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Benchmark: Reducing Surgical Plume Output with Smoke Evacuation

Kaitlynn Olano
kplyler@patriots.uttyler.edu

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Kaitlynn Olano BSN, RN, CNOR

The University of Texas at Tyler, School of Nursing

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Dr. Pamela Lake, Ph.D., RN, AHN-BC

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Executive Summary

This project focuses on addressing the critical issue of surgical smoke exposure in operating rooms through the strategic implementation of smoke evacuation systems. The primary objective is twofold: to prioritize the safety and well-being of healthcare professionals and to ensure that patient care remains uncompromised. It strives to reshape the operating room environment, making surgical plume exposure a thing of the past.

Extensive research forms the core of this project. A comprehensive literature synthesis, including systematic reviews, randomized control trials, prospective and cohort studies, and qualitative research, underscores the occupational safety concerns related to surgical plume exposure. This synthesis strongly advocates for comprehensive education and awareness initiatives aimed at all operating room personnel, from surgeons and anesthesiologists to perioperative nurses and surgical technicians.

To facilitate the transformation of operating rooms into smoke-free environments, the project outlines a systematic implementation plan that actively engages key stakeholders. Surgeons, anesthesiologists, perioperative nurses, and surgical technicians play pivotal roles in advocating for and facilitating the adoption of smoke evacuation systems. Through this collaborative approach, the project aims to ensure that every member of the surgical team is committed to the integration of smoke evacuation systems.

The project's findings undeniably support the implementation of surgical smoke evacuation systems. The financial benefits substantially outweigh the costs, with clear advantages including enhanced well-being for healthcare professionals, improved patient safety, and clearer surgical fields. The recommendations include widespread implementation of smoke evacuation systems, education and awareness initiatives for all personnel, continued stakeholder

involvement, and rigorous monitoring to ensure the sustained reduction of surgical plume exposure. In conclusion, this project underscores the compelling case for adopting smoke evacuation systems as a standard in the operating room, thereby enhancing patient care and creating a safer working environment for healthcare professionals.

Benchmark: Reducing Surgical Plume Output with Smoke Evacuation

Surgical plume comprises harmful fumes, particulate matter, and potentially infectious agents generated during surgical procedures employing electrocautery or laser devices. It poses a substantial health risk to healthcare professionals, including surgeons, anesthesiologists, perioperative nurses, and surgical technicians. The project endeavors to mitigate these health risks and enhance occupational safety by implementing advanced smoke evacuation systems in operating rooms. These systems are designed to capture and remove surgical plume at its source, reducing exposure and safeguarding the health of healthcare professionals. The overarching goal is to transform the operating room environment, ensuring that surgical plume exposure is significantly diminished. To accomplish this objective, the project conducts a comprehensive analysis of existing evidence, formulates an implementation plan, and offers recommendations to protect the well-being of healthcare professionals while maintaining impeccable patient care standards.

Rationale for the Project

The implementation of smoke evacuation systems in operating rooms is of paramount importance for several reasons, and it holds significant nursing implications. The project's central PICOT question, "With operating room staff participating in procedures involving a high output of surgical plume (P), how does the use of smoke evacuation (I) compared to no use of smoke evacuation (C) affect the rate of smoke plume-related illnesses (O) within three months (T)?" emphasizes the urgency and relevance of this initiative.

First and foremost, patient care and safety are inherently linked to this project. Patients should care about it because the health and well-being of healthcare professionals, including nurses, are integral to delivering high-quality care. When operating room staff are exposed to

surgical plume, they may unknowingly carry potential infectious agents, carcinogens, and harmful particulates to other patient care areas, endangering the patients they serve. This project aims to reduce the risk of healthcare-associated infections and illnesses, thereby directly improving patient safety. Nurses, in particular, play a pivotal role in patient care, and their well-being is a critical component of healthcare delivery.

Additionally, surgical smoke exposure can lead to a range of health issues for operating room staff, including nurses. Chronic exposure to surgical plume has been associated with respiratory problems, skin conditions, and other health risks. By implementing smoke evacuation systems, healthcare organizations can protect their valuable nursing workforce from these occupational hazards, leading to better staff retention and overall job satisfaction. Furthermore, this project emphasizes education and awareness among nurses, enabling them to advocate for their safety and that of their colleagues. It empowers nurses to take an active role in promoting a safe and healthy work environment.

Literature Synthesis

Systematic research was organized to find the most supportive evidence for the PICOT question, spanning databases such as PubMed, the Cumulative Index of Nursing and Allied Health Literature (CINAHL), and the Cochrane Database of Systematic Reviews. A range of the following keywords guided the systematic search: *surgical plume, surgical smoke, operating room staff, smoke evacuation, inhalation, laryngeal papillomatosis*, and *cautery*. A synthesis of the literature was conducted, and a table (see Appendix A) was created. The selected articles comprised systematic reviews, randomized control trials, prospective randomized studies, and cohort studies, complemented by one qualitative study featuring expert opinion, creating a comprehensive foundation for this change.

The critical role of evidence-based research becomes evident in discerning the magnitude of daily exposure experienced by operating room personnel and in presenting effective strategies to mitigate this exposure. The application of surgical smoke evacuation systems emerges as a potent means to substantially reduce individual exposure to surgical plume. For instance, Cheng et al. (2018) conducted a scientific inquiry dedicated to identifying volatile organic compounds (VOCs) in operating rooms, their sources, and the potential health risks they pose to operating room personnel. Their findings underscore the efficacy of surgical smoke evacuation in mitigating exposure to specific compounds, underscoring the necessity of employing such systems (Cheng et al., 2018). Similarly, Fox-Lewis et al. (2020) underscored the indispensable role of personal protective equipment (PPE), particularly N95 respirators, in preventing the transmission of HPV to healthcare workers during surgical procedures. This accentuates the significance of protective measures and hints at the requirement for holistic strategies to minimize exposure to hazardous agents present in surgical plume.

Van Gestel et al. (2020) delved into the concept of surgical smoke, placing a strong emphasis on the importance of clearly defining this concept, educating healthcare personnel, and advocating for safety measures for both healthcare workers and patients. Additionally, Zhou et al. (2019) explored the presence of HPV DNA in surgical smoke during LEEP procedures, highlighting potential health risks associated with HPV transmission to healthcare professionals exposed to surgical smoke. Their study emphasizes the importance of safety measures, including high-filtration masks and smoke evacuation systems (Zhou et al., 2019).

Quantitative data consistently affirms the efficacy of smoke evacuation systems in reducing surgical plume exposure within the operating room. For instance, a HEPA filter incorporated into a smoke evacuation system can effectively capture up to 94% of particulates

emitted from surgical smoke (Searle et al., 2020, p.844). The effectiveness of smoke evacuation is well-established, substantiated through air sampling and personnel monitoring of air particulates. Remarkably, in procedures known for generating substantial surgical plume, such as breast procedures, the use of smoke evacuation has resulted in a six-fold reduction in surgical plume levels when compared to situations where evacuation systems are not employed (Benson et al., 2019, p.991). Other studies encompass a variety of surgical procedures, including bilateral spine procedures, demonstrating that smoke evacuation can reduce surgical plume levels by 60% when applied to one side of the spine (Liu et al., 2018, p.173). Moreover, the utilization of smoke evacuation has been shown to significantly lower the levels of total volatile organic compounds (TVOC) in surgical plume (Tokuda et al., 2017, p.8). In cases where smoke evacuation systems may not be available, one article suggests a cost-effective alternative by proposing the use of surgical assist suctioning during cautery to reduce plume levels, incurring no additional costs (O'Brien et al., 2015, p.510). Additionally, research conducted by Markowska et al. (2020) centered on the analysis of chemical compounds in surgical smoke from burn patients, further illuminating potential health risks associated with exposure to specific chemical compounds and thus advocating for protective measures among medical personnel.

While quantitative data convincingly supports the effectiveness of smoke evacuation systems, the qualitative dimension of evidence-based research holds equal significance. Moon et al. (2018) conducted a qualitative study involving interviews with perioperative nurses to gauge their experiences with surgical plume. This investigation unearthed a disconcerting lack of awareness among healthcare professionals and administrators concerning the perils of surgical plume. During interviews, nurses expressed sentiments such as "dangerous, but unrecognized by hospital administrators," "surgical smoke is involuntary exposure," and "coexistence with

surgical smoke is part of the job" (Moon et al., 2018, p.903). This underscores the urgent need for educational and awareness initiatives for all individuals operating in the realm of the operating room, as a substantial number of perioperative nurses were found to be unaware of the associated risks (Moon et al., 2018, p.904).

In collective essence, these studies underscore the occupational safety concerns linked to surgical plume exposure, underscoring the gravity of this often-underestimated threat to healthcare workers. They strongly advocate for educational and training endeavors encompassing all operating room personnel as a core component (Moon et al., 2018, p.903). While most articles predominantly focus on the overall effectiveness of smoke evacuation, one article provides insights into the specifics of different smoke evacuation devices, emphasizing the importance of selecting a device tailored to the specific surgical context (Liu et al., 2018, p.173). Furthermore, some articles delve into the financial aspect related to the implementation of smoke evacuation systems, potentially influencing decision-making processes within healthcare facilities (Benson et al., 2019, p.991; O'Brien et al., 2015, p.510).

In summation, the comprehensive review of these articles contributes formidable support to the implementation of smoke evacuation systems in operating rooms as a means to reduce surgical plume exposure. They underscore the effectiveness of these systems, the necessity for education and awareness among healthcare professionals and administrators, and the pivotal role this initiative plays in safeguarding the health and safety of operating room staff (See Appendix A: Evidence Table).

Project Stakeholders

This benchmark project involves a diverse group of stakeholders, each with varying degrees of influence and interests. Primary among these stakeholders are patients and their

families. This project directly impacts patient safety and well-being by mitigating health risks associated with surgical plume exposure, aligning with ethical principles that prioritize the best care for patients. Patients and their families would naturally prefer surgical procedures conducted in an environment that minimizes these health risks, reflecting their preference for enhanced patient safety and care quality. Furthermore, healthcare professionals, including nurses, surgeons, anesthesiologists, and perioperative staff, are central stakeholders in this project. They are directly affected by surgical plume exposure, and their safety is a paramount concern. By implementing smoke evacuation systems, this project aligns with ethical principles that prioritize the well-being of these professionals. Additionally, healthcare professionals would favor working in an environment that minimizes occupational health risks, as their well-being and job satisfaction are closely tied to the reduction of exposure to surgical plume. Each stakeholder provides a key role in their interprofessional involvement. For example, the surgeon and anesthesiologist can provide input based on their personal experience with smoke evacuation and, if used as a trial period, they can also rally other physicians into using smoke evacuation. The nursing management, perioperative nurse, and scrub technician can consistently encourage the use of smoke evacuation, perform the evidence-based research needed to implement this change, and discuss the benefits of using a form of smoke evacuation to all the surgeons they work with.

Hospital administrators also play a critical role in this initiative. They have an ethical duty to provide a safe working environment for healthcare professionals and ensure patient safety. Implementing smoke evacuation systems aligns with these ethical obligations. Administrators may also consider the project's financial implications, including initial costs and operational expenses, with the cost/benefit analysis providing evidence of the long-term financial

benefits. Regulatory bodies and government agencies are further stakeholders, as they are tasked with promoting and enforcing regulations that ensure patient and healthcare worker safety. Manufacturers and suppliers of smoke evacuation systems are also financially interested in the project's success, benefitting from increased demand for their products. Research and academic institutions may support the project due to its potential to advance medical knowledge and promote patient safety. Finally, professional associations and unions, such as nursing and medical associations, often advocate for the well-being of healthcare professionals. They see the project as aligned with their ethical mission of supporting measures to reduce surgical plume exposure. Moreover, they may consider the project beneficial for patient safety, and, on behalf of their members, advocate for its implementation. In summary, this project touches a wide array of stakeholders, and ethical considerations primarily revolve around ensuring the safety and well-being of healthcare professionals and patients.

Implementation Plan

The implementation of smoke evacuation would occur in the operating room setting. The goal is to eventually have all operating rooms in the hospital system become a smoke-free environment. The data needed to justify the change that is warranted would be surgical plume levels near and away from the surgical field during all types of procedures performed at the facility, a baseline health status of the employees before, during, and after the implementation has occurred, and surveys for the staff to complete as a baseline knowledge assessment of surgical plume.

To implement the needed change, permission will be needed from the nursing director of the operating room, surgeons, and hospital administration for budget approvals. Allies for the proposed change would be perioperative staff, anesthesia staff, and nursing management. The

largest barrier to the implementation of smoke evacuation, second to cost, is surgeon reluctance because the devices may be too bulky or too loud. There are several different types of smoke evacuation systems that come in all shapes and sizes. The department can reach out to some of these companies to see if these companies would be willing to do a trial period with their products until the department is able to find a product that most of the surgeons agree on. Departmental costs for a new surgical smoke evacuation system would need to be supplemented by looking at the departmental budget to see if items are unused in the budget and submitting a request for approval for a smoke evacuation system to be in the budget. In the meantime, surgical assist suctioning can be used.

Resources needed for the proposed change would be a smoke evacuation device and training for the perioperative staff, anesthesia staff, and surgeons on not only the new smoke evacuation system but also surgical plume in general and the measures needed to ensure safe personal protective equipment is used appropriately. Additional costs that may be incurred by introducing this change would be training costs and the cost of a surgical smoke evacuation system. Following the cost of purchasing a smoke evacuation system, the only additional costs from then on should be a smoke evacuation cautery pencil. This would be paid for by the patient like any other cautery and, in fact, staff would open that instead of the regular cautery used. Over time, the smoke evacuation system should pay for itself as a result of improving the overall health of perioperative personnel, thus keeping individuals from having to be out on workers' compensation. The stakeholders would assist in carrying out the change with the project leader.

Timetable/Flowchart

In the pursuit of reducing surgical plume output through the effective utilization of smoke evacuation systems, the project will be meticulously structured into distinct phases. The initial

phase, which will span 2 to 3 weeks, will aim to create interest and awareness among key personnel in the perioperative setting, including nurses, scrub technicians, anesthesia staff, and surgeons. During this phase, baseline assessments will be conducted to gauge the existing knowledge levels of surgical plume among the perioperative staff. Additionally, baseline health assessments will be administered to ensure the well-being of the staff.

The second phase, which will extend over a period of 3 to 4 weeks, will involve the dissemination of evidence-based research to underline the significance of surgical plume and the crucial role of smoke evacuation systems. This information will be shared with all personnel, accompanied by the necessary materials such as links to articles and educational resources to facilitate a comprehensive understanding of the proposed changes. Simultaneously, stakeholders for the change project will be selected, with an initial call for volunteers from those who exhibit a keen interest in seeing the transformation brought into practice.

Moving on to Phase 3, a more extended duration of 6 to 8 weeks will be allotted to actively promote the use of smoke evacuation systems. During this phase, efforts will be made to establish connections with companies specializing in smoke evacuation products. Trials will be initiated to assess the effectiveness of these systems, and active measures will be taken to equip surgeons with smoke evacuation tools for use during their procedures. Ensuring the presence of smoke evacuation equipment in the operating room before the commencement of procedures will become a standard practice during this phase.

The fourth phase, which will span 3 to 4 weeks, will focus on gathering feedback from the perioperative staff, anesthesia personnel, and surgeons regarding their experiences with the smoke evacuation devices. Acknowledgment and recognition will be provided to perioperative staff members who actively encourage and facilitate the use of smoke evacuation systems. In

conjunction with this, a post-survey will be conducted to evaluate the enhancement of perioperative staff's knowledge about surgical plume following the implementation of smoke evacuation. Furthermore, health assessments will be conducted on perioperative staff to monitor their well-being and safety after the adoption of surgical smoke evacuation practices. This iterative and structured approach aims to reduce surgical plume output not only by instilling awareness but also by actively involving stakeholders and ensuring continuous evaluation and improvement throughout the process (See Appendix B: Flowchart).

Data Collection Methods

For this research project, the data collection process will involve recruiting a diverse group of 80 participants who play various roles in the operating room, with a focus on smoke evacuation procedures. To ensure comprehensive demographic representation, participants will span a wide age range, from 18 to 74 years. The data collection methods employed in this study will include surveys, questionnaires, and the utilization of the P-TAK measurement technique as described by Liu et al. (2020) for assessing particulate matter (See Appendix C: P-TAK Measurement). These specific data collection instruments have been thoughtfully selected based on their suitability for the research context, and our research team will diligently review scoring instructions to guarantee the precise assessment and interpretation of participant responses, thereby enhancing the overall data quality.

The data collection will encompass several crucial aspects. First, it will involve the monitoring of short-term symptoms experienced by the operating room staff, including but not limited to symptoms like headaches, nasal congestion, or cough. Second, a survey instrument would be used to understand the perioperative staff's current understanding of surgical smoke, contributing valuable insights to the overall analysis (See Appendix D: Surgical Smoke

Knowledge Assessment Tool). Additionally, it is imperative to assess the total emissions of surgical plume in the immediate vicinity of the operating room table as well as at more distant locations throughout the trial process. While it is essential to understand the surgeon's perspective on surgical plume, obtaining real-time data on surgical plume levels during procedures is vital to accurately gauge the effectiveness of smoke evacuation devices. To achieve this, we will employ the P-TRAK method as outlined by Liu et al. (2020) for real-time measurement of particulate levels, providing valuable insights into the impact of smoke evacuation on both the well-being of the staff and the reduction of surgical plume. This comprehensive data collection approach will ensure a thorough evaluation of the influence of smoke evacuation on both staff health and surgical plume reduction, contributing to a more comprehensive analysis of the research outcomes.

Evaluation

To potentially implement surgical smoke evacuation in the future, data analysis will play a crucial role in assessing the current state of surgical smoke exposure and understanding the factors associated with it. The analysis would aim to provide valuable insights that will inform the decision-making process regarding the potential future implementation of surgical smoke evacuation systems. To gain insights into the current scenario, descriptive statistics would be essential. These statistical measures, including the mean, median, and mode of Ultrafine Particles (UFP) concentrations or other pertinent variables, would be calculated to determine central tendencies. Additionally, measures of variability, encompassing the standard deviation, range, and variance of UFP concentrations, would be computed to understand the extent of data dispersion. Visual tools such as frequency distributions or histograms would be utilized to depict the distribution of data across different concentration levels. Calculating percentiles, like the 75th

percentile UFP concentration, would offer valuable information about exposure level distribution.

To guide decisions about the potential implementation of surgical smoke evacuation, inferential statistics would be an essential part of the analysis. Formulating hypotheses related to surgical smoke exposure and its potential health effects would be the starting point. Hypothesis testing would be employed to rigorously assess these hypotheses. Furthermore, correlation analysis will be carried out to explore associations between variables. Factors like room ventilation rates, surgical techniques, or the presence of smoke evacuation systems would be subject to investigation for their correlation with UFP concentrations. Regression analysis would be employed to fathom how UFP concentrations are influenced by various factors, including surgery type, duration, and the presence of smoke evacuation systems. Comparative analysis, facilitated by t-tests or ANOVA (Analysis of Variance), would enable the comparison of UFP concentrations under different circumstances (O'Brien et al., 2020). Reporting effect sizes would be imperative to gauge the practical significance of observed differences. Calculating confidence intervals would enhance the precision of measurements by providing a range within which population parameters may lie.

Cost/Benefit Analysis

The cost of implementing surgical smoke evacuation systems over one year includes both the initial purchase costs and ongoing operational expenses. The initial investment, estimated at $50,000, covers various elements like disposable smoke evacuation pencils, reusable dispersive electrodes, disposable laparoscopic tubing, and related supplies (Ball, K., 2022). Additionally, the ongoing annual costs of approximately $30,000 account for disposable items, filters, maintenance, electricity, and staff training on device use and maintenance (Ferko et al., 2021).

In contrast, the financial benefits of implementing surgical smoke evacuation systems over one year are substantial. The intervention leads to cost savings in various aspects. The estimated cost savings include $824,760 from reduced operating room time, a conservative $50,000 from reduced hospital stay expenses, $10,000 from avoided waste disposal costs, $20,000 from enhanced healthcare professional safety, and $10,000 from operational efficiency improvements (Ferko et al., 2021).

The financial benefits clearly outweigh the costs, making the intervention highly justified. But it's not just about the monetary gains; surgical smoke evacuation systems also offer non-financial benefits such as improved employee well-being, enhanced patient safety, and clearer surgical fields. These factors contribute to a healthier workforce and better patient outcomes, which are equally valuable.

Discussion of Results

Due to time constraints and a lack of necessary tools for implementation in the perioperative setting, this project was not executed. Nonetheless, it is noteworthy that extensive research supports the positive impact of smoke evacuation on reducing surgical plume levels. Whether through pencil operating surgical smoke evacuation or assisting in the suctioning of surgical plume, the literature consistently demonstrates the efficacy of efforts to decrease surgical plume, contributing significantly to the reduction of volatile organic compounds (VOCs) in surgical plume. The research encompasses various surgical specialties, including neurosurgery, breast surgery, and gynecological surgery. Conclusively, these studies advocate for increased implementation of such projects to foster additional research. When circumstances permit implementation, I anticipate that all stakeholders involved will gain valuable insights into

surgical plume, protective measures, the existing knowledge gaps, and the indispensable role that smoke evacuation systems should play in every operating room procedure.

Conclusions/Recommendations

A significant body of research has explored the topic of surgical plume in the operating room, investigating its physical impact on perioperative staff and examining the influence of implementing surgical smoke evacuation on plume levels. The overarching consensus derived from the scrutinized research articles is a call for further studies on this subject. The project achieved success from an educational perspective, as it facilitated the dissemination of knowledge to perioperative staff regarding the nature of surgical plume and the requisite measures to shield oneself from its effects. Looking ahead, recommended enhancements for this initiative include establishing surgical protocols as a standard step for diverse procedures, underscoring the criticality of upholding a secure and healthful environment for both patients and healthcare workers. Furthermore, comprehensive training for all perioperative personnel on the hazards associated with surgical smoke and the proper utilization of smoke evacuation systems would be advantageous. The ongoing endeavor to diminish the occupational hazards confronted by perioperative staff do not need to conclude here. With advancing technology and an expanding interest in evidence-based research, this occupational hazard can evolve into a relic of the past. The mitigation of preventable healthcare-associated complications stemming from surgical plume commences with the steadfast implementation of smoke evacuation measures.

References

Ball, K. (2022, November 4). Thinking of buying ... smoke evacuators. *Outpatient Surgery Magazine*. https://www.aorn.org/outpatient-surgery/article/2016-January-thinking-of-buying-smoke-evacuators

Benson, S., Maskrey, J., Nembhard, N., Unice, K., Shirley, M,. & Panko, J. (2019). Evaluation of personal exposure to surgical smoke generated from electrocautery instruments: A pilot study. *Annals of Work Exposures and Health*, 63(9), 990–1003. https://doi.org/10.1093/annweh/wxz070

Carbin, J. (2008). Expert advice to help you clear the air in your OR. *Outpatient Surgery: A Division of AORN*. https://www.aorn.org/outpatient-surgery/article/2001-June-a-primer-on-smoke-evacuation

Cheng, N.-Y., Chuang, H.-C., Shie, R.-H., Liao, W.-H., & Hwang, Y.-H. (2018). Pilot studies of VOC exposure profiles during surgical operations. *Annals of Work Exposures and Health*, 63(2), 173–183. https://doi.org/10.1093/annweh/wxy099

Ferko, N., Wright, G. W., Syed, I., Naoumtchik, E., Tommaselli, G. A., & Gangoli, G. (2021). A device category economic model of electrosurgery technologies across procedure types: A U.S. hospital budget impact analysis. *Journal of Medical Economics, 24*(1), 524–535. https://doi.org/10.1080/13696998.2021.1915626

Fox-Lewis, A., Allum, C., Vokes, D., & Roberts, S. (2020). Human papillomavirus and surgical smoke: A systematic review. *Occupational and Environmental Medicine*, 77(12), 809–817. https://doi.org/10.1136/oemed-2019-106333

Liu, N., Filipp, N., & Wood, K. B. (2020). The utility of local smoke evacuation in reducing surgical smoke exposure in spine surgery: A prospective self-controlled study. *The Spine Journal*, 20(2), 166–173. https://doi.org/10.1016/j.spinee.2019.09.014

Markowska, M., Krajewski, A., Maciejewska, D., Jeleń, H., Kaczmarek, M., & Stachowska, E. (2020). Qualitative analysis of surgical smoke produced during burn operations. *Burns*, 46(6), 1356–1364. https://doi.org/10.1016/j.burns.2020.02.014

Moon, H. N., Park, B. H., & Chang, S. O. (2021). Operating room nurses' perceptions of the impact of surgical smoke and its countermeasures: A mixed-methods study. *Nursing & Health Sciences*, 23(4), 898–907. https://doi.org/10.1111/nhs.12885

O'Brien, D., Lee, E., Soo, J., Friend, S., Callaham, S., & Carr, M. (2020). Surgical team exposure to cautery smoke and its mitigation during tonsillectomy. *Otolaryngology–Head and Neck Surgery*, 163(3), 508–516. https://doi.org/10.1177/0194599820917394

Romano, F., Gustén, J., De Antonellis, S., & Joppolo, C. (2017). Electrosurgical smoke: Ultrafine particle measurements and work environment quality in different operating theatres. *International Journal of Environmental Research and Public Health*, *14*(2), 137. https://doi.org/10.3390/ijerph14020137

Searle, T., Ali, F. R., & Al-Niaimi, F. (2020). Surgical plume in dermatology: An insidious and often overlooked hazard. *Clinical and Experimental Dermatology*, 45(7), 841–847. https://doi.org/10.1111/ced.14350

Tokuda, Y., Okamura, T., Maruta, M., Orita, M., Noguchi, M., Suzuki, T., & Matsuki, H. (2020). Prospective randomized study evaluating the usefulness of a surgical smoke evacuation system in operating rooms for breast surgery. https://doi.org/10.21203/rs.2.20119/v

Van Gestel, E. A. F., Linssen, E. S., Creta, M., Poels, K., Godderis, L., Weyler, J. J., De Schryver, A., & Vanoirbeek, J. A. J. (2020). Assessment of the absorbed dose after exposure to surgical smoke in an operating room. *Toxicology Letters*, 328, 45–51. https://doi.org/10.1016/j.toxlet.2020.04.003

Vortman, R., McPherson, S., & Cecilia Wendler, M. (2020). State of the science: A concept analysis of surgical smoke. *AORN Journal*, 113(1), 41–51. https://doi.org/10.1002/aorn.13271

Zhou, Q., Hu, X., Zhou, J., Zhao, M., Zhu, X., & Zhu, X. (2019). Human papillomavirus DNA in surgical smoke during cervical loop electrosurgical excision procedures and its impact on the surgeon. *Cancer Management and Research*, Volume 11, 3643–3654. https://doi.org/10.2147/cmar.s20197

Appendix A: Evidence Table

Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
Benson et al. (2019). Evaluation of personal exposure to surgical smoke generated from electrocautery instruments: A pilot study.	NO NE	Design: Cohort design Method: Cohort study doing three types of personal air sampling on five different OR on multiple procedures.	There were a total of 106 procedures. Setting: Five OR performing varieties of procedures. Characteristics: Only five ORs; three types of personal air sampling	Independent variable: electrocautery Dependent variable: surgical smoke levels and volatile organic compounds.	Measurement devices used: PAH RTAM	US EPA Method TO-15	IV: P < 0.0004 DV: P = 0.0031 DV: P = 0.0001	Level IV Evidence Strengths: RCT including cohort studies; Comparing three PAS in OR; Multiple procedures. Limitations: small sample size; not including difference EP. Recommendations: further OR PAS surveys; focus on most common VOCs
Cheng et al. (2018). Pilot studies of	NO	Design: Cross sectional	Sample: 24 breath samples	Independent Variable: EC used in OR	Gas Chromatography/Mass	Wilcoxon two-sample test and	DV: sevoflurane (P = 0.0082), dimethyl sulfide (P = 0.0550), and methyl	Level IV Evidence Strengths: rigorous methodology, clear hypotheses, a comprehensive literature review, ethical considerations,

Legend:

ANA= anesthesia, ANOVA test= analysis of variable; BS= breast surgery; COREQ= consolidated data for reporting qualitative research; CPC= condensation particulate counter; CS= cohort study; CSS= cervical spinal surgery; DMS = dermatological surgery; DRI= direct reading instruments; DS= descriptive survey; EC= electrocautery; EO= expert opinion; EP= exposure parameters; FTVR-01 TVOC= Total Volatile Organic Compound measurement; LSS= lumbar spinal surgery; N= number in study; NSE= no smoke evacuation; OE= occupational exposure; OR= operating room; ORN= operating room nurse; PAH= polycyclic aromatic hydrocarbon; PAS= personal air sampling;PM = preventative measures; PPC= particulates per centimeter; PRS= prospective randomized study; PSE= para incisional smoke evacuation; PSM= protective safety measures; PTS= patients;PMM = particulate matter measurer; P-TRAK Model 8525= condensation particle counter; QLS= qualitative study; RCT= randomized control trial; RTAM= real time area monitoring; SAS= surgical assist suction; SE= smoke evacuation; SEP= smoke evacuation pencil; SP = surgical plume; SR= systematic review; SSE= surgical smoke evacuation; SS= spine surgery; SSL= surgical smoke levels; SURG= surgeon; T&A= tonsillectomy and adenoidectomy; US EPA= United States Environmental Protection Agency; VOC= volatile organic compound; w/= with; w/o= without

Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
VOC exposure profiles during surgical operations.	NE	obersvation study Methods: breath sample collection, chemical analysis, and statistical methods to assess the exposure of ORN to SP.	Characteristics: VOC tests performed during BS, ortho, general, and laparoscopic surgery. Setting: OR	Dependent Variable: VOCs in breath samples	Spectrometry (GC/MS) Proton-Transfer-Reaction Mass Spectrometry (PTR-MS) Fast Mobility Particle Sizer (FMPS) for particle measurement	median two-sample test	methacrylate (P = 0.0606) Samples were significantly higher after surgery.	statistical significance, well-defined variables, peer review, significant contributions to knowledge, and reproducibility Limitations: potential selection bias, limited generalizability due to the specific surgical context, possible measurement errors, and the need for further research to confirm findings Recommendations: larger samples, assessing accumulated chemical exposure, using real-time monitoring, and improving exposure reduction measures
Fox-Lewis et al. (2020). Human papilloma virus and surgical	NONE	Design: Systematic Review Methods:questionnaire-based	Sample: 335 articles Characteristics: HPV transmission during	Independent Variable: EC in OR; PPE Dependent Variable:	Full text review by one author	Articles were grouped by study type and their key findings	IV: More EC is more SS DV: HPV DNA in SS	Level I Evidence Strengths: examination of studies regarding HPV DNA in surgical smoke, safety recommendations for smoke-generating procedures, and

Legend:

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
smoke: A systematic review.		surveys, laboratory testing using polymerase chain reaction (PCR), comparative analyses, literature review, data synthesis, and evidence rating	OR procedures Setting: Multiple OR	HPV DNA, incidence of HPV transmission, and prevalence of HPV-related disease		summarised accordingly		transparent acknowledgment of potential study limitations Limitations: potential publication bias, the outdated methodologies of some included studies, and the uncertainty regarding the presence of viable HPV in SS. Recommendations: Further research on HPV in OR and ORN risk for HPV because of SS.
Liu et al. (2020). The utility of local smoke evacuation in	NONE	Design: Prospective self-controlled study	There were 51 spine surgeries. Setting: OR	Independent variables: para incisional smoke evacuation, smoke	Measurement models: P-TRAK Model 8525	Wilcoxon signed-rank test	IV1: $p<0.001$; reduced 59.7% IV2: $p<0.001$; reduced 44.1%	Level IV Evidence Strengths: RCT including cohort studies: comparable statistical data concerning SSE and different SE

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
reducing surgical smoke exposure in spine surgery: A prospective self-controlled study		Method: Measuring surgical smoke while using para incisional smoke evacuator and smoke evacuation pencil during spine surgery	Characteristics: Only spine surgery patients. Included in the study was the operating room nurse, anesthesia, and surgeon. 25 spine surgeries with para incisional smoke evacuation, 26 spine surgeries with smoke	evacuation pencil, and no smoke evacuation. Dependent variable: surgical smoke			IV3: 100,000 ppc DV: <75% w/SE	Limitations: Study only included SS. Recommendation: Include other specialties in the OR; Trial on other SS like CSS instead of just LSS.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
			evacuation pencil.					
Markowska et al. (2020). Qualitative analysis of surgical smoke produced during burn operations.	NONE	Design: Quantitative Design **Study translated to English -> not qualitative study** Methods: solid-phase microextraction (SPME) to collect VOC from SS.	Sample: 432 compounds Characteristics: Only burn operations Setting: West Pomeranian Centre of Treating Severe Burns and Plastic Surgery	Independent Variable:Procedure performed; EC used; PPE Dependent Variable: VOC	Solid-Phase Microextraction (SPME) and Gas Chromatography-Mass Spectrometry (GCxGC-ToFMS)	Permutational multivariate analysis of variance (PERMANOVA)	IV: Less EC meant less ss DV: SS contained a large amount of various VOCs	Level IV Evidence Strengths: novelty in addressing the composition of SS; advanced analytical techniques; and examination of variations in smoke composition Limitations: its preliminary nature, the inability to estimate specific compound concentrations, exclusion of certain toxic substances, unspecified sample size, and the lack of longitudinal data Recommendations: implementation of robust safety measures, enhanced ventilation systems, further research on health risks, increased awareness and training for healthcare professionals, careful patient selection, and advocacy for regulatory guidance

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
Moon et al. (2021). Operating room nurses' perceptions of the impact of surgical smoke and its countermeasures: A mixed-methods study	N O N E	The authors used a qualitative study design with expert opinion. Method: mixed-method study with descriptive survey.	There were 12 operating room nurses interviewed. Setting: OR Characteristics: Only 6 operating room nurses with less than 10 years of experience; Only 6 operating room nurses with greater than	Independent variable: descriptive survey Dependent variable: operating room nurse experience.	Measurement devices used: Focus group interviews; descriptive survey; COREQ	Braun and Clarke's (2006); SPSS version 24.0; Cohen's (1988) formula	IV: Severe lack of awareness; need for education DV: ORN >10 years' experience knew more PSM than ORN <10 years' experience	Level VI Evidence Strengths: QLS with ORN of varying experience, two-tiered focus group study with DS Limitations: Limited number of participants; Only ORNs from two hospitals. Recommendations: Perform focus group studies on more hospitals with a larger number of participants to ensure no biased opinions.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
			10 years of experience.					
O'Brien et al (2020). Surgical team exposure to cautery smoke and its mitigation during tonsillectomy.	N O N E	Design: Randomized control trial Method: Three types of surgical smoke evacuation during Tonsillectomy and Adenoidectomy procedures.	There were a total of 30 procedures for this study. Setting: OR Characteristics: Only Tonsillectomy and Adenoidectomy; Measured with direct reading instruments in OR	Independent variables: smoke evacuation pencil, surgical assist suctioning, and no smoke evacuation. Dependent variable: surgical smoke levels	Measurement tools used were direct reading instruments and a condensation particulate counter.	ANOVA test Post hoc Tukey test	IV: P = .0009 IV: P <.0001 IV: P = .4035 DV: SSL drastically decreased with SEP and SAS than with NSE	Level II Evidence Strengths: RCT including cohort studies: comparable statistical data concerning SEP, SAS, and NSE for decreasing SSL. Limitations: Only pertaining to T&A procedures. Recommendation: Include other specialties in the OR; Trial on other ENT procedures.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
Searle et al. (2020). Surgical plume in dermatology: An insidious and often overlooked hazard.	N O N E	Design: Opinion of Authorities Method: Systemic review of SR of DMS SSL and PM during DMS	Setting: dermatological surgeries in the OR Characteristics: Only dermatology	Independent variables: electrocautery, laser, and preventative measures. Dependent variables: Surgical smoke levels.	HEPA ULPA	PMM	IV: increases SSL IV: higher concentration of SSL in DMS IV: decreased amount of SSL by 94% and 99%. DV: showed increased effects from laser and EC; PM shows effective measures.	Level VII Evidence Strengths: Shows effectiveness of PM on lowering SSL. Limitations: Not a lot of significant statistical data. Recommendations: Do own personal sampling; Include other specialties than DMS
Tokuda et al. (2020). Prospective randomized study evaluating the usefulness	N O N E	Authors used the systemic review, prospective randomized study method design for	There were 62 breast cancer patients included in the study. Setting: OR	Independent variable: smoke evacuation. Dependent variables: level of VOCs and	Instrument used for measurement: FTVR-01 TVOC monitor	Methods for analyzing data: Students t-test Welch's t-test	IV: p<0.001 DV1: 70 ug/m^3 w/o SE 30 ug/m^3 w/SE DV2: p<0.05	Level I Evidence Strengths: Systematic review with RCTs. Multiple types of statistical data to prove purpose. Limitations: Study only included BS.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
of a surgical smoke evacuation system in operating rooms for breast surgery		breast cancer patients. Method: Measuring volatile organic compounds during breast surgery with and without smoke evacuation.	Characteristics: Only breast surgery patients. Also includes operating room nurse, anesthesia, and surgeon. 32 breast surgeries with smoke evacuation, 30 without smoke evacuation.	occupational exposure.				Recommendation: Include other specialties of surgeries to gain more data on the effectiveness of SE
Van Gestel et al. (2020). Assessme	N O	Design: observational cross-	Sample: 15 participants	Independent variable: EC	Gas Chromatography-Mass Spectrometry	comparative analysis, exceedan	IV: More EC produced more SS	Level IV Evidence Strengths: real-world setting, diverse participant group, ethical approval,

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
nt of the absorbed dose after exposure to surgical smoke in an operating room.	N E	sectional study Method:Air sampling and Urinary Biomonitoring	Characteristics: data collected through air sampling for VOCs and polycyclic aromatic hydrocarbons (PAHs) and urinary biomonitoring for internal exposure assessment Setting: hospital in Antwerp, Belgium	used in procedure Dependent variable: (VOCs) and polycyclic aromatic hydrocarbons (PAHs)	(GC-MS), High-Performance Liquid Chromatography (HPLC), Solid-Phase Microextraction (SPME), Thermal Desorption-Gas Chromatography (TD-GC), and passive sampling devices	ce analysis, statistical tests	DV: Increased VOCs and PAHs in SS during procedure	comprehensive approach combining air sampling and urinary biomonitoring, and longitudinal data collection over a 5-day period Limitations: small sample size, limited data collection timeframe, variability in surgical conditions, absence of a control group, unspecified measurement methods, and challenges in correlating external and internal exposure data Recommendations: larger sample size, control group, further research into topic.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
Vortman et al. (2020). State of the science: A concept analysis of surgical smoke.	N O N E	Design: concept analysis; qualitative research design Method: The authors conducted an extensive literature review to gather existing information and research on the concept of ss.	Sample: 36 studies Characteristics: Analysis of multiple studies defining the contents of SS. Setting: AORN	Attributes, antecedents, and consequences of surgical smoke	No measurement devices used.	literature review and theoretical analysis	SS contains many VOCs that can negatively effect ORN.	Level VI Evidence Strengths: comprehensive literature review, the establishment of conceptual clarity regarding surgical smoke, its multidisciplinary approach, implications for practice and policy, and its encouragement of further research Limitations: scarcity of recent nursing literature on surgical smoke, an absence of precise education requirements for perioperative personnel regarding surgical smoke hazards, and the necessity for further research Recommendations: further research to explore the short- and long-term health effects of SS.

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
Zhou et al. (2019). human papilloma virus DNA in surgical smoke during cervical loop electrosurgical excision procedures and its impact on the surgeon.	N O N E	Design: Quantitative descriptive study Method: fluorescence hybridization technique and polymerase chain reaction (PCR) assays for the detection of HPV DNA in cervical cells, surgical	Sample: 134 participants Characteristics: presence of human papillomavirus (HPV) DNA in SS generated during loop electrosurgical excision procedures (LEEP) Setting: OR during GYN procedures	Independent variable: Distance of suction from the surgical site Dependent variable: HPV DNA in SS	fluorescence hybridization techniques and PCR assays	Chi-square test and logistic regression analysis	human papillomavirus (HPV) DNA was present in SS generated during loop electrosurgical excision procedures (LEEP)	Level II Evidence Strengths: multiple methods to detect HPV DNA and focus on healthcare operator safety and the correlation of HIV infection risk Limitations: small sample size, the potential for false-negative results in detecting HPV DNA, and study did not investigate long-term health outcomes Recommendations: increased awareness, consistent use of high-filtration masks, implementation of smoke evacuation systems, further research on long-term health effects, monitoring of exposed healthcare professionals, education, and policy development to mitigate the risks associated with surgical smoke exposure containing HPV DNA

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Citation: (i.e., author(s), date of publication, & title)	Conceptual Framework	Design/ Method	Sample/ Setting	Major Variables Studied and Their Definitions	Measurement of Major Variables	Data Analysis	Study Findings	Strength of the Evidence (i.e., level of evidence + quality [study strengths and weaknesses])
		smoke, and nasal swabs						

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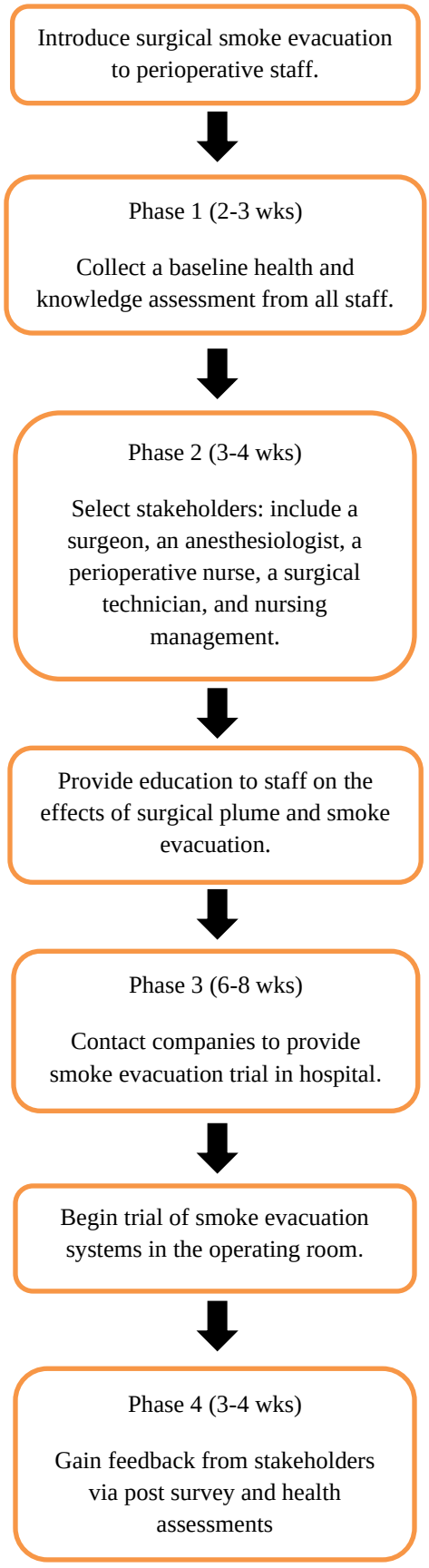
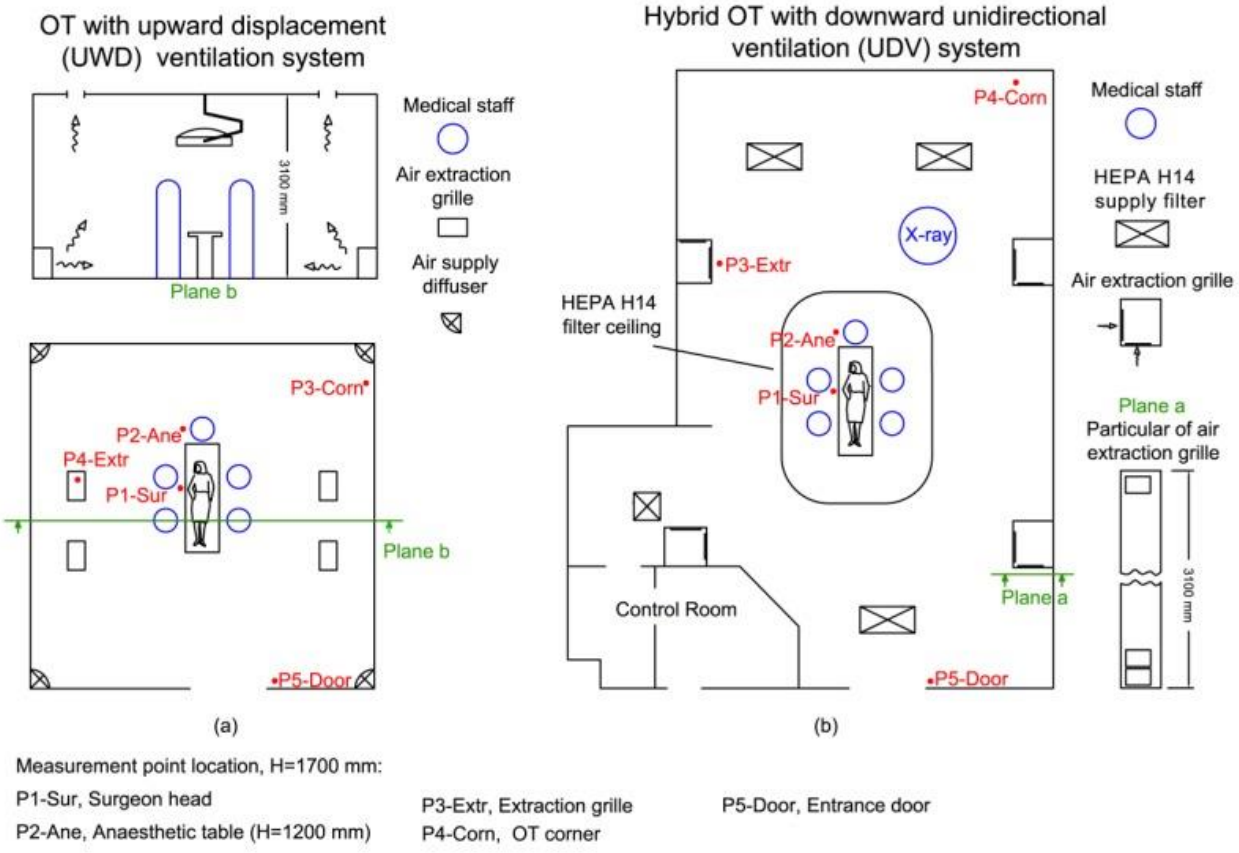
Appendix B: Flowchart



Appendix C: P-TRAK Measurement



Operating theatres and sampling probe layout position using the P-TRAK measuring device: (a) OT with upward displacement airflow (UWD) ventilation system; (b) Hybrid OT with unidirectional downward airflow (UDV) ventilation system.

From “Electrosurgical smoke: Ultrafine particle measurements and work environment quality in different operating theatres” by Romano, F., Gustén, J., De Antonellis, S., & Joppolo, C. (2017). *International Journal of Environmental Research and Public Health*, *14*(2), 137. https://doi.org/10.3390/ijerph14020137

Appendix D: Surgical Smoke Knowledge Assessment Tool

1. I understand what surgical smoke is and its potential health risks.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

2. I am aware of the sources of surgical smoke in the operating room.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

3. I know the various components and hazardous substances present in surgical smoke.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

4. I understand the potential health effects of exposure to surgical smoke.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

5. I am familiar with the recommended safety measures and guidelines to control surgical smoke exposure.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

6. I can identify the appropriate respiratory protection and equipment for mitigating surgical smoke exposure.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

7. I know the importance of surgical smoke evacuation systems and how to use them effectively.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

8. I am aware of the regulations and standards related to surgical smoke management in our facility.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

9. I have received training on surgical smoke safety in the past year.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

10. I feel confident in my ability to protect myself and my colleagues from the potential risks associated with surgical smoke.
    - 1 (No Understanding)
    - 2 (Limited Understanding)
    - 3 (Moderate Understanding)
    - 4 (Good Understanding)
    - 5 (Expert Understanding)

Additional Comments:

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