An estimated project timeline is provided in Appendix F.

Measures

Evaluated measures were divided into three main categories (Table 1). Outcome measures were chosen to address the specific aims of describing SED use and perceived benefits/barriers of its use. Process measures indicated activities to be undertaken to measure the outcomes. Balancing measures considered contextual factors that may influence outcomes. Measure data was collected via surveys, targeted interviews, and record review. Appendix G defines each measure and its associated data collection procedure.

Table 1

Evaluated Measures

Outcome Measures	Process Measures	Balancing Measures
1. Percentage of cases utilizing SEDs 2. Identify surgical specialties who utilize SEDs most frequently/infrequently 3. Identify perceived benefits of SED use 4. Identify perceived barriers to SED use	1. Number of procedure cards requesting SEDs (record number and surgical specialty) 2. Number of cases performed at DCH 3. Feedback from sample after initial PDSA cycle 4. Percent response rate after final PDSA cycle	1. Survey burden 2. Change in SED use or SED perception as a result of survey distribution during second PDSA cycle

Analysis

Survey response data was analyzed using Qualtrics software. Analyses were stratified by provider type and included percentage of survey respondents, sources of education on SS, and perceived benefits and barriers of SED use (all visually represented by bar graphs). Quantitative survey data derived from Likert scale and multiple-choice questions was analyzed and visually represented in graphical form. Quantitative data derived from procedure card, supply utilization, and case volume reports were analyzed utilizing Microsoft Excel software, and calculations regarding SED requests, SED

utilization, and case volume were organized in tabular form. Qualitative analyses were derived from targeted interview data using manual coding for themes and subthemes, and a table was utilized to categorize thematic responses.

Ethical Considerations

Ethical considerations included safe handling of data and maintaining anonymity of survey respondents. This project was reviewed by the OHSU Institutional Review Board (IRB) and considered IRB-exempt (IRB ID: STUDY0022640). Data was secured via OHSU encryption, password protection, and two-factor authentication, and the authors report no conflicts of interest involved in the undertaking of this QI project.

Results

Results are presented below. A timeline of the interventions is included in Appendix H. Report data results can be found in Appendix I, final PDSA cycle results can be found in Appendix J, and targeted interview data has been organized into thematic categories in Appendix K.

Report Data

Supply utilization data (Table I1) revealed a total of 174 SEDs utilized annually at DCH. Assuming one SED type was utilized per case, SEDs were utilized in 2.7% of all annual cases. Excluding non-SS generating procedures (endoscopy and ophthalmology), SEDs were utilized in 3.2% of the 5,518 SS-generating procedures. Assuming one SED type was requested per procedure card, procedure card data review (Table I2) indicated 5.7% of total procedure cards requested SEDs. The 2.5% difference between SEDs requested and SEDs utilized during SS-generating procedures cannot be accounted for by report data. DCH does not routinely include surgical specialty on procedure cards, and as such, 79% of procedure cards did not have a surgical service indicated. Of the procedure cards that specified surgical specialty, the plastics service requested 12 SEDs on their 27 total cards (44.4%), while otolaryngology requested three SEDs on their 22 total cards (13.6%). By contrast, case volume data (Table I3) revealed

otolaryngology performed the highest percentage of total cases at DCH (25.5%), while plastics only performed 4.5% of total cases. While procedure card data was limited, it highlighted a discrepancy between case volume and SED requests by surgical service.

PDSA Cycle One (Survey) Data

After survey development, OHSU's EMG provided feedback regarding survey question content and edits were made accordingly. The first PDSA cycle included survey distribution to eight OR personnel from various specialties (anesthesia providers, CSTs, RNs, and surgeons). No recommendations were submitted by survey respondents for survey improvement, and therefore, no changes were made prior to the second PDSA cycle. However, the initial PDSA cycle illuminated a logistical issue of emailing individual survey links to all OR personnel, and as such, PDSA Cycle Two included utilization of OR Management Team members for distribution of anonymous survey links via electronic mailing lists.

PDSA Cycle Two (Survey) Data

PDSA Cycle Two results were obtained from widespread distribution of an anonymous survey link via email to all OR personnel; two subsequent email reminders were sent one week apart. 19 surgeons and two anesthesia providers responded to the OHSU-specific survey rather than the DCH survey, and as a result, responses required deliberate separation utilizing survey result filters (available through Qualtrics) in order to identify respondents who selected "children" and "other" (indicating both adults and children) as their primary patient population. Survey response rates were as follows: 45% for surgeons, 31% for anesthesia providers, 50% for CSTs, and 49% for RNs. The majority of surgeons and anesthesia providers reported more than 15 years of work experience, while the majority of CSTs and RNs reported less than five years (Figure J1). Surgeons and anesthesia providers reported receiving SS information primarily from non-industry sponsored continuing education (e.g. journal articles, colleagues, etc.) or no education, whereas CSTs and RNs reported receiving information from both

industry-sponsored (e.g. continuing medical education [CME] courses, seminars, etc.) and non-industry sponsored continuing education (Figure J2).

When asked whether SS is hazardous to one's health, RNs and CSTs were the largest groups to select "agree" or "strongly agree" (Figure J3). The majority of RNs strongly agreed when asked if SEDs should be used during every SS-generating procedure (Figure J4). However, when asked if they recommend the use of SEDs often, only 16.7 % of CSTs selected "agree" or "strongly agree" and 27.3% of RNs selected "agree" (Figure J5). The majority of anesthesia providers were neutral when asked about the hazards of SS (Figure J3) and 55.6% selected "strongly disagree" when asked if they often recommend the use of SEDs (Figure J5). 78% of anesthesia providers believe they are exposed to SS in the OR (Figure J6), but 34% do not know how often SEDs are used (Figure J7). Nearly half of anesthesia providers (44%) indicated SEDs are utilized 50% of the time or more (Figure J7). This is inconsistent with the report data, and in stark contrast to the 67% and 77% of CSTs and RNs (respectively) that believe SEDs are utilized less than half the time (Figure J7).

Most surgeons responded "strongly agree" when asked if they believed SS is hazardous (Figure J3) and the majority also agreed they are exposed to SS in the OR (Figure J8). However, when asked how frequently they utilized SEDs for any surgical case, 37% reported "never" and 21% reported "less than half the time." Some surgeons reported more frequent use by indicating they use SEDs "all the time" (21%), "more than half the time" (10.5%), or "about half of the time" (10.5%) (Figure J9). Of note, most surgeons indicated they primarily utilize SEDs during open procedures rather than minimally invasive procedures (Figure J10). 42.1% of surgeons responded as "neutral" when asked whether they agree their colleagues don't use SEDs as much as they do, while 26.3% responded "strongly disagree" (Figure J11). Analyses of SED use by surgical specialty could not be meaningfully evaluated from the survey data due to small sample size.

When asked why SEDs are not utilized more often, anesthesia providers, CSTs, and RNs all indicated "surgeon choice" as the primary reason, followed by "inconvenience due to the bulkiness of the device" (Figure J12). About 15% of anesthesia providers, CSTs, RNs and surgeons agreed SEDs are "too noisy" (Figure J12). 33.3% of surgeons reported SEDs are problematic due to "inconvenience or interference (including bulkiness of the device)," followed by 22.2% who selected "impaired surgical field visualization" (Figure J13). When asked why they choose not to utilize an SED during a case, <3% of surgeons indicated that SEDs "are ineffective for the evacuation of smoke" (Figure J14).

Targeted Interview Data

Targeted interview data (Appendix K) revealed nine primary themes regarding SS/SED use at OHSU/DCH: 1) perceptions of SS hazards; 2) education surrounding SS/SEDs; 3) appropriateness of current SED utilization; 4) perceived benefits of SED use; 5) perceived barriers to SED use; 6) SED users/non-users; 7) opposing opinions regarding SED use; 8) passive/active roles of various OR personnel; and 9) suggestions for future changes regarding SED use. The majority of interviewees believed SS is hazardous and believed SEDs are currently underutilized at OHSU/DCH. All provider types reported receiving education on SS/SEDs from in-services, professional organizations, colleagues, or self-guided research, with the exception of the anesthesia provider, who reported never having received education on the matter. Perceived benefits of SED use included patient safety and OR personnel safety, while perceived barriers included impaired visualization (particularly in the pediatric population) and noise. Orthopedics and spine cases were referenced as heavy users at DCH, while plastics, urology and neurosurgery were described as SED non-users. Of note, these comments appear in direct contrast to the procedure card and case volume data previously described. Nearly all interviewees commented on the current opposing opinions surrounding SED use in the OR, with frustrations expressed by surgeons, RNs, CSTs, and OR Management alike. One surgeon expressed frustration with OR staff insisting on SED use, due to the belief that there is no explicit evidence to support its use, while another surgeon

expressed frustration with the lack of standardization of SED use in all SS-generating procedures. RNs, CSTs, and OR Management all expressed frustrations with the lack of legislative or institutional policy mandating SED use for SS-generating procedures. An anesthesia provider expressed no particular frustrations on the matter. Several groups commented on the passive role of the anesthesia department in the broader discussion relating to SS. Suggestions for future changes regarding SED use at OHSU/DCH primarily focused on legislative and institutional policy changes, improved educational efforts, and a cultural change.

Discussion

Summary

The aim of this QI project was to describe the current state of SED use at DCH and identify perceived benefits and barriers to their use. Primary findings from this project include:

- Utilization: Based on supply utilization data analyses, SED utilization occurs in only 3.2% of annual SS-generating cases at DCH.
- Users: From report data, SED users include plastics, orthopedics, and otolaryngology services, while non-users include cardiothoracic, neurosurgery, and urology services. Targeted interview data identified orthopedic surgeons as SED users, while plastics, urology, and neurosurgery services were identified as SED non-users.
- Benefits and barriers to use: Perceived benefits of SED use include patient safety and OR personnel safety. Surgeons identified barriers to SED use as inconvenience or interference (including bulkiness of the device) and impaired surgical field visualization. RNs, CSTs, and anesthesia providers cited surgeon choice as the most likely reason for lack of SED use.
- Perception of SS as a hazard: The majority of RNs, CSTs, and surgeons perceive SS as a hazard, while the majority of anesthesia providers are unsure. RNs and CSTs have received more

industry-sponsored education on SS compared to anesthesia providers and surgeons. However, neither RNs, CSTs, nor anesthesia providers routinely suggest the use of SEDs.

- Theoretical framework: Rogers DOI explained the influence of the innovation's attributes, characteristics of adopters, and the larger sociocultural context surrounding SED use at DCH.

Interpretation

SEDs are underutilized at DCH, with a 3.2% calculated utilization rate. Literature quantifying SED utilization in the U.S. is relatively sparse and no pediatric data currently exists. However, one study reported 14% of OR personnel always utilized smoke evacuation during electrosurgery (Steege et al., 2016), and another reported 10% of dermatologic surgeons consistently utilized smoke management strategies (Georgeson & Litner 2018). Of note, both studies relied on perceived SED use (self-reported surveys) versus actual (quantitative) SED use, and the latter study broadly defined SS mitigation strategies. In this current project, SED use was well below the comparative literature; this may be related to the narrow population foci (pediatrics) and/or the assessment of actual SED use. Interestingly, survey responses indicated overestimation of true SED utilization among DCH OR personnel across provider types, while the majority of interviewees accurately predicted SEDs to be heavily underutilized, highlighting the importance of objectively quantifying SED use.

By contrast, the collective opinion among interviewees regarding SED users/non-users did not align with report data. Report data indicated plastics, orthopedics and otolaryngology to be SED users, whereas interviewees believed only orthopedics were users. This discrepancy may be due to the limited number of procedure cards that indicated the surgical service, as well as individual perceptions and biases among interviewees. Additionally, the report data did not indicate the specific procedure for which an SED was requested. Therefore, if an SED was routinely requested for a high-volume case (e.g. tonsillectomy/adenoidectomy), the actual SED utilization could be higher than calculated. Common SED users/non-users were not easily identified in current literature for comparison, although

recommendations from the AORN endorse SED use during all SS-generating cases, regardless of surgical specialty. According to OHSU OR management, SED utilization rates have increased among specialties (e.g. general surgery and otolaryngology) due to concern regarding potential transmission of the COVID-19 virus through SS, which is consistent with recent literature on the topic (Swerdlow, 2020b).

Identified benefits and barriers of SED use at DCH appear consistent with those listed in the literature, such as protection from PM, mutagens, carcinogens, and infectious agents as benefits (Alp et al., 2006; Limchantra et al., 2019; Pierce et al., 2011; Swerdlow, 2020a), and surgeon resistance/refusal as barriers (Edwards & Reiman, 2008; Georgeson & Lipner, 2018; Swerdlow, 2020a). This finding highlights the need to partner with surgeons to resolve common barriers to SED use, including the design/usability of SEDs and lack of surgeon recognition of SS as a hazard (Edwards & Reiman, 2008). This echoes survey data in which surgeons consistently ranked inconvenience/bulkiness of the device, impaired visualization, and/or noisiness as barriers to SED use. However, strategies to mitigate these barriers at DCH via SED equipment upgrades have not been successful and further advancements in SED technology (e.g. smaller cautery headpieces) are unlikely to fully resolve the barrier of surgeon resistance/preference. Notably, surgeons at DCH indicated a high exposure to SS and believed SS to be hazardous, but did not indicate a high degree of concern. For instance, survey free responses mention the use of alternative means of SS evacuation such as suction devices, and interview data suggests acknowledgement of the hazardous compounds found in SS, but surgeons believe there is a general lack of correlational data to suggest direct harm. This suggests SED utilization could be encouraged if there was greater concern among surgeons regarding their exposure to SS, as evidenced by survey free response data indicating an increase in SED usage after concerns related to COVID-19. Furthermore, surgeons reported receiving either no education or non-industry sponsored education about SS. With that, implementation of employee training addressing hazards of SS could be beneficial to increase SED utilization (Steege et al., 2016). Employee-based (e.g. non-industry) education may be preferable to

industry-sponsored education, given that interview data suggests a high level of skepticism towards the latter. Still, given the fact that surgeon preference remains the dominant factor in SED use, implementation of legislative policy or employer standard procedures may be most effective in increasing SED utilization (Steege et al., 2016).

Survey response and interview data indicated support of SED use from RNs, CSTs, and OR management. This was an expected finding, as the majority of CSTs and RNs are concerned about the hazards of SS and report receiving SS education from AORN in-services and publications – an organization which recommends the use of SEDs during SS-generating procedures (AORN, 2017). CSTs and RNs accurately perceived a low use of SEDs at DCH, yet they did not often recommend SED use. Nationwide compliance with smoke evacuation recommendations by perioperative nurses is inconsistent. However, surveys have found that compliance is correlated with increased knowledge and training, as well as increased specialization, interconnectedness, and leadership support (Ball, 2012). At DCH, RNs and CSTs would most likely benefit from leadership support, legislative changes, and/or employer standard procedures to empower them to recommend SED use.

In contrast, 60% of anesthesia providers report receiving no education on SS, the majority report a "neutral" perception regarding the hazards of SS, and most believe SEDs are utilized often at DCH, contradicting evidence from supply utilization data. On the other hand, anesthesia providers had a high perception of exposure to SS. The interview data corresponds to the survey data by indicating a neutral stance towards the dangers of SS and little anesthesia buy-in regarding SED use. This is consistent with the anesthesia community's lack of organized support regarding SS education or routine SED utilization (Swerdow, 2020a). Anesthesia providers at DCH would likely benefit from formal education surrounding the hazards and evacuation of SS.

Rogers DOI theory served as the theoretical framework for this project with the goal of assessing three variables: the innovation's attributes, characteristics of the adopters, and the larger sociocultural

context. The primary characteristic of SEDs that appear to positively influence its adoption involve the observation that SEDs evacuate SS better than other methods (e.g. suction); however, the complexity of SEDs (e.g. noisiness/bulkiness) and lack of compatibility with the needs of potential adopters (e.g. surgical field interference) seem to reduce its adoption rate. The rate at which an individual adopts a new innovation is determined by their degree of innovativeness and their perceived need for the innovation. Currently at DCH, some OR personnel favor SED use (RNs, CSTs, and some surgeons), some are neutral (anesthesia providers), and others oppose it (some surgeons). According to survey and interview data, the majority of RNs and CSTs could be considered innovators and early adopters, anesthesia providers could be considered late adopters, and surgeons could present in any of the five categories. The respective stage of adoption may relate to the individual's perception of SS as a hazard, where the majority of RNs and CTS (early adopters/innovators) strongly agree SS is an occupational hazard and anesthesia providers (late adopters) tend to be neutral regarding the hazards of SS. Surgeons recognize the hazards of SS, yet inconsistently apply smoke evacuation measures. The larger sociocultural context at DCH appears to influence SED adoption, as currently its use is largely dependent on surgeon preference. To overcome this sociocultural norm at DCH, implementation of employer standard procedures and/or legislative policy will likely be necessary to increase SED use.

Strengths & Limitations

Overall project strengths included higher-than-average survey response rates, utilization of both quantitative and qualitative data collection methods to provide a comprehensive picture of the current state of SED use at DCH, and a focus on SED use in the pediatric population. Typically, overall response rate for online surveys is 32.6% (Watt et al., 2002). Therefore, response rates for all OR provider groups in this QI project were close to or above average. However, "some authors feel that there is no scientifically established minimum acceptable response rate" and in such instances, it is important to determine the degree to which sampled respondents differ from the target population (Burns & Kho,

2015). After analyzing procedure card, survey, interview data, and reports from management, sampled responses appear to correlate well with the target population, as evidenced by previous publications on this topic. In addition, the EMG's review of survey questions prior to distribution served to enhance the validity of the survey. However, EMG review of survey questions may also have created opportunity for bias as a result of potential censorship.

Lack of procedure card data available for review proved to be a limitation in this project. DCH does not routinely indicate the surgical service on procedure cards, and thus, data regarding SED users and non-users was limited. In addition, data regarding the number of SEDs utilized per case were unavailable, and as such, true SED utilization may be even lower than calculated, as it was assumed only one SED was utilized per case. Similarly, given that the type of procedure for which SEDs were requested is unknown, the data may underrepresent actual SED use for high volume cases (i.e. tonsillectomies and adenoidectomies). Assumptions were also made (based upon current literature) regarding what constitutes a SS-generating procedure, and thus could impact the accuracy of calculations regarding SED utilization in SS-generating procedures. Finally, SED use in open versus laparoscopic cases could not be discriminated, a factor which appears to influence SED utilization at DCH according to targeted interviews.

The outcome measures of this project were balanced with overall survey burden on the respondents. Survey respondents indicated minimal survey burden by reporting five minutes or less spent on completing the survey. Of note, it is possible a shift in SED perception/use occurred among survey respondents/interviewees as a direct result of this project; however, this could not be readily assessed.

An anonymous survey link was created in the hopes of mitigating potential sources of bias during both PDSA cycles, and PDSA Cycle One survey recipients were selected at random. However, individuals in both PDSA cycles may have been more likely to respond to the survey if they had strong

feelings on the topic of SS/SEDs, potentially biasing results. Furthermore, all DCH surgeons and two anesthesia providers selected the incorrect survey link, which is a limitation to the means of survey distribution. Interviewees were specifically chosen by OR Management Team members, creating potential for bias during the interview process, given that most OR Management Team Members support the use of SEDs. The small sample size of interview participants could also have led to a biased representation of interview data. Lastly, the results of this project are specific to the context of DCH ORs, and as such, are not generalizable to other institutions.

Conclusions

Survey and interview responses indicate a need for statewide legislative changes, implementation of an institutional policy to mandate SED use, or a significant change in the culture surrounding SED use at DCH in order to improve SED utilization. As of June 23, 2021, Oregon House Bill (HB) 2622 was signed into law during the undertaking of this project, resulting in a legislative change that preceded cultural shifts or new institutional policies. This law mandates SED use during all SS-generating procedures in Oregon (HB 2622, 2021). Improved education on SS and SED use at DCH has the potential to increase acceptance by late adopters and lead to a smoother integration of this law into practice. Future work on this topic should focus on introducing standardized education regarding the hazards of SS to all OR personnel and improving communication among staff members regarding SED use during SS-generating procedures at DCH.

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Appendix A

Members of QI Project Team

OHSU Nurse Anesthesia Program Faculty

- Dr. Julie Soelberg, PhD, CRNA
  - DNP Project Chairperson
  - Assistant Professor- OHSU Nurse Anesthesia Program
- Dr. Barry Swerdlow, MD, FASA
  - DNP Project Consultant
  - Assistant Professor- OHSU Nurse Anesthesia Program

OHSU/DCH OR Management Team

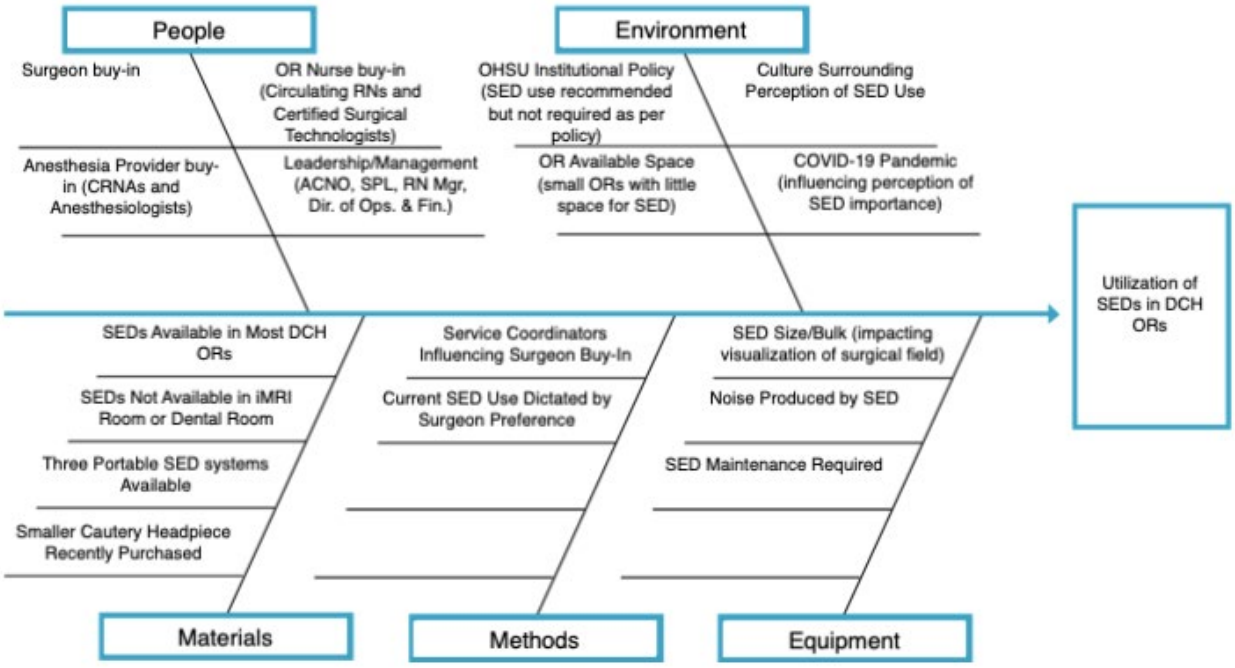
- Dio Sumagaysay, RN, MS
  - Associate Chief Nursing Officer (ACNO), Perioperative & Procedural Services, OHSU
- Jodi Cox
  - OHSU Executive Assistant of Perioperative Administration
- Daniel DeVries, RN
  - DCH OR Nurse Manager
- Candice Donovan, RN
  - DCH OR Specialty Practice Leader
- Jamie Harrell
  - OHSU/DCH Director of Perioperative Operation and Finance
- Anna McAllister, RN, BSN, CNOR
  - OHSU/DCH Procedure Card Specialist
- Haley Sands, RN, MSN
  - OHSU OR Nurse Manager
- Patty Kimbro, RN, MSN
  - OHSU OR Nurse Manager
- Brian Droege, RN
  - OHSU Perioperative Specialty Practice Leader

Appendix B

Cause and Effect Diagram

Team: Zhang & Jodoin **Project:** SED Use at DCH

1) Input the effect you'd like to influence.
2) Input categories of causes for the effect (or keep the classic five).
3) Input causes within each category.



Appendix C

Letter of Support from Implementation Site

Letter of Support from Clinical Agency

Date: *11/30/2020*

Dear *Kawen Zhang & Lindsay Jodoin*,

This letter confirms that I, *Dio Sumagaysay*, allow *Kawen Zhang & Lindsay Jodoin*, (OHSU Doctor of Nursing Practice Student) access to complete their DNP Final Project at our clinical site. The project will take place from approximately *01/04/2021* to *05/31/2021*.

This letter summarizes the core elements of the project proposal, already reviewed by the DNP Project Preceptor and clinical liaison (if applicable):

Project Site(s):
Doernbecher Children's Hospital (DCH)
Perioperative Services
700 SW Campus Dr.
Portland, OR, 97239

Project Plan:
Smoke evacuation devices (SEDs) are available, but not uniformly utilized, at DCH. The specific aims of this project are to describe the current state of SED use and identify perceived benefits and/or barriers of its use. By assessing and describing the current state of SED use at DCH, a comprehensive understanding of its underutilization may allow for future local interventions that effectively and consistently protect employees from the hazards of surgical smoke. This project seeks to understand factors that influence adoption of SED's at DCH by using survey questions informed by Roger's Diffusion of Innovation (DOI) theory. Rogers DOI theory describes how an innovation moves through a social system by taking into account characteristics of the innovation, individual and organization. The methodological framework of this QI project is the Model for Improvement, developed by the Institute for Healthcare Improvement (IHI). Utilization of the IHI's Plan-Do-Study-Act (PDSA) cycle will help refine survey length, clarity/format of questions, and survey distribution. This QI project will utilize record review, survey methodology, and targeted interviews to describe the current state of SED use and identify perceived benefits and barriers to their use in DCH ORs. Our goal is to fulfill record review, have a 75% survey response rate from each discipline, and complete targeted interviews by May 31, 2021. A Qualtrics survey distributed to a sample of DCH surgeons, RNs, and anesthesia providers will serve as the primary method of data collection for this QI project. Additional methods of data collection will include interviews with selected key individuals (including OR management, known SED users, and known SED non-users), review of surgeon procedure card reports, supply utilization reports, and case volume reports. All report data will be taken from November 1, 2019 to October 31, 2020 and survey data will be obtained from January – May 2021. Outcome measures (percent of cases utilizing SEDs, surgical specialties that utilize SEDs frequently/infrequently, and perceived barriers/benefits of SEDs), process measures (survey feedback from provider sample after initial PDSA cycle and percent survey response rate after final PDSA cycle), and balancing measures (survey burden and change in SED perception) will be collected. Report, survey response, and interview data will be compiled into Microsoft Excel and protected via OHSU encryption, password protection and two-factor authentication. Data from surveys will be anonymous and coded with unique identifier numbers. DCH management team members will aid in identifying key stakeholders to interview, assist with survey distribution, and provide record reports.

During the project implementation and evaluation, *Kawen Zhang & Lindsay Jodoin* will provide regular updates and communicate any necessary changes to the DNP Project Preceptor.

Our organization looks forward to working with this student to complete their DNP project. If we have any concerns related to this project, we will contact *Kawen Zhang & Lindsay Jodoin* and *Julie Soelberg* (student's DNP Project Chairperson).

Regards,

DIO MAC SUMAGAYSAY — DNP Project Preceptor

Signature

ACNO — Job Title

12/14/2020 — Date Signed

Appendix D

Survey Questionnaire with Roger's Diffusion of Innovation Theory Classifications

Surgeons

The aim of this quality improvement project is to describe the state of surgical smoke evacuation at Doernbecher Children's Hospital (DCH) and identify perceived benefits/problems with its use.

1. What surgical specialty/specialties do you work in? *(select all that apply)*
    i. Cardiothoracic
    ii. Dental
    iii. Otolaryngology
    iv. General Surgery
    v. Gynecology
    vi. Ophthalmology
    vii. Neurosurgery
    viii. Orthopedics
    ix. Podiatry
    x. Plastic Surgery
    xi. Urology
    xii. Vascular
    xiii. Other: _____
2. Do you work primarily with adults or children? *(select one)*
    i. Adults
    ii. Children
    iii. Other: _____
3. How many years have you worked in an operating room environment? *(select one)*
    i. < 5 years
    ii. 5-10 years
    iii. 10-15 years
    iv. > 15 years
4. I have received education about surgical smoke from: *(select all that apply)* [knowledge]
    i. Industry-sponsored continuing education (e.g., continuing medical education (CME) courses, seminars, etc.)
    ii. Non-industry sponsored continuing education (e.g., seminars, journal articles, colleagues, etc.)
    iii. Other: _____
    iv. I have not received education regarding surgical smoke
5. On a scale of 1-5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree) please rate the following:
    i. I am exposed to surgical smoke in the operating room [knowledge]
    ii. I believe that surgical smoke is hazardous to my health [knowledge]
    iii. I feel my colleagues don't use smoke evacuation devices as often as I do [confirmation]
    iv. I am not concerned about my exposure to surgical smoke [knowledge]
6. Circle the best answer:
    i. I use a surgical smoke evacuation device for open and minimally invasive cases that generate surgical smoke: *(select one)* [implementation]

a. All the time
b. More than half the time
c. About half the time
d. Less than half the time
e. Never

ii. Use of smoke evacuation devices is problematic for me due to: (circle all that apply) [persuasion]

a. Surgical smoke evacuation is unnecessary
b. Too noisy
c. Inconvenience or interference (including bulkiness of the device)
d. Impaired surgical field visualization
e. Loss of haptics/tactile feedback
f. Impairment of safe dissection
g. Surgical smoke evacuation devices are ineffective for evacuation of smoke

iii. When I choose NOT to use a surgical smoke evacuation device, the reasons are: *(select all that apply)* [persuasion/decision]

a. Surgical smoke evacuation is unnecessary
b. Too noisy
c. Inconvenience (including bulkiness of the device)
d. Impaired surgical field visualization
e. Surgical smoke evacuation devices are ineffective for evacuation of smoke
f. There is no surgical smoke generated with the surgery
g. Loss of haptics/tactile feedback

iv. I use smoke evacuation devices more often with: *(select one)* [decision]

a. Open procedures
b. Minimally invasive procedures
c. Equally with open and minimally invasive procedures

7. Please provide any comments you desire to include with this quality improvement survey related to surgical smoke and smoke evacuation at DCH: _____
8. How can this survey be improved? _____
9. How long did this survey take to complete? _____

OR Nursing Staff

The aim of this quality improvement project is to describe the state of surgical smoke evacuation at Doernbecher Children's Hospital (DCH) and identify perceived benefits/problems with its use.

1. What is your role in the operating room? (*select all that apply)*
   i. Scrub nurse / Perioperative nurse
   ii. Circulating Nurse
   iii. Registered Nurse First Assistant
2. Do you work primarily with adults or children?
   i. Adults
   ii. Children
   iii. Other: _____
3. What surgical specialty/specialties do you work in? *(select all that apply)*
   i. Cardiothoracic
   ii. Dental
   iii. Otolaryngology

iv. General Surgery
v. Gynecology
vi. Ophthalmology
vii. Neurosurgery
viii. Orthopedics
ix. Podiatry
x. Plastic Surgery
xi. Urology
xii. Vascular
xiii. I work with all surgical specialties
xiv. Other: _____

4. How many years have you worked in an operating room environment? *(select one)*
   i. < 5 years
   ii. 5-10 years
   iii. 10-15 years
   iv. > 15 years
5. I have received education about surgical smoke from: *(select all that apply)* [knowledge]
   i. Industry-sponsored continuing education (e.g., continuing medical education (CME) courses, seminars, etc.)
   ii. Non-industry sponsored continuing education (e.g., seminars, journal articles, colleagues, etc.)
   iii. Other: _____
   iv. I have not received education regarding surgical smoke
6. On a scale of 1-5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree) please rate the following:
   i. I am exposed to surgical smoke in the operating room [knowledge]
   ii. I believe that surgical smoke is hazardous to my health [knowledge]
   iii. Surgical smoke evacuation devices should always be used during any surgical smoke generating procedure [persuasion]
   iv. I often suggest a smoke evacuation device be used during a procedure [implementation]
   v. I am NOT concerned about my exposure to surgical smoke [knowledge]
7. Circle the best answer:
   i. The reasons smoke evacuation devices are not utilized more often in the OR are: *(select all that apply)* [persuasion/decision]
      a. Too noisy
      b. Inconvenience including bulkiness of device
      c. Impaired surgical field visualization
      d. Surgical smoke evacuation is unnecessary
      e. Surgical smoke evacuation devices are ineffective for evacuation of surgical smoke
      f. Smoke evacuation devices are difficult to set up
      g. Surgeon choice
      h. Loss of haptics/tactile feedback
      i. I don't know
   ii. In my practice, use of surgical smoke evacuation devices for cases that generate smoke occurs approximately: *(select one)* [implementation]
      a. All the time
      b. More than half the time

c. About half the time
d. Less than half the time
e. Never
f. I don't know

8. Please provide any comments you desire to include with this quality improvement survey related to surgical smoke and smoke evacuation at DCH: _____
9. How can this survey be improved? _____
10. How long did this survey take to complete? _____

Certified Surgical Technologists

The aim of this quality improvement project is to describe the state of surgical smoke evacuation at Doernbecher Children's Hospital (DCH) and identify perceived benefits/problems with its use.

1. What surgical specialty/specialties do you work in? *(select all that apply)*
   i. Cardiothoracic
   ii. Dental
   iii. Otolaryngology
   iv. General Surgery
   v. Gynecology
   vi. Ophthalmology
   vii. Neurosurgery
   viii. Orthopedics
   ix. Podiatry
   x. Plastic Surgery
   xi. Urology
   xii. Vascular
   xiii. I work with all surgical specialties
   xiv. Other: _____
2. Do you work primarily with adults or children?
   i. Adults
   ii. Children
   iii. Other: _____
3. How many years have you worked in an operating room environment? *(select one)*
   i. < 5 years
   ii. 5-10 years
   iii. 10-15 years
   iv. > 15 years
4. I have received education about surgical smoke from: *(select all that apply)* [knowledge]
   i. Industry-sponsored continuing education (e.g., continuing medical education (CME) courses, seminars, etc.)
   ii. Non-industry sponsored continuing education (e.g., seminars, journal articles, colleagues, etc.)
   iii. Other: _____
   iv. I have not received education regarding surgical smoke
5. On a scale of 1-5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree) please rate the following:
   i. I am exposed to a significant amount of surgical smoke in the operating room [knowledge]
   ii. I believe that surgical smoke is hazardous to my health [knowledge]

iii. Surgical smoke evacuation devices should always be used during any surgical smoke generating procedure [persuasion]
iv. I often suggest a smoke evacuation device be used during a procedure [implementation]
v. I am not concerned about my exposure to surgical smoke [knowledge]

6. Circle the best answer:
   i. The reasons smoke evacuation devices are not utilized more often in the OR are: *(select all that apply)* [persuasion/decision]
      a. Too noisy
      b. Inconvenience including bulkiness of device
      c. Impaired surgical field visualization
      d. Surgical smoke evacuation is unnecessary
      e. Surgical smoke evacuation devices are ineffective for evacuation of surgical smoke
      f. Smoke evacuation devices are difficult to set up
      g. Surgeon choice
      h. Loss of haptics/tactile feedback
      i. I don't know
   ii. In my practice, use of surgical smoke evacuation devices for open and minimally invasive cases that generate smoke occurs approximately: *(select one)* [implementation]
      i. All the time
      ii. More than half the time
      iii. About half the time
      iv. Less than half the time
      v. Never
      vi. I don't know
7. Please provide any comments you desire to include with this quality improvement survey related to surgical smoke and smoke evacuation at DCH: _____
8. How can this survey be improved? _____
9. How long did this survey take to complete? _____

Anesthesia Providers

The aim of this quality improvement project is to describe the state of surgical smoke evacuation at Doernbecher Children's Hospital (DCH) and identify perceived benefits/problems with its use.

1. What is your role in the operating room?
   i. Anesthesiologist
   ii. Certified Registered Nurse Anesthetist
2. Do you work primarily with adults or children?
   i. Adults
   ii. Children
   iii. Other: _____
3. My anesthesia subspecialty is:
   i. None
   ii. Other: _____
4. How many years have you worked in an operating room environment? *(select one)*
   i. < 5 years
   ii. 5-10 years
   iii. 10-15 years
   iv. > 15 years

5. I have received education about surgical smoke from: *(select all that apply)* [knowledge]
    i. Industry-sponsored continuing education (e.g., continuing medical education (CME) courses, seminars, etc.)
    ii. Non-industry sponsored continuing education (e.g., seminars, journal articles, colleagues, etc.)
    iii. Other: _____
    iv. I have not received education regarding surgical smoke
6. On a scale of 1-5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree) please rate the following:
    i. I am exposed to surgical smoke on a regular basis in the operating room [knowledge]
    ii. I believe that surgical smoke is hazardous to my health [knowledge]
    iii. Surgical smoke evacuation devices should always be used during any surgical smoke generating procedure [persuasion]
    iv. I often suggest that a smoke evacuation device be used during a procedure [implementation]
    v. I am NOT concerned about my exposure to surgical smoke [knowledge]
7. Circle the best answer:
    i. The reasons surgical smoke evacuation devices are not utilized more often in the OR are: *(select all that apply)* [persuasion/decision]
        a. Too noisy
        b. Inconvenience including bulkiness of device
        c. Impaired surgical field visualization
        d. Surgical smoke evacuation is unnecessary
        e. Surgical smoke evacuation devices are ineffective for evacuation of surgical smoke
        f. Smoke evacuation devices are difficult to set up
        g. Surgeon choice
        h. Loss of haptics/tactile feedback
        i. I don't know
    ii. In my practice, use of surgical smoke evacuation devices for open and minimally invasive cases that general smoke occurs approximately: *(select one)* [implementation]
        a. All the time
        b. More than half the time
        c. About half the time
        d. Less than half the time
        e. Never
        f. I don't know
8. Please provide any comments you desire to include with this quality improvement survey related to surgical smoke and smoke evacuation at DCH: _____
9. How can this survey be improved? _____
10. How long did this survey take to complete? _____

Note. Survey questions are labeled with the corresponding stage of adoption process according to Roger's Diffusion of Innovation Theory, as indicated by the bolded brackets.

Appendix E

Targeted Interview Questions by Provider Type

Anesthesia Provider

1. Do you believe surgical smoke (SS) is harmful? Why or why not?
2. Where have you received information concerning SS?
3. In your opinion, which surgical specialty utilizes smoke evacuation devices (SEDs) most often and why? Which specialty utilizes SEDs least often and why?
4. In your opinion, is SS evacuation underutilized, overutilized, or utilized appropriately at OHSU? Why do you think that is?
5. Which cases are you regularly involved in that generate the most SS?
6. What, if any, changes would you like to see at your facility regarding SS evacuation?
7. Compared to other professional organizations, there is little writing in the anesthesia literature or from anesthesia organizations concerning surgical smoke. Why do you believe this is the case?
8. What do you think are the responsibilities of anesthesia providers with respect to smoke exposure of operating personnel?
9. Are there any steps you feel that the anesthesiology department or the individual could take to promote a safe OR environment with regards to SS?
10. Are there barriers that have prevented any of these steps from being taken previously?

Surgeons

1. Do you believe surgical smoke (SS) is harmful? Why or why not?
2. Where have you received information concerning SS?
3. In your opinion, is SS evacuation underutilized, overutilized, or utilized appropriately at your facility? Why?
4. Could you describe your own personal experiences with smoke evacuation devices (SEDs)?
5. Can you discuss the precise aspects of SEDs that potentially interfere with your surgeries? For example:
    a. Do they impair visibility?
    b. Do they add to the complexity of an already complex care situation?
    c. Does the noise interfere with communication among operating room staff?
    d. Are the pencil devices awkward to hold?
6. What can your institution do to make SEDs more user-friendly and less problematic for surgeons?
7. Are there any other changes you would like to see at your facility regarding SS evacuation?

Registered Nurses / Certified Surgical Technologists

1. Do you believe surgical smoke (SS) is harmful? Why or why not?
2. Where have you received information concerning SS?
3. In your opinion, which surgical specialty utilizes smoke evacuation devices (SEDs) most often and why? Which specialty utilizes SEDs least often and why?
4. In your opinion, is SS evacuation underutilized, overutilized, or utilized appropriately at your facility? Why?
5. Which cases are you regularly involved in that generate the most SS?
6. What, if any, changes would you like to see at your facility regarding SS evacuation?

7. How could the institution optimize communication and discussion about surgical smoke evacuation among staff?
8. Does SED setup interfere with operating room workflow?
    a. If so, what adjustments have been made in the past, and what adjustments could be made in the future, to preserve workflow that would still allow SED use in each case?

OR Management

1. Do you believe surgical smoke (SS) is harmful? Why or why not?
2. Where have you received information concerning SS?
3. In your opinion, which surgical specialty utilizes smoke evacuation devices (SEDs) most often and why? Which specialty utilizes SEDs least often and why?
4. In your opinion, is SS evacuation underutilized, overutilized, or utilized appropriately at your facility? Why?
5. What, if any, changes would you like to see at your facility regarding SS evacuation?
6. What are the major impediments (institutional or otherwise) to implementation of an effective smoke evacuation program at OHSU?
7. What are the practice differences between CHH and OHSU/DCH pertaining to surgical smoke evacuation? Why do these practice differences exist?

Appendix F

Estimated Project Timeline

	2020	2021					
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.-Sep.
Finalize project design/approach	X						
Complete IRB determination		X					
PDSA Cycle One		X	X				
PDSA Cycle Two			X	X			
Final data analysis				X	X		
Complete final paper					X	X	X
Prepare for project dissemination							X

Appendix G

Operational Definitions and Data Collection Procedures for Individual Measures

Measure	Type	Definition	Data Collection
Percentage of cases utilizing SEDs	Outcome measure	Number of cases using SEDs divided by the total number of cases at DCH	Procedure card and surgical case volume records
Identify surgical specialties who utilize SEDs most frequently/infrequently	Outcome measure	Cardiovascular, dental/oral, general surgery, gynecology, hepatobiliary, neurosurgery, ophthalmology, orthopedic surgery, otolaryngology, plastic surgery, surgical oncology, urology, or vascular	Procedure card and surgical case volume records
Identify perceived benefits of SED use	Outcome measure	Features of SED use OR personnel identify as beneficial	Survey and targeted interview responses
Identify perceived barriers to SED use	Outcome measure	Features of SED use OR personnel identify as problematic	Survey and targeted interview responses
Number of procedure cards that request SEDs	Process measure	The total number of procedure cards that list SED equipment	Procedure card records
Number of cases performed at DCH	Process measure	Total number of cases performed at DCH from November 1, 2019 through October 31, 2020	Surgical case volume records
Number of available SEDs at DCH	Process measure	Total number of stationary and portable SEDs available throughout the DCH facility	Targeted interview responses
Feedback from sample after initial PDSA cycle	Process measure	Comments received from initial provider sample regarding survey length, clarity of questions, function of survey question format, and identification of unintended effects	Targeted interview responses from initial provider sample

Measure	Type	Definition	Data Collection
Percent response rate after final PDSA cycle	Process measure	Number of completed surveys divided by the total number of surveys distributed	Survey responses
Survey burden	Balancing measure	Provider perception of excessive survey length and unclear questions	Feedback ascertained during PDSA Cycle 1 and 2
Change in SED use or SED perception as a result of survey distribution during second PDSA cycle	Balancing measure	Alterations in SED use or SED perception attributed to distribution of the survey	Feedback acquired from future works

Appendix H

Timeline of Interventions

Intervention	Date Performed
Compiled procedure card data	November 24, 2020
Submitted survey questions to OHSU's EMG	January 5, 2021
Distributed PDSA Cycle One	February 4, 2021
Sent reminder emails to PDSA Cycle One recipients	February 11, 2021 February 18, 2021
Deadline for PDSA Cycle One responses	February 19, 2021
Distributed PDSA Cycle Two	March 10, 2021
Sent reminder emails to PDSA Cycle Two recipients	March 17, 2021 March 24, 2021
Deadline for PDSA Cycle Two responses	March 26, 2021
Conducted targeted interviews	April 19, 2021 – April 30, 2021

Appendix I

Procedure Card, Supply Utilization, and Case Volume Report Data Results

Table I1

Percentage of Cases Utilizing SEDs

SED Type	Number of Cases Utilizing	Percentage of SS-Generating Procedures[1]
PenAdapt®	131	2.4%
PlumePen Elite®	40	0.7%
PlumePort ActiV®	3	0.1%
TOTAL	174	3.2%

Note. All report data was taken from November 1, 2019 – October 31, 2020.

[1]SS-generating procedures exclude endoscopy and ophthalmic procedures (n = 5,518), and all calculations are based upon one SED per case.

Table I2

Procedure Cards Requesting SEDs

Surgical Specialty[1]	Total Cards	Total Number of SEDs Requested	Types of SEDs Requested	
All Cards[2]	1,636	93	Buffalo Equipment	27
			PlumePen®	59
			Plastics Pack (includes PlumePen®)	6
			PlumePort ActiV ®	1
Cardiothoracic	37	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Dental / Oral	4	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0

Surgical Specialty[1]	Total Cards	Total Number of SEDs Requested	Types of SEDs Requested	
General Surgery	4	1	Buffalo Equipment	0
			PlumePen®	1
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Gynecology	6	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Hepatobiliary	3	1	Buffalo Equipment	0
			PlumePen®	1
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Neurosurgery	32	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Ophthalmology	25	1	Buffalo Equipment	1
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Orthopedics	90	7	Buffalo Equipment	4
			PlumePen®	3
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Otolaryngology	22	3	Buffalo Equipment	1
			PlumePen®	2
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Plastics	27	12	Buffalo Equipment	2
			PlumePen®	4

Surgical Specialty[1]	Total Cards	Total Number of SEDs Requested	Types of SEDs Requested	
			Plastics Pack (includes PlumePen®)	6
			PlumePort ActiV ®	0
Urology	34	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Vascular	5	0	Buffalo Equipment	0
			PlumePen®	0
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0
Service Not Indicated	1,292	65	Buffalo Equipment	17
			PlumePen®	48
			Plastics Pack (includes PlumePen®)	0
			PlumePort ActiV ®	0

Note. All report data was taken from November 1, 2019 – October 31, 2020.

[1]DCH does not routinely include the surgical specialty on the procedure cards.

[2]Procedure cards can have more than one authorization, and therefore the totals will not add up.

Table I3

Surgical Cases Performed at DCH

Surgical Specialty	Number of Cases	Percentage of Total Cases
Otolaryngology	1,626	25.5%
General Surgery	1,045	16.4%
Gastrointestinal - Endoscopy	839	13.2%
Urology	721	11.3%
Orthopedics	709	11.1%
Neurosurgery	397	6.2%
Oral / Maxillofacial	319	5.0%

Plastics	287	4.5%
Cardiothoracic	216	3.4%
Medical / Surgical	98	1.5%
Dermatology	75	1.2%
Ophthalmology	16	<1%
Gynecology	13	<1%
Abdominal Transplant	8	<1%
Vascular	2	<1%
Other	2	<1%
TOTAL	6,373	100%

Note. All report data was taken from November 1, 2019 – October 31, 2020.

Appendix J

PDSA Cycle 2 Survey Results

Figure J1

Work Experience

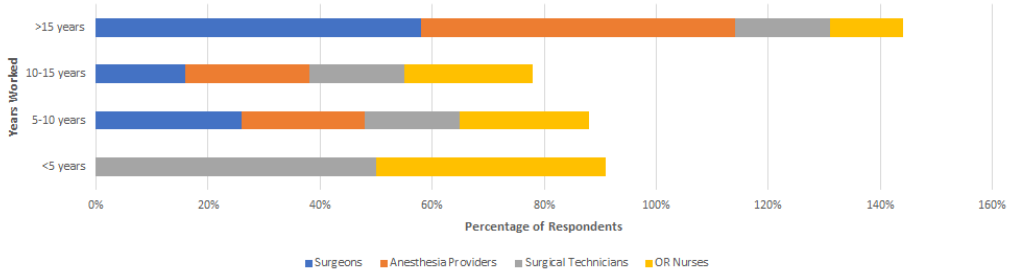


Figure J2

Sources of SS Education

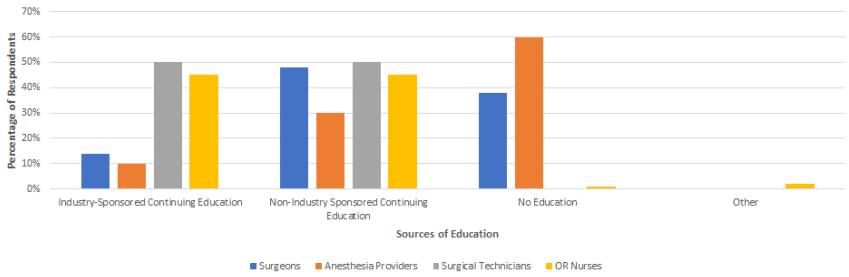
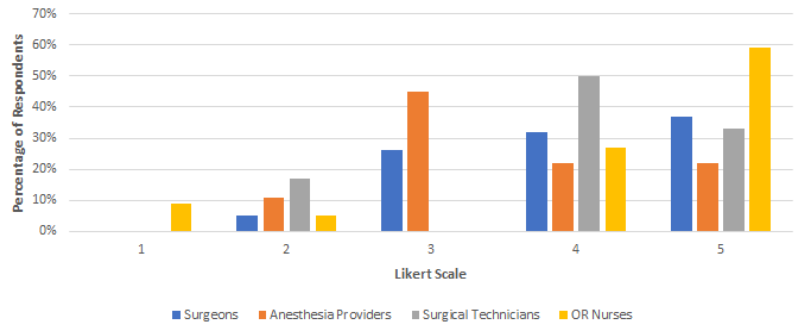


Figure J3

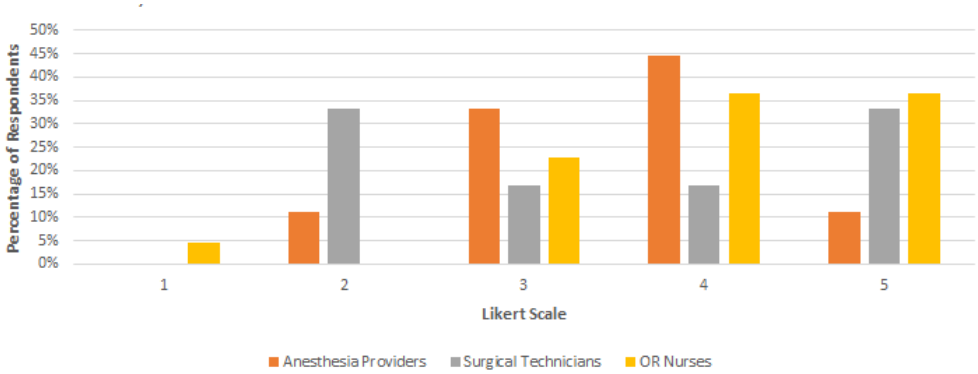
Perceptions of SS Hazards



Note. Respondents were asked to rate whether they agreed that SS is a health hazard on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J4

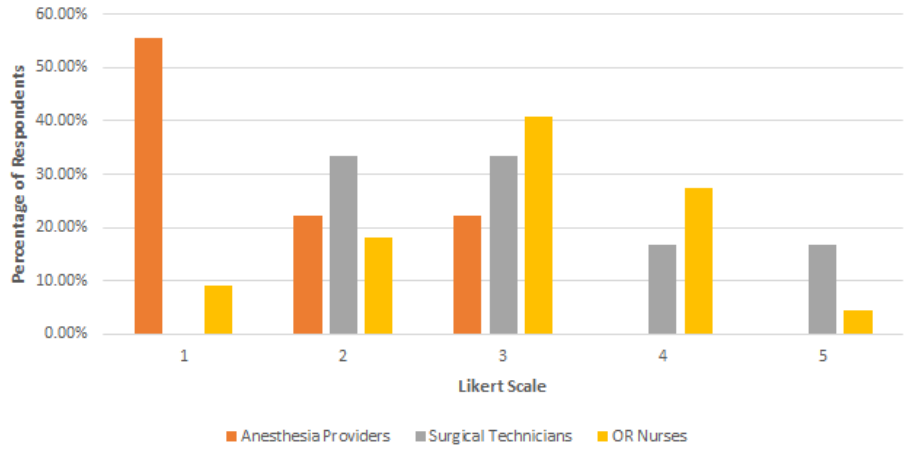
Positions on SED Utilization for Every SS-Generating Procedure



Note. Respondents were asked to rate whether they agreed that SEDs be used during any SS-generating procedure on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J5

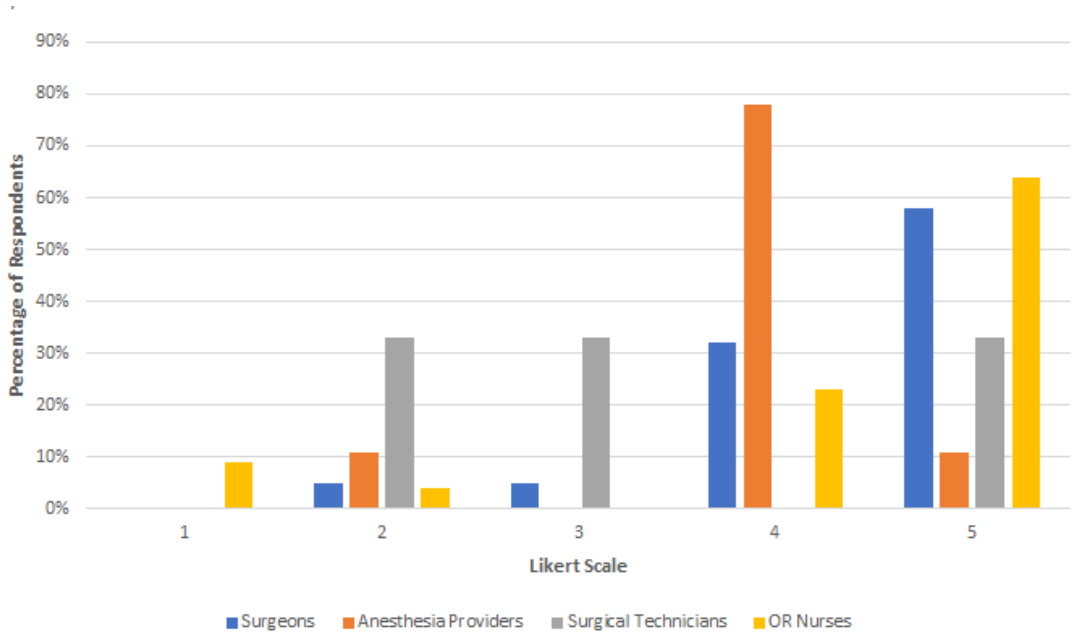
Suggestion of SED Utilization by Provider Type



Note. Respondents were asked to rate whether they agreed that they often suggest an SED be used during a surgical procedure on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J6

Perceptions of Exposure to SS



Note. Respondents were asked to rate whether they agreed that they are exposed to SS in the OR on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J7

Perceptions of SED Use Frequency

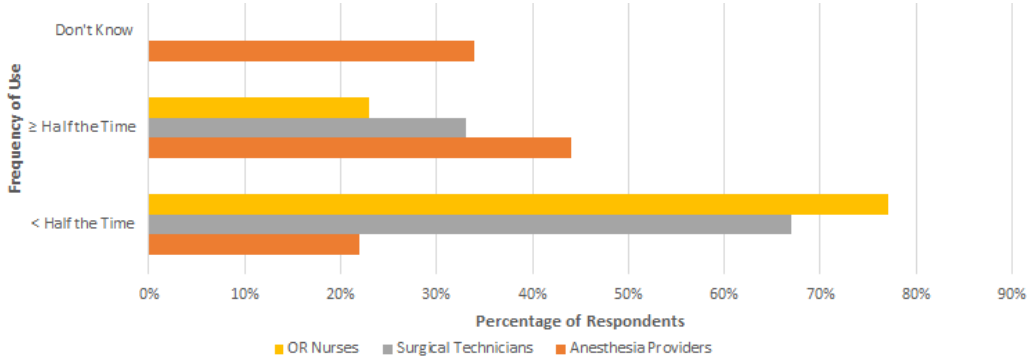
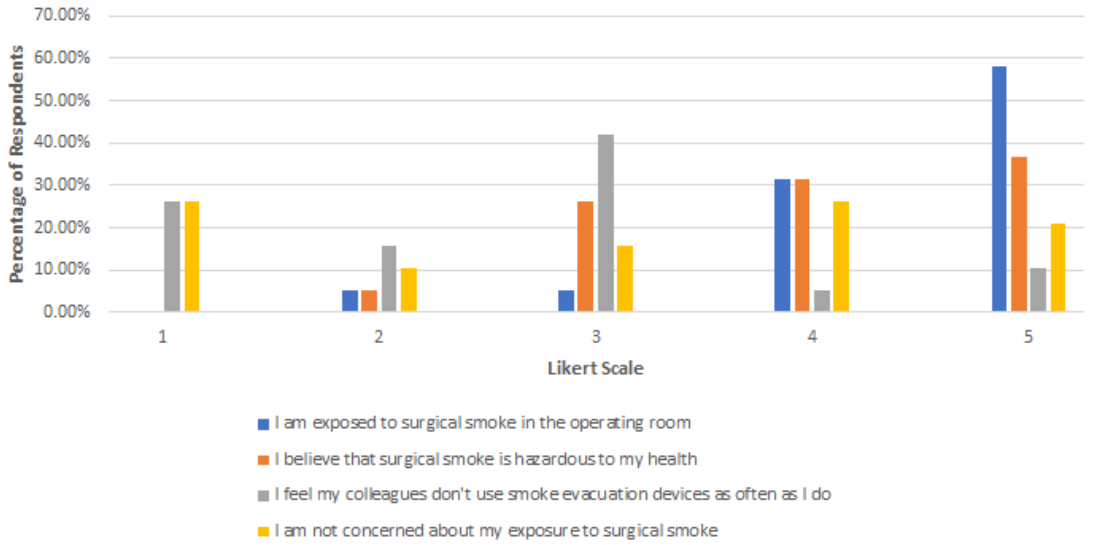


Figure J8

Surgeon Perceptions of SS



Note. Surgeons were asked to rate whether they agreed with each statement on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J9

SED Use by Surgeons for Open and Minimally Invasive Cases

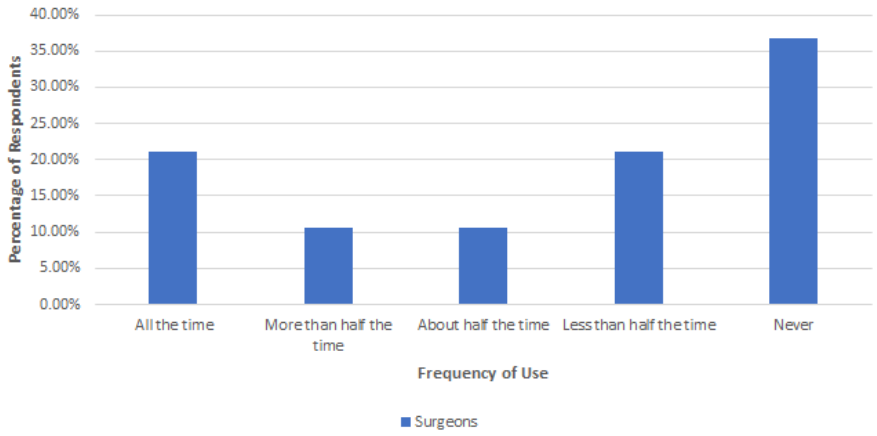


Figure J10

SED Utilization by Procedure Type

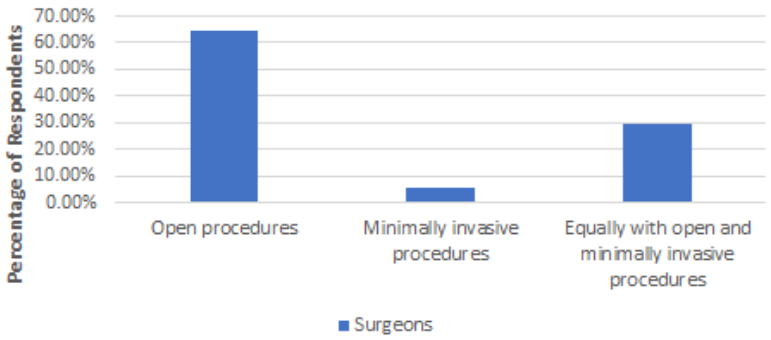
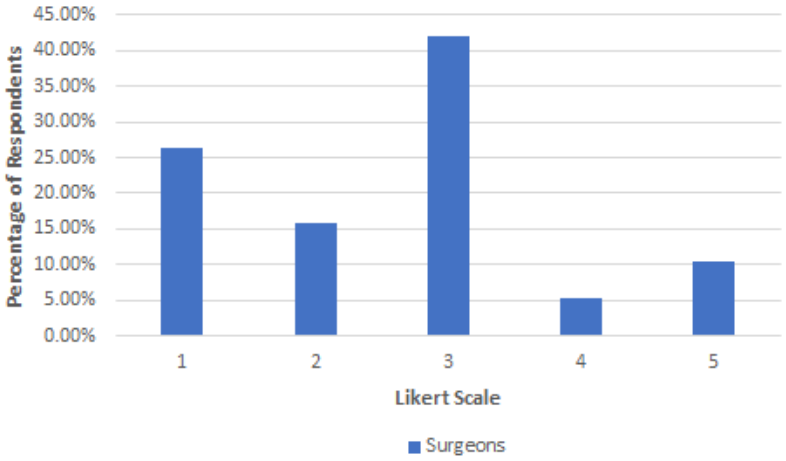


Figure J11

Comparison of SED Use to Colleagues



Note. Respondents were asked to rate whether they agreed that their colleagues don't use SEDs as much as they do on a scale of 1 to 5 (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).

Figure J12

Reasons SEDs are Not Utilized

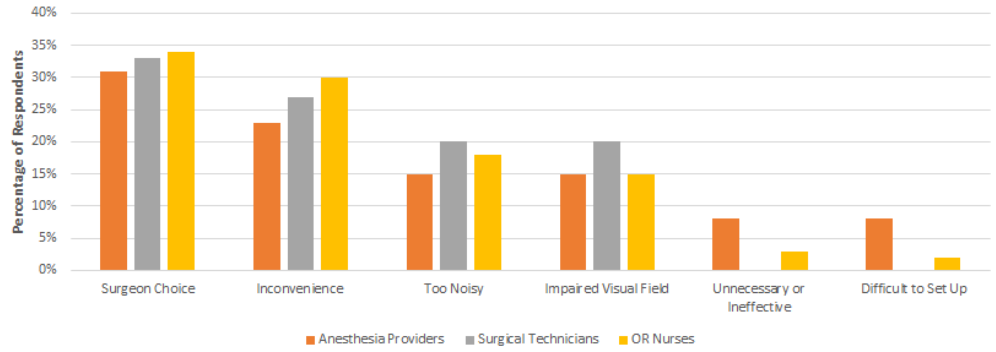


Figure J13

Reasons Surgeons Find SEDs Problematic

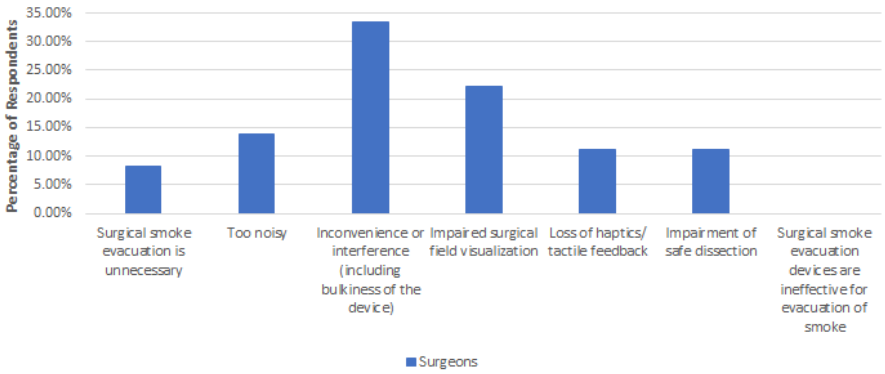
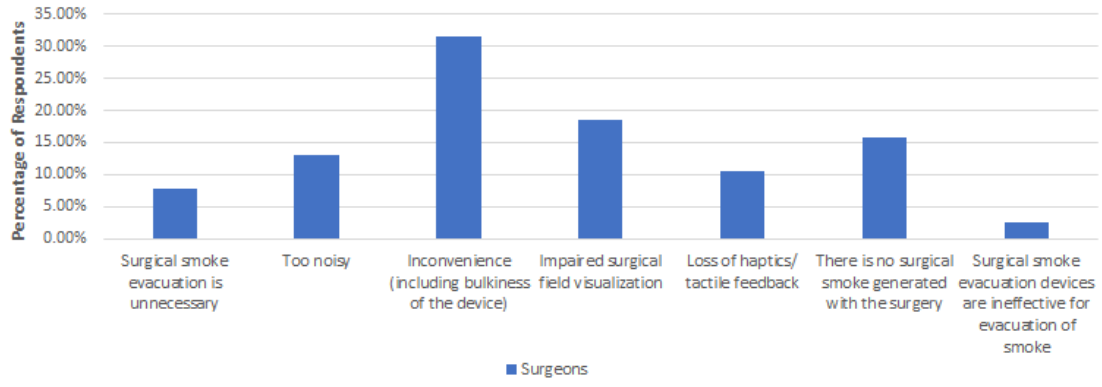


Figure J14

Reasons Surgeons Don't Use SEDs



Appendix K

Themes Derived from Targeted Interviews

Themes	Coding Phrases	Examples by Provider Type
Perceptions of SS Hazards	Believes SS is hazardous	• Surgeon = Underwent a lung operation for a benign tumor in the lung, believes it to be related to SS exposure • RN = Referenced statistic regarding ablation of one gram of tissue to be equivalent in carcinogenicity to six cigarettes • CST = Stated particles in SS smaller than 0.1 microns can become entrapped within the respiratory tract and have been shown to be harmful • OR Management = Has known three people who have been diagnosed with oral cancer and has attributed it to SS exposure
	Does not believe SS is hazardous	• Anesthesia = Does not believe there is conclusive evidence that SS is harmful • Surgeon = Believes there hasn't been a study to show OR personnel dying from smoke-related diseases
Education Surrounding SS/SED	Self-taught	• Surgeon = Felt SED companies were "fear-mongering", examined scientific literature, and did not find any data showing cause and effect between SS and illness • Surgeon = Conducted own literature search • CST = Researched current available evidence, undertook it as a project, and presented it to staff
	In-services	• Surgeon = Mentioned SED company in-service was the first exposure to the topic • RN = Referenced SED company in-service • CST = Stated SED company in-service prompted further exploration
	Professional organizations	• RN = Discussed AORN resources • CST = Mentioned AST conferences and journal articles • OR Management = Referenced AORN and emails from state legislature

Themes	Coding Phrases	Examples by Provider Type
	Colleagues	• RN = Credited colleagues who are passionate about SEDs with bringing awareness to the topic • OR Management = Credited former employee with bringing awareness to the topic
	No education	• Anesthesia = Stated there had not been any education on the matter
Appropriateness of Current SED Utilization	Believes SEDs are underutilized	• Surgeon = Stated SEDs are underutilized, because it is not yet a standard practice • RN = Stated SEDs are underutilized, since only two services at DCH use it routinely • OR Management = Stated SEDs are heavily underutilized, due to lack of full buy-in at DCH • OR Management = Stated underutilization was primarily a result of surgeon preference • OR Management = Stated SEDs are underutilized, and encounters the common argument of "show me the causative data", but felt there is a lack of understanding that RCTs cannot be performed to obtain this kind of data • OR Management = Stated SEDs are underutilized, as they should be utilized for all cases to mitigate any potential risk, which they currently are not • CST = Stated SEDs are underutilized at an institutional level, but more surgeons have increased their SED use in recent years • RN = Stated "appropriate" utilization would be 100% of cases
	Unsure if SEDs are utilized appropriately	• Surgeon = Described not feeling sure if SEDs are utilized appropriately. Stated they probably have a role in some cases, but would need to do more research. However, described willingness to adopt SED use if evidence supported it • OR Management = Referenced the fact that utilization is dependent upon the site. Described appropriate utilization at CHH, but underutilization in SOR

Themes	Coding Phrases	Examples by Provider Type
Perceived Benefits of SED Use	OR personnel safety	• Surgeon = Believes SED use should be mandated for OR personnel safety as a part of OSHA • OR Management = Emphasized that SEDs keep everyone in the OR safe • CST = Compared SS safety to fire safety, and encouraged annual education regarding SS • RN = Referenced frequent headaches from smoke inhalation and fear of impact on health
	Patient safety	• CST = Stated SS has been shown to be harmful to patients and SEDs should be used routinely for patient safety
	SED technology has greatly improved	• Surgeon = Found current SED technology to be reliable and a significant improvement from prior models, with no issues regarding loss of haptics
Perceived Barriers to SED Use	Impaired visualization	• Surgeon = Stated handheld devices are cumbersome and difficult to see around • Anesthesia = Discussed overhearing surgeons say SEDs are bulky and impair visualization • CST = Believes small size of pediatric patients can make visualization difficult with SEDs
	Noise	• Surgeon = Described noise from SEDs to be distracting to the flow of the case • CST = Stated they are noisy systems
	Loss of haptics / tactile feedback	• Surgeon = Emphasized that SEDs interfere with tactile feedback while ablating tissue
	Setup Time	• Surgeon = Mentioned the fact that some circulators are not as comfortable with the setup, so it takes time
	Patient safety	• Surgeon = Believes loss of haptics with handheld device impacts patient safety by making it more difficult to assess tissue and increases risk of complications

Themes	Coding Phrases	Examples by Provider Type
SED Users / Non-Users	Users	• RN = Referenced orthopedics and spine cases as users at DCH • OR Management = Referenced plastics as users at OHSU • RN = Referenced plastics, ENT, and general surgery as users at OHSU
	Non-users	• RN = Referenced urology, plastics, and neurosurgery as non-users at DCH • CST = Referenced neurosurgery and orthopedics as non-users at OHSU • OR Management = Referenced surgical oncology and spine cases as non-users at OHSU
Opposing Opinions Regarding SED Use	Surgeons feeling frustrated	• Surgeon = Described an adversarial culture surrounding SED use in the OR. Desires a way to address the issue in a rational way. Believes that if SEDs can't be used in a particular case, then those who are uncomfortable with that can scrub into another room
	RNs and CSTs feeling frustrated	• OR Management = Believes the issue is placing stress on interpersonal relationships in the OR, and expresses desire for OHSU to move beyond surgeons being the sole decision maker for everyone's health and safety • OR Management = Described the discussion surrounding SEDs as becoming increasingly more adversarial, causing significant division among staff • CST = Referenced a distinct hierarchy in the OR, with some surgeons being more intimidating and adversarial than others, but others being fairly open to a discussion regarding SED use • RN = Expressed frustration that OHSU as an institution is about "bettering the health of all Oregonians", but surgeons won't use SEDs for the health of their colleagues

Themes	Coding Phrases	Examples by Provider Type
Passive and Active Roles of OR Personnel	Passive role of anesthesia department	• OR Management = Described the anesthesia department as appearing indifferent on the issue, but believes this may be because they don't want to be in the middle of their surgical and nursing colleagues • Anesthesia = Believes it is possible that data has not been presented to anesthesia providers, or that anesthesia groups are less impressed by the data • RN = Believes there is a lack of education among anesthesia providers, similar to most other provider groups
	Active / influential role of CSTs	• RN = Emphasizes that CSTs have a very influential role in SED use, as they are opening up the supplies for the procedure
Suggestions for Future Changes Regarding SED Use	Standardized policy for SED use	• Surgeon = Would like to see an institutional mandate for SED use for OR personnel safety • OR Management = Would like to see a change in the language used in the OHSU SED policy so that SED use is not up to provider preference • OR Management = Would like to see the institution push surgeons to challenge their own habits • CST = Would like to see replacement of Bovies with PlumePens® in all packs
	State legislative changes	• OR Management = Looking forward to passage of Oregon bill to mandate SED use, which would completely change the discussion around SED use
	Increased buy-in from surgeons	• RN = Expressed frustration with setting up an SED for a case, only to have a surgeon say they don't use that • CST = Would like to see surgeons try various SEDs to find one they feel comfortable using

Themes	Coding Phrases	Examples by Provider Type
	Change in culture	• Surgeon = Would like to create a culture where everyone feels comfortable asking if SEDs are being used • CST = Would like to create a culture where SED use is automatic • OR Management = Feels a small team would be needed to champion this initiative in order for it to be as successful as it was at CHH
	Increased education	• Surgeon = Would like to see consistent training regarding SED use for all OR personnel • CST = Would like to create annual continuing education courses regarding hazards of SS • OR Management = Would like to increase education and familiarity with SEDs in the hopes of adopting consistent SED use prior to state mandate
	Encouraging further conversation	• Surgeon = Would like to get to a place where everyone is comfortable talking about SS and having a difference in opinion
	No suggestions for future changes	• Anesthesia = Stated no opinion on future changes, does not feel there is enough evidence of harm and hears reports from surgeons that SEDs are substandard