REPORT 3 OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH (A-25)
Protections Against Surgical Smoke Exposure
(Resolution 404-A-24)

EXECUTIVE SUMMARY

BACKGROUND. Resolution 404-A-24, "Protections Against Surgical Smoke Exposure," was referred. This resolution called for AMA to support efforts to limit surgical smoke in operation rooms. This report provides a summary of the available evidence on the potential health impacts of surgical smoke, currently available preventive strategies, the landscape of legislative activity to limit surgical smoke, and a summary of potential concerns or barriers to effective prevention.

METHODS. English language reports were selected from searches of the PubMed and Google Scholar databases using the search terms: "surgical smoke" AND "health" as well as "surgical smoke" AND "prevention." Additional searches were performed on both effectiveness and cost concerns of current preventive measures. Legal websites were searched to identify which states have passed legislation on this topic. Additional articles were identified by manual review of the reference lists of pertinent publications. Web sites managed by federal agencies and advocacy organizations were also reviewed for relevant information.

DISCUSSION. Surgical smoke results from the use of energy-generating devices during surgery, including electric knives, ultrasonic scalpels, and lasers, which causes the temperature of tissue to rise to the point of tissue vaporization, released as surgical smoke. Surgical smoke has been estimated to be about 95 percent water vapor and five percent organic byproducts, the latter being responsible for potential adverse exposure risks. Surgical smoke is a health concern as it may contain a number of known health hazards, including benzene, toluene, hydrogen cyanide, formaldehyde, viruses, and bacteria. The potential negative impacts from surgical smoke are severalfold. First, surgical smoke may limit visibility within the operative field, affecting the safety of the surgical operation to some extent if it is not actively cleared. Second, surgical smoke can cause short-term discomfort and potential illness to surgical staff. Depending on the size and types of particles released, surgical smoke can cause acute irritation of the eyes and throat while smaller particles in smoke can settle further in the lungs. Inhalation of particulate matter smaller than 2.5 micrometers (PM2.5) has been associated with increased incidence of asthma, chronic obstructive pulmonary disease, lung cancer, and cardiovascular disease. Lastly, surgical smoke may increase the risk of disease transmission through the presence of viral and bacterial pathogens in the smoke. Despite potential health hazards, there is heterogeneity of findings in the available research, which is partially explained by challenges in understanding the true exposure risk, as it differs by the type of surgery, specialty, profession, and what role an individual has in the operating room. However, there are several preventive measures recommended by multiple organizations that can be employed to reduce risk to personnel, which include the use of smoke evacuation equipment, having appropriate ventilation, and wearing appropriate PPE, which may include surgical masks or N95 respirators.

CONCLUSION. While more research is needed to better understand the potential health impacts associated with surgical smoke, there is currently no known safe level. In taking a public health precautionary principal approach, it is reasonable to take preventive measures even if health hazards are uncertain. Recommended preventative approaches are well known and consistent across multiple organizations. Additionally, increased education on the potential health risks of surgical smoke among health care personnel is needed, as many have not received any sort of training or education on the subject.

REPORT OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH

CSAPH Report 3-A-25

Subject: Protections Against Surgical Smoke Exposure

Presented by: John T. Carlo, MD, MS, Chair

Referred to: Reference Committee D

INTRODUCTION

Resolution 404-A-24, "Protections Against Surgical Smoke Exposure," was referred. This resolution called for AMA to support efforts to limit surgical smoke in operation rooms. Testimony noted conflicting evidence as well as ergonomic and cost considerations of smoke evacuation technologies. This report provides a summary of the available evidence on the potential health impacts of surgical smoke, currently available preventive strategies, the landscape of legislative activity to limit surgical smoke, and a summary of potential concerns or barriers to effective prevention. While surgical smoke can also be of concern to patients, this report focuses on the issue from an occupational health and safety perspective for health care personnel.

BACKGROUND

Surgical smoke results from the use of energy-generating devices during surgery, including electric knives, ultrasonic scalpels, and lasers, which causes the temperature of tissue to rise to the point of tissue vaporization, released as surgical smoke. Surgical smoke has been estimated to be about 95 percent water vapor and five percent organic byproducts, the latter being responsible for potential adverse exposure risks.[1] Surgical smoke is a health concern as it may contain a number of known health hazards, including benzene, toluene, hydrogen cyanide, formaldehyde, viruses, and bacteria.[2] The potential negative impacts from surgical smoke are severalfold. First, surgical smoke may limit visibility within the operative field, affecting the safety of the surgical operation to some extent if it is not actively cleared. Second, surgical smoke can cause short-term discomfort and potential illness to surgical staff.[3,4] Depending on the size and types of particles released, surgical smoke can cause acute irritation of the eyes and throat while smaller particles in smoke can settle further in the lungs. Inhalation of particulate matter smaller than 2.5 micrometers ($PM_{2.5}$) has been associated with increased incidence of asthma, chronic obstructive pulmonary disease, lung cancer, and cardiovascular disease.[5] Lastly, surgical smoke may increase the risk of disease transmission through the presence of viral and bacterial pathogens in the smoke.[6]

METHODS

English language reports were selected from searches of the PubMed and Google Scholar databases using the search terms: "surgical smoke" AND "health" as well as "surgical smoke" AND "prevention." Additional searches were performed on both effectiveness and cost concerns of current preventive measures. Legal websites were searched to identify which states have passed legislation on this topic. Additional articles were identified by manual review of the reference lists

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of pertinent publications. Web sites managed by federal agencies and applicable professional and advocacy organizations were also reviewed for relevant information.

DISCUSSION

Health hazards of surgical smoke

There are several different types of energy-generating devices utilized during surgery to cut and cauterize tissue, including electric knives, ultrasonic scalpels, and lasers. The composition of surgical smoke, particle size, and the amount produced is dependent on the device used and the type of tissue where it is employed. For example, the cauterization of solid organs or fat tissue versus muscle tissue has been found to create higher emissions.[7] In one study, much higher levels of ultrafine particulate matter were measured while operating on the liver compared to surgeries involving muscle, adipose tissue, and blood vessels.[3] Additionally, surgical smoke particles with the smallest size, generally less than 0.1 micrometers (μm), are produced by electrocautery, followed by laser tissue ablation (~0.3 μm) and ultrasonic scalpel usage (0.35–6.5 μm).[8] Particle sizes of less than five μm are of more concern as they are respirable, with smaller particles of sizes less than two μm being of the greatest concern as they can penetrate and be deposited deeper in the lungs.[8] Surgical smoke is a health risk for a range of health care staff. The Occupational Safety and Health Administration (OSHA) estimates that around half a million workers, including surgeons, nurses, anesthesiologists, gynecologists, perioperative practitioners, dermatologists, and surgical technologists, are exposed annually to surgical smoke.[9]

Concern over surgical smoke is driven by its composition as it may contain several known health hazards, including chemicals such as hydrogen cyanide, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs – such as benzene, toluene, formaldehyde, etc.), pathogens (viruses and bacteria), and particulate matter.[1] However, the exposure to any of these health hazards may differ by specialty and profession, in terms of the type of surgeries they perform, as well as what role an individual has in the operating room. Additionally, exposure levels differ among staff members depending on where they stand during surgical procedures and the length of working hours. Coupled with the heterogeneity in the study methods used to assess risk and different types of surgery, it remains a challenge to obtain an accurate picture of exposure to surgical smoke to operating staff during procedures. While there have been a predominance of nonhuman studies assessing negative impacts of surgical smoke, human studies have yet to show a direct causal link between surgical smoke exposure and poor health outcomes besides acute irritative symptoms such as headache, eye irritation and watering, and throat irritation and cough.[3,4]

Studies assessing operating staff exposure to various chemicals in surgical smoke illustrate these multiple challenges. For example, there are concerns that surgical smoke contains VOCs such as benzene and formaldehyde, but studies conducted by the National Institute of Occupational Safety and Health (NIOSH) where they sampled surgical theaters found few VOCs. Even when detected, they were at levels below OSHA and NIOSH recommended exposure limit levels.[10] Another study has noted that VOCs were found to be higher during open surgery versus laparoscopic surgery.[3]

Nonetheless, due to the varied components in surgical smoke, there are several different biological mechanisms and pathways impacting health. Potential health impacts from surgical plumes are categorized into four main groups and are summarized below.

Respiratory impacts

There is a potential for ultrafine particles (particles 0.1μm in size) in surgical smoke plumes that can penetrate and be deposited deep in the lungs.[10] Known health impacts of particulate matter

(PM) exposure include cardiovascular effects, including heart attacks, heart failure, and strokes, as well as respiratory effects, including asthma attacks and increased respiratory symptoms such as coughing, wheezing, and shortness of breath.[5] Data from the U.S. Nurses' Health Study, an ongoing prospective cohort that started in 1976 with biennial surveys, have shown that operating room (OR) nurses have a higher risk of chronic obstructive pulmonary disease compared to nurses in administrative positions, but they were equivalent to those working in the emergency department or within in-patient hospital units.[11] From this same study, OR nurses were also found to have lower incidence of asthma compared to those working in administrative positions.[12] On the other hand, other studies have noted OR staff have an increased risk of respiratory diseases, such as sinus problems, allergies, asthma, and bronchitis, compared to the general population.[13]

For PM, direct measurement of smoke in 100 laparoscopic surgeries found unhealthy concentrations of PM 2.5 but the measurement duration was not reported, which restricts comparisons with established standards that are used for other occupational settings or the U.S. Clean Air Act.[3] Multiple studies have found widely variable concentrations of PM levels, some over known Environmental Protection Agency (EPA) limits, others comparable to daily office exposure or lower than outdoor urban or rural environments, and still others found very brief but extremely high peaks in concentrations.[3,14] Another limitation that could explain wide variations in findings on PM levels is that studies examining surgical plumes for ultrafine particles have used devices that are unable to discern between water vapor and PM, a significant design flaw as living tissue has a high-water content.[10] As a whole, these data make it difficult to conclude whether surgical smoke contains levels of PM of concern for OR personnel.

Cancer risk

Several of the compounds found in surgical smoke are known carcinogens, notably benzene, 1,2-dichloroethane, and polycyclic aromatic hydrocarbons (PAHs).[15] In one study, the concentration of PAHs from 10 mastectomies were investigated to estimate cancer risk to surgical staff. Looking at the PAH concentrations within the breathing zones of surgical staff, the study authors found the concentrations to be 20 to 30 times higher than those in regular outdoor environments and thus their cancer risk was significantly higher than the benchmark set by EPA.[16] To note, even though measured PAH concentrations were higher by the surgeon, the anesthetic technologists had a higher cancer risk due to their longer working hours in operation rooms.[16] While the increased cancer risk may be greater than the general population, assessed exposure levels have varied from study to study, with some noting higher concentrations while others have noted they are within acceptable limits.[3] Due to the PM and carcinogenic compounds within surgical smoke, an increased risk of lung cancer is a concern among surgical personnel in the literature. Several studies have aimed to compare the carcinogenic risk of surgical smoke to smoking cigarettes, with comparisons ranging from exposure similar to smoking six cigarettes to inhaling the secondhand smoke of 27 to 30 unfiltered cigarettes a day.[17,18]

The first study on this was published in 1981. Utilizing electrosurgery tools on a canine tongue, smoke condensates was collected in a closed box system to assess the mutagenicity of the smoke using the Ames test (a well-established assay to evaluate the mutagenicity of agents) and found that the smoke from one gram of tissue was equivalent to those from three to six cigarettes in terms of total mutagenicity.[17] More recently, a study by plastic surgeons assessed ablated human and porcine tissue to determine how much tissue was destroyed over five minutes and then reviewed the total electrosurgery time in their operating room over a 44 day period to determine a daily average level of exposure. Using the one gram of tissue equivalency to six cigarettes assumption from the 1981 study, it was concluded that daily electrosurgery produced the equivalent of secondhand smoke of 27-30 unfiltered cigarettes.[18] Although these figures are often cited in the

literature to demonstrate the hazards of surgical smoke, several researchers have called these findings into question. They argue that the methods used in the original 1981 study were limited in that the mutagenicity test was based on smoke produced in a close-system smoke chamber, which is not reflective of the surgical theater environment and exposure, and thus the concluded equivalency is faulty and misleading.[3,10,19]

Importantly, there is no evidence demonstrating that exposure to surgical smoke increases the risk of lung cancer. On the contrary, the Nurse's Health Study cohort, which focused on 87,000 nurses with and without operating room experience in 1984, showed no increase in lung cancer incidence at follow-up nearly 15 years later. In fact, the nurses with the longest operating room experience had significantly less incidence of lung cancer on follow-up, even after controlling for cigarette smoking history.[3]

Infectious diseases

Another concern with surgical smoke is the presence of viral fragments within the plume with some evidence demonstrating RNA or DNA fragments of SARS-CoV-2, human papillomavirus (HPV), hepatitis B, and human immunodeficiency virus (HIV) in surgical smoke.[20] Concern over HPV exposure in surgical smoke has been raised more frequently due to the common use of energy-generating devices in LEEP and anal wart ablative surgeries. While HPV particles have been detected in surgical smoke and inhalation of these particles into the upper airways has been detected, the evidence for transmission is more controversial.[21] The evidence of HPV-related disease in operation room staff following exposure to HPV is largely based on retrospective and survey data, which did not verify findings through confirmatory testing, and a small number of case studies (n = 4).[6] Increased prevalence of HPV infection or HPV-related disease in operating room staff following occupational exposure to surgical smoke has not been convincingly demonstrated.[6]

For example, HPV DNA was detected in nasal epithelial cells of surgeons performing ablative surgery on HPV+ patients much more frequently than surgeons who do not conduct these types of operations. However, with a notable loss of follow-up, all became negative at two years.[21] The highest level of evidence and most cited studies have been case reports of laser surgeons diagnosed with HPV+ laryngeal papillomatosis (n = 1) and tonsillar cancer (n = 2), as well as an operating room nurse with papillomatosis who was frequently exposed to ablative excision of anogenital warts.[3] Another more recent study assessed HPV prevalence among operating room staff using post-surgery nasal swabs to detect whether HPV was present and in greater than 98 percent of samples, no HPV was present. The operating team had used a smoke evacuator system, and an overwhelming majority wore surgical masks, versus N95 masks. In the less than two percent of staff where HPV DNA was detected in nasal swabs, no HPV related disease was detected after 3-6 months of follow-up.[6] Researchers have noted that despite the limited evidence for HPV-related disease risk from surgical smoke, for cases where HPV lesions are to be cauterized, the use of smoke evacuators and/or N95 masks are reasonable precautionary measures.[10]

During the COVID-19 pandemic, concern over the transmissibility of human coronavirus during surgical procedures was also raised. A 2021 study evaluating the existence and infectivity of human coronavirus RNA in surgical smoke found that while viral RNA was present in the smoke, it was not demonstrated to be infectious and the study authors found that surgical masks were able to effectively reduce the amount of viral RNA by at least 99.8 percent.[20] Lastly, there have been no case reports of suspected transmission of HIV or viral hepatitis via surgical smoke.[10] Evidence for concern is solely based on existence of DNA fragments in surgical smoke.

Reproductive outcomes

Female surgeons have been shown to have higher rate of adverse pregnancy outcomes and infertility compared to the general population, but there have been no studies evaluating the direct effects of exposure of surgical smoke on reproductive outcomes.[7] However, other studies have demonstrated negative reproductive health outcomes from various components found in surgical smoke. For example, PM exposure has been linked to low birth weight and preterm labor. Toluene has been associated with cognitive impairment, congenital defects and infertility while benzene has been linked to an increased risk of childhood leukemia. Lastly, 1,2-Dichlorethane is associated with an increased risk of spontaneous abortion and infertility (but in animal studies only).[7] These are just a few of the 45 different chemicals that have been identified in surgical smoke. More research is needed to better understand whether OR exposure to surgical smoke could be related to negative reproductive health outcomes.

Known prevention strategies, evidence of effectiveness, and barriers to implementation

The issue of clinician exposure to surgical smoke was brought to the attention of the OSHA, the primary federal agency responsible for developing protective standards related to health care occupations, nearly 35 years ago but regulations were never formulated on the topic.[22,23] Despite the lack of a federal regulatory standard, OSHA, NIOSH, the American National Standards Institute, ECRI, and the Association of periOperative Registered Nurses (AORN) have developed recommendations on minimizing exposure to surgical smoke in the operating environment.[24–27] AORN has a Go Clear program, a comprehensive surgical smoke-free recognition program for facilities who want to ensure a smoke-free environment.[25] Across guidance documents, the most recommended preventive measure to limit exposure to surgical smoke in the operating rooms is utilizing smoke evacuation equipment to remove smoke near the surgical site where smoke is generated.[28] An operating room smoke evacuation system is designed to capture surgical smoke and includes a capture device (either free standing or fitted over an electrosurgical tool), a vacuum system, and some type of filtration unit capable of capturing contaminants.[1,29] Illustrative examples are provided at the end of this report.

Wearing personal protective equipment (PPE), including standard surgical masks or even N95 respirators and masks containing activated carbon have also been recommended. PPE can provide some level of protection but is not protective against all possible particles contained in surgical smoke, particularly particles less than 0.3 μm (the functional limit of N95 masks).[24] Additionally, having appropriate ventilation in the operation room to avoid any lingering presence of smoke in the operating environment is also recommended.[9] However, NIOSH determined that the Centers for Disease Control and Prevention's (CDC) recommended air exchanges per hour is insufficient on its own for adequate surgical smoke evacuation.[7] Furthermore, in outpatient surgical settings there may be little to no ventilation in comparison to operating rooms, which are required to adhere to specific ventilation requirements.[24] From outside the U.S., the British Association of Dermatologists has called for smoke extractors to be made available in all settings where dermatology surgery takes places and further occupational health research on potential health risks from surgical plumes be conducted.[30]

Due to concerns of increased risk HPV infection and resulting oropharyngeal cancer in health care personnel, HPV vaccination of health care staff exposed to HPV through surgical smoke has been raised as a potential preventative strategy.[31] In the U.S., the American Society for Colposcopy and Cervical Pathology (ACSSP) has recommended the HPV vaccine for individuals working in

gynecology routinely exposed to HPV.[32] However, the American College of Obstetricians and Gynecologists and CDC's Advisory Committee on Immunization Practices do not currently have similar recommendations for health care personnel to receive the HPV vaccine.[33,34] The AMA has sent a letter to the CDC asking them to review the available evidence for recommending the HPV vaccine for health care professionals to prevent health care related infection of HPV.

While implementing smoke evacuation systems is understood to be the most effective strategy for reducing surgical smoke exposure, their use is limited and inconsistent, with one study finding that only about 10 percent of surgeons consistently use them.[35] A number of barriers to implement effective preventive strategies, both at the individual and organizational level, have been identified.[36] At the individual level, barriers to usage include surgeon resistance, impaired surgical view, excessive noise, and lack of education.[7] To illustrate the lack of education among surgical staff, in a 2016 survey of dermatologist residents, nearly 72 percent had not received any education on the potential hazards of electrosurgery smoke during their medical training.[37] In terms of excessive noise, a 2021 study assessed the noise associated with 11 identified surgical smoke evacuators used during dermatologic surgery and found none of them had sound levels greater than the permissible upper limit as recommended by OSHA, and therefore would not be considered an occupational hazard based on a 8-hour exposure.[38]

Even if smoke evacuator noises do not exceed OSHA standards, operating team members may subjectively still find the noise excessive, a distraction, or an annoyance. Perceived excessive noise in the operation room can increase risk for error, by making it difficult to hear critical information or communicate effectively, and thus presents an unsafe environment the patient.[39] However, as the smoke evacuator would only need to be operational during the period in which smoke is being produced by electrosurgery tools, it could be assumed the noise would not be a constant and therefore minimally distracting.

At the organizational or hospital level, barriers include a lack of resources, associated costs with purchases smoke evacuation systems, and insufficient or nonexistent internal policies on the matter.[40] Improving awareness among health care staff around the potential harms of surgical smoke and the protective measures designed to minimize personal harm among health care workers could help improve personal and organizational uptake of appropriate preventive measures.

Legislation

As there is no federal standard or regulation around surgical smoke, some states have passed policy to require surgical smoke evacuation systems. Rhode Island was the first state to pass such a policy in 2018.[24] Based on a review of state laws in the summer of 2024, 18 states have passed surgical smoke legislation. In terms of countries that have passed legislation on this topic, Denmark was the first and remains one of the only countries in the world to pass national legislation requiring employers to install evacuation systems that remove smoke and other harmful substances as close as possible to the source in surgical theaters.[41] To date, there are no evaluation or implementation studies that have assessed the effectiveness or impacts of these state laws on reducing surgical smoke exposure.

AMA POLICY

Existing AMA policy does not address surgical smoke directly but supports the development of regulations to protect workers from occupational carcinogens using the best available scientific data and the protection of medical trainees from potential hazardous exposures.[42]

CONCLUSIONS

While more research is needed to better understand the potential health impacts associated with surgical smoke, there is currently no known safe level. In taking a public health precautionary principal approach, it is reasonable to take preventive measures even if health hazards are uncertain. There are several preventive measures that are recommended by multiple organizations and can be employed to reduce risk to personnel, which include the use of smoke evacuation equipment, having appropriate ventilation, and wearing appropriate PPE, which may include surgical masks or even N95 respirators. Additionally, increased education on the potential health risks of surgical smoke among health care personnel is needed, as many have not received any sort of training or education on the subject.

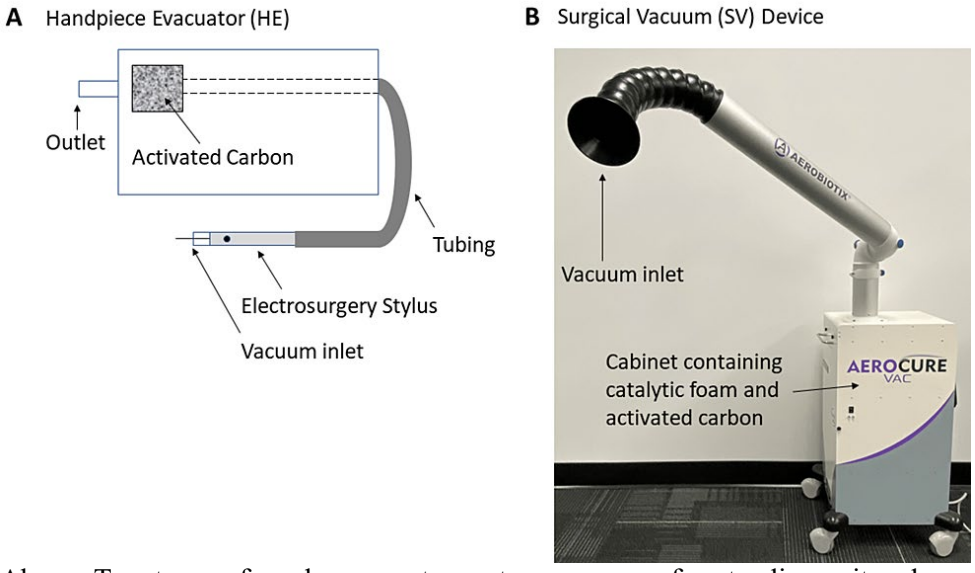
RECOMMENDATIONS

The Council on Science and Public Health recommends that the following be adopted, and the remainder of the report be filed.

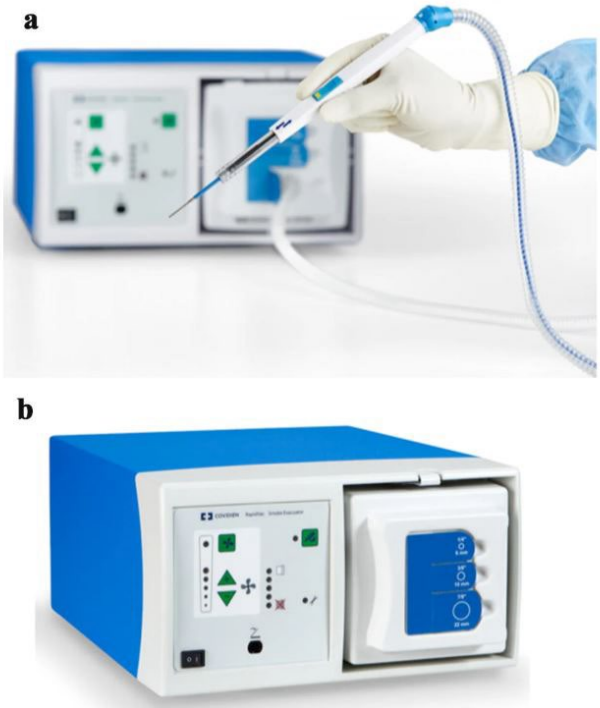
That our American Medical Association:
(1) supports efforts to limit surgical smoke exposure ~~in operating rooms~~, including where exposure to infectious diseases ~~such as human papillomavirus~~ may occur, using various methods such as smoke evacuators, appropriate ventilation, and/or appropriate personal protective equipment;
(2) recommends education on surgical smoke among medical students and health care professionals ~~that work and/or train in operating rooms~~ to improve awareness of the potential dangers of surgical smoke and preventive measures that can be taken; and
(3) encourages ongoing monitoring, data collection, and longitudinal research into the health impacts of surgical smoke to better inform understanding of potential health risks and evidence-based interventions to reduce risk. (New HOD Policy)

Fiscal Note: less than $1,000

APPENDIX: Examples of Smoke Evacuation Systems. TO NOTE: The AMA does not endorse any specific smoke evacuation device or manufacturer. These are only included as illustrative of different types of systems.



Above: Two types of smoke evacuator systems, one as a freestanding unit and one with the vacuum inlet over the electrosurgery tool.[43]



Smoke evacuation device showing (a) electrosurgical pencil containing capture system surrounding protruding electrode connected to (b) vacuum-driven smoke evacuator with replaceable ULPA filtration unit. ©2020 Medtronic. All rights reserved. Used with permission of Medtronic

Above: Example of a smoke evacuation device with an electrosurgical pencil containing capture system.[1]

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