OR Air Quality: Is it time to consider adjunctive air cleaning technology?

Barnes, Sue; Twomey, Carolyn; Carrico, Ruth; Murphy, Cathryn; Warye, Kathy

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OR Air Quality: Is It Time to Consider Adjunctive Air Cleaning Technology?

Sue Barnes, BSN, RN, CIC, FAPIC; Carolyn Twomey, BSN, RN; Ruth Carrico, PhD, DNP, FNP-C, FSHEA, CIC; Cathryn Murphy, PhD, FSHEA, CIC; Kathy Warye, BA

ABSTRACT

Patients undergoing surgery may be at risk for infection from airborne particles such as dust, skin scales, respiratory aerosols, and hair fibers emanating from multiple sources in the OR, including personnel, heater-cooler devices and surgical smoke. This risk is increased in surgical patients undergoing procedures involving implanted devices. Surgical personnel are also at risk from exposure to surgical smoke which can contain viable viral particles including human papillomavirus virus. Air quality in the OR is improved by engineering controls (e.g., maintaining positive pressure); and, during the past decade there has been innovation in the field of adjunctive technology designed to improve OR air quality including built in UV disinfection and mobile UV disinfection plus high efficiency particulate air filtration (HEPA). Some of these technologies additionally provide continuous monitoring of circulating air particle counts. Further research regarding the risk reduction benefits of these adjunctive air-cleaning technologies in operating rooms is warranted.

Key words: *surgical smoke, heater-cooler units, air cleaning technology, surgical plume, Mycobacterium chimaera.*

BACKGROUND

Air in the OR may contain contaminants in the form of surgical smoke (also called surgical plume) and other bacteria-laden particles (e.g., dust, skin squames) that may create potential health hazards for surgical team members and patients.[1,2] When a surgeon uses an electrosurgical unit or a laser for thermal destruction of tissue, it generates surgical smoke. Surgical smoke can contain carbon monoxide, viral and bacterial fragments, as well as carcinogenic and mutagenic particles that can create health risks for surgical team members.[3-5]

The risk of patient infection from contaminated air is greatest when the procedure involves an implant such as total joint arthroplasty.[6] In recent years, there have been reports of OR air contamination with *Mycobacterium chimaera* from the exhaust of heater-cooler units, which has resulted in surgical infections and patient death, underscoring the serious risks associated with contaminated OR air.[7]

Currently in the United States (US), approaches to ensuring high quality air in ORs are limited to implementing engineering controls for maintaining air pressure (i.e., positive in relation to adjacent areas), velocity (i.e., a minimum of 20 air changes per hour), temperature (i.e., between 68° F and 75° F [20° C and 24° C]), humidity (i.e., between 20% and 60%) and air filtration.[8-10] Air quality standards that include limits for the number of bacteria and specific particles have not been established for US ORs though they have been established for US compounding pharmacies,[11] and for European ORs.[12] Progress, however, has been made in adjunctive technology designed to improve the quality of OR air. This includes ultraviolet (UV) disinfection systems built into the OR, as well as mobile devices combining UV disinfection and HEPA filtration,.[13-18]

SURGICAL SMOKE

Peer reviewed reports have described adverse health outcomes for the surgical team and patients caused by exposure to surgical smoke, including human papillomavirus (HPV) infection, cancer, and bacterial infection.[19,20] The US Occupational Safety and Health Administration (OSHA) estimates that each year in the US 500,000 surgeons and perioperative health care workers including RNs and surgical technologists, perform procedures that generate laser or electrosurgical smoke.[21] In 1996, the National Institute of Occupational Safety and Health (NIOSH) warned of "toxic gases and vapors", and various health risks including mutagenic threats present in surgical smoke.[22(p1)]

Smoke from laser and electrosurgery is caused by the fast heating of cells that creates pressure, and the subsequent release of cell membranes and contents, as well as surrounding structures, into the OR environment. The type and amount of tissue being cauterized as well as the environmental conditions affect the materials that are released during laser and electrosurgery. Generally, surgical smoke is composed of 95% steam and 5% solid particulate matter.[23]

When a laser is used, the content of the smoke is affected by the pulse duration and the energy application.[24] The average size of particles contained in laser smoke is 0.3 micrometers compared with an average particle size of less than 0.1 micrometer contained in electrosurgery smoke.[24] These processes of cauterization of living skin and subcutaneous tissue may release chemical compounds into the OR air that include aromatic hydrocarbons (e.g., cresol, phenol, benzene, toluene, xylene), aldehydes (e.g., formaldehyde, acetaldehyde, acrolein), hydrocyanic acid, carbon monoxide, and nitrile compounds.[24] Some of these compounds are toxic and/or carcinogenic.[24] For example, if acrylonitrile (a nitrile compound that forms hydrocyanic acid)

penetrates the skin and lungs of an individual it can cause nausea and vomiting. Experts have reported that it can also increase the risk of myocardial infarction.[25] Similarly, exposure to benzene found in surgical smoke can cause headaches and nausea.[25] Baggish and Elbakry[26] reported lung effects including congestive interstitial pneumonia, bronchiolitis, and emphysema in rats exposed to laser smoke. Tomita et al[27] estimated that exposure to surgical smoke generated by laser cautery of one gram of tissue is comparable to smoking three cigarettes, while burning the same amount of tissue during electrosurgery is comparable to smoking six cigarettes.

Studies have demonstrated that surgical masks worn by surgical team members do not provide adequate protection from surgical smoke.[28] The most effective exposure prevention precaution for surgical team members is using sufficient smoke evacuation systems for procedures involving laser or electrosurgery. The efficacy of smoke capture is affected by the smoke evacuator flow rate, distance of the evacuator nozzle to the surgical site, tubing size, and amount of smoke generated.[28] According to the AORN Guideline for Surgical Smoke Safety, "the capture device (e.g., wand, tubing) of a smoke evacuation system should be positioned as close to the surgical site as necessary to effectively collect all traces of surgical smoke."[28(p493)]

Surgical Smoke and HPV

The smoke from laser and electrosurgery can contain infectious viruses such as the HIV, hepatitis B, and various types of the human papillomavirus (HPV).[29] The true risk of HPV transmission from surgical smoke generated during laser or electrosurgery procedures continues to be debated.[29-33] Garden et al[29] captured laser smoke after carbon dioxide laser treatment and analyzed the smoke for viral DNA content. The researchers found that intact viral DNA was aerosolized during laser treatment; however, they did not demonstrate that the viruses were

infectious. In a similar study to determine if HPV DNA was present in laser smoke, Hughes et al[30] detected no HPV DNA during five procedures involving ablation of HPV-positive warts. In another study, Garden et al[31] collected laser smoke containing papillomavirus DNA and reinoculated the collected smoke into the skin of calves. The researchers found that tumors containing the same virus present in the laser smoke developed at all of the inoculated sites. They concluded that laser smoke could transmit disease.

Studies have reported that surgical team members maybe at risk of developing HPV when inhaling surgical smoke containing virus particles during condyloma ablation.[32,33] In one report, a laser surgeon developed laryngeal papillomatosis, a condition in which benign tumors (i.e., papilloma) caused by the HPV virus develop along the aerodigestive tract. Tissue samples from the surgeon's tumors contained HPV DNA. The surgeon reported having performed laser therapy on patients with anogenital condylomas which are known to harbor HPV.[32] Another report of occupational HPV infection involved a gynecological OR nurse, who assisted in numerous electrosurgical and laser excisions of anogenital condylomas, and subsequently developed recurrent laryngeal papillomatosis. The authors concluded there was a high probability of association between the reported occupational exposure of the nurse and the development of her laryngeal papillomatosis.[33]

Surgical Smoke and Cancer

Rioux et al[34] reported two cases of cancer in laser surgeons. The first case involved a 53-year-old male gynecologist who developed HPV 16-positive tonsillar squamous cell carcinoma. The physician had no risk factors for cancer or HPV except long term occupational exposure to laser smoke during more than 3,000 laser ablations and loop electrosurgical excision procedures over

20 years of practice. The second case involved another male gynecologist with a 30-year history of performing laser ablation and loop electrosurgical excision procedures, who developed HPV 16-positive cancer of the tongue.

To determine whether viable malignant cancer cells are present in surgical smoke, Fletcher et al[35] cauterized mouse melanoma cells, and assessed cell viability immediately and 7 days after collection. The researchers found that the surgical smoke contained viable cancer cells for up to one week after collection. This finding supported the researchers' hypothesis that port site metastasis after laparoscopic colon resection could be the result of seeding malignant cells contained in surgical smoke. These findings also support the argument that surgical smoke creates a risk for perioperative personnel who potentially could inhale viable tumor debris in surgical smoke.

BACTERIA IN OR AIR

There are reports of bacterial transmission risk via surgical smoke. Schultz[3] used an experimental model of porcine tissue embedded with *Serratia marcescens* to determine the extent of viable bacteria present in surgical smoke. The researchers found that the plume from blended current electrosurgery (where the surgeon performs cutting and coagulation functions at the same time) contained viable bacteria, whereas the plume from coagulation electrosurgery and lasers did not. In a related study,

Capizzi et al[36] used an air filter to quantitatively test for pathogens in laser smoke during laser resurfacing. The researchers found viable bacteria including coagulase-negative staphylococcus, *Corynebacterium*, and *Neisseria*. The researchers theorized that if the patient were colonized with pathogenic bacteria such as *Staphylococcus aureus*, the surgical team could

be exposed and, based on the air circulation patterns in the facility, individuals in adjacent rooms could also be exposed. For example, if a patient undergoes ulcer debridement under moist conditions it can lead to significant air contamination with pathogens such as *S aureus* and *Pseudomonas aeruginosa*, which have been reported to remain detectable in air for some time after aerosolization. This is a risk in any procedure where a laser or electrosurgery is used in moist and pathogen-dense tissue if the pathogen is not completely eradicated. The level of risk depends on the type and concentration of the pathogen and the surgical team's use of appropriate personal protective equipment.[37]

Circulating airborne bacteria-laden particles from equipment with contaminated air exhaust such as heater-cooler devices, as well as hair, dust, skin squames, or respiratory aerosols from surgical team members can create a risk of infection for patients, especially during procedures involving an implant.[38,39] Introducing a foreign body into a patient can reduce the number of organisms necessary to cause an infection by a factor of 100,000. This is because the human body's primary immunologic response focuses on the implant as a foreign body, instead of focusing on the microorganisms contaminating the surgical wound.[40] The contaminating microorganisms are thus able to multiply, form a biofilm, and cause an infection.[40]

Outbreaks of invasive *M. chimaera* surgical infections associated with heater-cooler devices used during cardiac surgery procedures have affected patients in several countries since 2015.[7] Investigations of these outbreaks clearly demonstrate that the surgical infections, with associated morbidity and in some cases mortality, were transmitted to surgical patients by OR air contaminated with exhaust from the heater-cooler devices.[7]

Foot traffic and door openings disrupt the positive air pressure in the OR and may result in the settling of contaminating microorganisms attached to airborne particles (e.g., dust, lint) in

the open surgical incision or on the surgical implant, surgical instruments, or surgical team members' gloves.[40-44] Lynch et al[44] observed and recorded behaviors of perioperative personnel in the OR. The researchers collected information that included the number of people entering and leaving the OR, their positions, and their reason for leaving or entering the room. The researchers found there were more than 3,000 door openings over the course of 28 procedures. The number of door openings ranged from 19 to 50 per procedure. The number of door openings increased as the length of the case increased, and was also associated with the number of people in the OR.

CONTROLLING OR AIR QUALITY

The engineering controls implemented to limit circulating particles and bacteria in US ORs are defined by the Facility Guidelines Institute (FGI)[8,9] and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).[10] These guidelines are supported by the Centers for Disease Control and Prevention (CDC),[45] AORN,[46] and the Association for the Advancement of Medical Instrumentation (AAMI).[47] The engineering controls include maintaining air pressure (i.e., positive pressure in relation to adjacent areas), velocity (i.e., a minimum of 20 air changes per hour, four of which are from outside air), temperature (i.e., between 68° F and 75° F [20° C and 24° C]), humidity (i.e., between 20% and 60%), and using sequential air filtration.[8,9,10,45-47]

Additionally, FGI recommends using sequential HEPA filters for ORs with a minimum efficiency reporting value (MERV) rating of 7 (designed to capture particles 10 to 3 micrometers in size) and 14 (designed to capture particles from 1 micrometer to 0.3 micrometers in size).[8,9] The MERV is a measurement scale used to rate air filters based on the size of a particle they are able to filter out of the air. The higher the MERV rating, the more effective the filter.[8,9]

All of these guidelines for improving air quality in ORs are based on consensus of professional expert opinion, versus being mandated by law or regulation.

ADJUNCTIVE OR AIR CLEANING TECHNOLOGY

During the past decade there have been innovations in adjunctive technology for improving OR air quality. Some of these are UV disinfection systems designed to be built in to the HVAC or lighting systems in an OR. There are also mobile units that provide both HEPA filtration and UV-C disinfection for all air in the OR for the duration of the procedure. Combining HEPA plus UV disinfection of air in a mobile device provides benefits including:

- filtering particulates from the air including those associated with surgical smoke,
- inactivating microorganisms (disinfection) using UV-C light,
- requiring a minimum of space (i.e., 400 ft^2; 122 m^2) and operating successfully when located a distance (i.e., 13 ft; 4 m) from the procedure,
- running continuously during a procedure without an operator present,
- not creating any air turbulence or disruption of the OR air balance.[14-18]

Several conference reports[14-17] and one laboratory pilot study[18] have described the efficacy and benefits of OR air cleaning technology using HEPA filtration plus UV-C disinfection. At the 2017 Australasian College for Infection Prevention and Control annual conference, Walsh[16] reported that air filtration and disinfection units combining HEPA filtration and UV-C disinfection technologies significantly reduced the total and viable particle counts in a highly-controlled OR setting, and suggested that this may reduce the potential for patient infection. Ongoing innovation and refinement of air cleaning technologies as well as ongoing research exploring all risks and benefits associated with the technology is prudent given the risk of patient

infection associated with contaminated OR air and the health risks to surgical team members associated with exposure to surgical smoke.

DISCUSSION

In addition to adhering to engineering controls for maintaining air quality in ORs AORN recommends implementing specific perioperative practices to reduce environmental and air contamination. These practices include minimizing foot traffic and the number of door openings during surgical procedures,[48] clipping patient hair in a location outside of the OR before bringing the patient to the OR,[49] and having surgical team members wear long sleeves and to cover all hair.[50]

AORN and NIOSH support the use of smoke evacuators to eliminate surgical smoke and minimize the associated exposure risks for surgical team members.[22,28] Using smoke evacuators, however, is not mandatory and compliance is not universal.[22,51,52] Smoke evacuators may be inconsistently used in ORs for several reasons including the

- cost of tubing and filters,
- need to position the evacuator wand as close as possible to the incision,
- time required to set up, and
- noise from the evacuator.

When the evacuator wand is placed close to the surgical site, it could get in the way and interfere with the surgical procedure. As well, evacuators create negative pressure over the surgical site. Negative air pressure in an isolation room is designed to contain airborne contaminants within the room. In a similar manner, the negative pressure created by a smoke evacuation system could theoretically pull any nearby circulating bacteria-laden particles toward the incision.[53]

Beyond supporting established engineering controls for air filtration, air pressure, velocity, temperature, and relative humidity, professional organizations have not provided additional recommendations, and regulatory agencies have not introduced regulations for mandatory testing of the quality of OR air. Mandatory air quality standards (i.e., limits for specific particle counts and bacteria levels) are in effect for US compounding pharmacies[11] and European ORs,[12] but not for US ORs.[11] The US Pharmacopeia General Chapter <797> Pharmaceutical Compounding—Sterile Preparations[11] requires compounding pharmacies to comply with the International Organization for Standardization class 5 standards for cleanroom air quality.[54] A class 5 cleanroom is limited to at most 100,000 particles (0.1 micrometers in size) per cubic meter of air.[53] Both compounding pharmacies and ORs implement aseptic practices; however, it could be argued that the standard for air quality in an OR should be *more* stringent than the standard for a compounding pharmacy, because there are many more factors causing air contamination (e.g., heater-cooler devices, skin squames and hair shed from surgical team members, bioaerosols, bacteria-laden air particles disseminated via foot traffic and door openings during procedures).

Without a regulatory mandate for measuring air quality and achieving specific air quality standards in US ORs, there remains a risk of infection for patients, especially those patients undergoing surgical procedures involving implants.[6,40] Currently, many surgical disciplines engage in the implantation of biomedical devices. In the US, approximately 1.2 million joint arthroplasty procedures are performed annually.[55] That number is expected to increase to 3.8 million by 2030.[55] The amount of patient suffering and the associated health care cost for each infection is tremendous.[55] Recent reports estimate that the range of associated costs for a prosthetic joint infection is between $100,000 and $400,000.[56]

CONCLUSION

The contamination of air in the OR presents a potential infection risk for surgical patients. Surgical team members may also be at risk from air contaminated with surgical smoke. Recent innovations have made air cleaning technology available for ORs and are designed to work adjunctively with existing engineering controls. Early evidence of air cleaning technology efficacy is compelling, though continuing refinement of the technology and additional research that focuses on the benefits of improving OR air quality for patients and surgical team members is warranted.

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Sue Barnes, BSN, RN, CIC, FAPIC, is an independent clinical consultant in infection prevention and control in San Mateo, CA. *As a consultant to companies that may be affected by the research reported in the paper, Ms Barnes has disclosed an affiliation that could be perceived as posing a potential conflict of interest for the publication of this article.*

Carolyn Twomey, BSN, RN, is the vice president of Clinical, Research, and Regulatory at the IrriMax Corporation, Henrico, VA. *As an employee of a company that sells products to companies that may be affected by the research reported in the paper, Ms Twomey has disclosed an affiliation that could be perceived as posing a potential conflict of interest for the publication of this article.*

Ruth Carrico, PhD, FNP-C, FSHEA, CIC, is an associate professor in the Division of Infectious Diseases at the University of Louisville in Louisville, KY. *Ms Carrico has no declared affiliation that could be perceived as posing a potential conflict of interest for the publication of this article.*

Cathryn Murphy, PhD, FSHEA, CIC, is an adjunct associate professor of Health, Sciences and Medicine at Bond University, Robina, Queensland, Australia; and the chief executive officer and creative director, Infection Control Plus Pty Ltd, West Burleigh, Queensland, Australia. *As the employee of a company that provides consulting services to companies that may be affected by research in this article, Dr Murphy has disclosed an affiliation that represents a potential conflict of interest.*

Kathy Warye, BA, is the founder of Infection Prevention Partners, Washington, DC. *As the founder of a company that provides services to companies that may be affected by the research reported in the paper, Ms Warye has disclosed an affiliation that could be perceived as posing a potential conflict of interest for the publication of this article.*

Key Takeaways

- Exposure to surgical smoke can lead to adverse health outcomes for the patient and surgical team that include respiratory irritation, transmission of HPV, skin cancer, and bacterial infection.
- AORN and the National Institute for Occupational Safety and Health support the use of smoke evacuators to eliminate surgical smoke and minimize the risk of exposure for surgical team members.
- Circulating airborne bacteria-laden particles from heater-cooler units, as well as hair, dust, skin squames or respiratory aerosols from surgical team members can create a risk for patient infection, especially during procedures involving an implant.
- Currently, air quality in US ORs is maintained by implementing engineering controls that include sequential air filtration and maintaining positive air pressure, at least 20 air changes per hour, relative humidity between 20% and 60%, and temperature between 68° F and 75° F (20° C and 24° C).
- Mobile adjunctive air cleaning technology comprising HEPA filtration and UV-C disinfection may reduce environmental and air contamination, when implemented in addition to existing engineering controls.