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Clearing the Smoke: The Evidence behind Risk of Electrocautery Smoke and Mitigation Strategies

Madison Rose Tyle, MS*
Amra Olafson, MD*
Matthew E. Hiro, MD*†
Wyatt G. Payne, MD*†

Background: Electrocautery has been a useful, fundamental instrument utilized for surgical procedures since its implementation in the 1920s. However, concerns exist regarding the health hazards of the by-product smoke associated with the use of electrocautery.

Methods: A comprehensive review of articles on the composition, mitigation, and effects of smoke was conducted using the PubMed search engine and excluding articles that did not meet the predetermined inclusion criteria. From January 1963 to December 2021, a total of 264 articles resulted, and a total of 69 articles were included in this narrative review.

Results: Surgical smoke contains volatile organic compounds, polycyclic aromatic compounds, viral particles, and ultrafine particles. There has been some evidence of mutagenicity to bacterial cells during animal in vivo studies, and one human survey study has shown similar mutagenic effects. We also discuss additional hemostatic techniques that can be used, including the use of hemostatic and antithrombolytic agents, epinephrine infiltration, and the use of tourniquet when appropriate.

Conclusions: Further studies should be conducted regarding human effects, but until the data are available, we recommend precautionary measures and actions to protect operating room staff from cautery smoke exposure. *(Plast Reconstr Surg Glob Open 2024; 12:e6039; doi: 10.1097/GOX.0000000000006039; Published online 13 August 2024.)*

INTRODUCTION

The use of cautery for surgical procedures dates back thousands of years, as the ancient Egyptians utilized a mixture of local poultices, excision, and cautery for tumor treatment in 3000 BCE (before the common era).[1] Other instances of cautery in medicine were described by Hippocrates dating back to 450–340 BCE.[2] Refinements led to ongoing developments throughout history into the early 20th century. Dr. William T. Bovie, a biophysicist, created electrosurgical circuitry that delivered high-frequency electric currents to minimize blood loss, decrease the likelihood of infection, and cause the least amount of tissue damage during surgical procedures.[3] Dr. Bovie was able to catch the attention of Dr. Harvey Cushing, a noted neurosurgeon who was searching for better methods of obtaining hemostasis during surgical procedures. Together, Drs. Bovie and Cushing successfully demonstrated the effectiveness of this novel device with improved hemostasis after successful brain tumor excision on October 1, 1926.[3]

Electrosurgery is the process by which a probe conducts an electrical current into tissue to generate heat. The electrode tip utilized in electrosurgery, contrary to popular belief, is cold. The contact between the human tissue and the cold electrode tip creates resistance for current passing through, converting electrical energy to thermal energy, thus heating the tissue.[4] Electrocautery can be classified as monopolar or bipolar in configuration. Monopolar electrocautery allows current from the electrode tip to travel through the patient's body to a dispersive grounding pad, where the current is sent back to the generator, completing a full circuit loop. In monopolar electrocautery, the heat produced is at its maximum at the site of entry and decreases with distance from the generator. Due to the grounding requirement, monopolar

*From the *Department of Plastic Surgery, University of South Florida College of Medicine, Tampa, Fla.; and †Department of Plastic Surgery, Bay Pines VA Healthcare System, Plastic Surgery Section, Bay Pines, Fla.*

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electrocautery has an increased risk of burns and damage to other conductive implantable medical devices or contact metal points. With bipolar electrocautery, a dispersing pad is not required because the electric circuit is closed by the two close probes of the handpiece. Aside from the configurations, there are also two predominant settings for electrocautery—cutting and coagulation. The cutting setting is achieved by a continuous sine wave form with a low voltage. These settings allow for rapid electrosection and little tissue damage, but they are poor for coagulation. The coagulation setting is achieved by a pulsatile wave form with a high initial voltage that returns to zero after each burst. This setting quickly congeals vasculature, allowing for rapid control of blood loss. Regardless of setting, the heat delivered to the tissue via the electrical current will produce smoke byproducts.[4]

Despite the widespread use of electrocautery in surgical practices and procedures, the generated smoke has brought about questions on the dangers for healthcare personnel. Early studies have compared the amount of smoke with cigarettes with similar mutagenicity.[5–7] With this review and report of the literature, we discuss the composition and possible toxic, adverse effects of electrosurgical smoke plumes. Mitigation strategies are also discussed, along with guidelines and policies by regulating and advisory entities on this topic.

METHODS

A search using the criteria (electrocautery OR bovie OR diathermy) AND (smoke plume OR smoke) was conducted to include articles published between January 1963 and December 2021 utilizing the PubMed search engine. A total of 264 articles resulted, and a total of 69 articles were included in this review. We focused our review on the composition of smoke, health effects, and mitigation plans. Review articles were excluded, as well as irrelevant articles and one article without an English translation. Irrelevant articles included electrocautery effectiveness as a surgical tool, cigarette smoking risk, and various articles on bony healing. Three articles on smoke suction were also excluded due to unavailability of abstract or full article. The review of the literature and exclusion of articles was performed by two members of the research team, and no automation tools were used in the process. Additionally, we examined current safety guidelines regarding operating room smoke exposure set by regulatory boards via searches of the Food and Drug Administration and Occupation Safety and Health Administration (OSHA) websites. Finally, we included a brief discussion on adjunctive operating room strategies to minimize electrocautery use.

RESULTS

Results of Bovie smoke contents and possible effects, if applicable, are included in Supplemental Digital Content 1. (**See table, Supplemental Digital Content 1**, which displays a compilation of the references used in this review with relevant findings. **http://links.lww.com/PRSGO/D409**.)

Takeaways

Question: What are the effects of surgical smoke exposure in the operating room, and how can we mitigate them?

Findings: A literature review was conducted, and 69 articles were reviewed. Surgical smoke contains volatile organic compounds, polycyclic aromatic compounds, viral particles, and ultrafine particles. Alternative hemostatic techniques can be used, such as use of hemostatic and antithrombolytic agents, epinephrine infiltration, and the use of tourniquet when appropriate.

Meaning: Surgical smoke exposure can have negative health effects on operating room personnel, but smoke evacuation and alternative hemostatic techniques are available to mitigate exposure.

Selected studies from the table have been further discussed later, in addition to regulatory board stances. Forty-one of the listed studies were basic science studies, 21 were cross sectional studies, four were animal studies, two were surveys, and one was a prospective cohort study.

Composition of Surgical Smoke

Supplemental Digital Content 2 lists the volatile organic compounds, viruses, and bacteria isolated from surgical smoke. (**See table, Supplemental Digital Content 2**, which displays a list of chemical compounds identified in smoke plumes from included review articles. **http://links.lww.com/PRSGO/D410**.) Of those listed, the bolded and italicized are categorized as likely to be known carcinogenic entities per the American Cancer Society.[8] Air sample capture during breast surgery detected 23 volatile organic compounds, including methanol, acetone, isopropyl benzene, toluene, and propane, with significantly higher samples in mammary glands when compared with subcutaneous, breast adipose, and breast tumor tissues.[9] Hill et al[5] measured the average amount of diathermy in a 2-month period in a plastic surgery operating room, with findings of smoke plume amount equivalent to 27–30 cigarettes daily. The same group surveyed plastic surgery practices for use of smoke extractors, with only 66% of practices reporting availability of dedicated smoke evacuators.[5] A study measuring smoke production during reduction mammoplasty revealed eleven different gases, with furfural, a skin, mucous membrane, and respiratory irritant, exceeding the recommended occupational limit severalfold.[10] Similarly, surgeon exposure during abdominoplasty showed the highest ultrafine particle exposure rates when compared with various procedures in orthopedic, other plastic and urologic surgical specialties.[11]

Pathologic Effects of Surgical Smoke

The first study to demonstrate the risk of surgical smoke was performed in 1981.[7] In this canine study, researchers found that surgical smoke in a closed box environment was as mutagenic as cigarette smoke.[7] Gatti et al[12] performed a similar mutagenicity analysis of smoke in reduction mammaplasty. They found that the smoke particles were mutagenic to one of two bacterial strains.[12]

Table 1. Regulations on Electrocautery Smoke Exposure

Governing Body	Guidelines/Recommendations
OSHA	Does not currently have specific standards for laser and electrosurgery smoke plume
NIOSH	Surgical smoke evacuation should be on whenever airborne smoke particles are being produced; however, there are no consequences for not following this recommendation.
Joint Commission	The implementation of surgical smoke evacuation procedures, standard precautions, a consistent review of policies for surgical smoke safety practices, continual education on surgical smoke safety, and periodic trainings for proper evacuation and precautions should be done. These are all recommendations with no consequence for noncompliance.
Association of Perioperative Registered Nurses	LEV systems are sufficient for proper protection of operating room personnel, and the recommendation is that the suction apparatus should be installed no further than 2 inches from the smoke-generating source. However, there are no consequences for not following these recommendations.

Rats exposed to cautery show increased histopathological laryngeal mucosa inflammation compared with nonexposed rats.[13] Stewart et al[14] evaluated the effect of operation-generated particulate matter on cultured human small airway epithelial cells. In their comparison to cigarette smoke and office environment air, corresponding samples from the operating room environment showed less significant DNA damage.[14] Gates et al[15] explored whether operating room nurses had increased lung cancer rates and found no significant lung cancer association.

Mitigation

Surgical masks were initially designed to prevent sterile field contamination and not to prevent inhalation of smoke particles.[16] Mask efficiency can be categorized in terms of protection from a range of particle sizes. Particles between 10 and 50 µm are considered intermediate droplets, whereas particles less than 10 µm are categorized as aerosol forming droplets, which can be inhaled. A surgical mask is also designed to provide a physical barrier from fluids, but respirator masks are designed to prevent aerosol inhalation, with 12–16 times the protection of surgical masks.[17] N95 masks are designed to filter 95% of 0.3-µm particles.[17] Several studies have reviewed and elucidated the efficacy of masks in mitigating exposure to chemicals identified in surgical smoke.[18–20] Surgical masks have failed to demonstrate consistent protection from surgical smoke in multiple studies, whereas N95 respirators have demonstrated an increase in inhalation protection.[19,20] Surgical masks have been shown to inhibit the passage of bacteria and viruses contained in surgical smoke.[21,22]

Cautery pencils connected to suction and assistant-held Yankauer suction have demonstrated lower exposure rates when compared with nonevacuation groups.[23] O'Brien et al[24] did not find a significant difference in exposure when comparing the smoke evacuation cautery pencil to assistant-held Yankauer suction. Stewart et al[14] found that a pencil evacuator was superior to assistant-held suction. Local exhaust ventilation (LEV) systems have been shown to reduce the airborne particles and volatile organic compounds. These systems are composed of motorized suction systems with included air filters that connect to a hose that is placed near the site of smoke.[25,26]

Regulations

We also reviewed the current guidelines and recommendations by regulatory boards, such as the Joint Commission, OSHA, National Institute of Occupational Safety and Health (NIOSH), and Association of Perioperative Registered Nurses (Table 1). These regulatory boards describe the importance of using smoke evacuation techniques, such as LEV systems and suction, as well as the need for a periodic review of policies and consistent staff training on the matter; however, these recommendations are only encouraged, not required.[27]

The Joint Commission released an advisory in December 2020 that provides a summative review of the current guidelines surrounding surgical smoke exposure and evacuation.[28] Through a cross-reference of this advisory and governing bodies' websites, the current regulations and recommendations are thoroughly described. OSHA does not currently provide or reinforce specific standards that regulate surgical smoke in the operating room.[28,29] NIOSH recommends the use of LEV and room wall suction systems, along with employee training on the harmful effects of surgical smoke exposure and the importance of N95 usage.[30] The Association of Perioperative Registered Nurses, like the NIOSH, openly supports initiatives for surgical smoke evacuation in the operating room.[28] Considering these recommendations, it is evident that surgical smoke evacuation is becoming a more commonly recognized hazard.

DISCUSSION

Although prior studies have demonstrated multiple hazardous chemicals in cautery smoke, the evidence of negative human health effects is not completely clear at this time. One nursing survey study did not demonstrate increased lung cancer risk.[15] Even data that demonstrate a mutagenic risk with smoke exposure have several limitations. For example, the Tomita et al[7] and Gatti et al[12] studies on the mutagenic effect of smoke are questioned regarding their lack of accounting for increased distance of respiratory zone and ventilation effects, as they were performed in a closed box environment. Additionally, those studies that demonstrate the positive mutagenicity effects were performed on bacterial cell lines, and they did not show similar mutagenic effects on animal DNA.[7,12,14] Another study questioned if the chemicals in smoke are actually due to harmful aerosolization of cleaning agents.[14]

Although there is a lack of clarity in some of the literature with regard to the toxic human health effects of electrocautery smoke, there is reliable literature

demonstrating toxicity or mutagenicity that should be heavily weighed. The risk of hazardous cell or particle exposure after electrocautery has been reported in the context of viral, such as human papillomavirus (HPV) or human immunodeficiency virus, or bacterial release. Eight patients with plantar warts were exposed to both CO_2 laser and electrocoagulation as a removal method for their growth to determine the presence of viral particles in plumes produced from each of these modalities.[22] The vapor from each was assayed for infectious bovine papillomavirus. HPV DNA was detected in 57% of the samples.[22] Other case reports have also shown HPV inoculation in surgeons or other operating room personnel after exposure and inhalation of surgical smoke.[31,32] Bacterial transmission in electrocautery smoke plumes has also been demonstrated via surgical simulations with porcine spinal tissues.[21] Twenty pieces of porcine spinal tissues underwent surgical operation with electrocautery exposure to room temperature air for propagation of bacterial growth. Nineteen (95%) of the 20 smoke swabs tested positive for bacterial growth.[21] These studies thoroughly demonstrate the ability of cancerous, viral, and bacterial cells to be transmitted via surgical smoke plumes during surgery, creating the potential for inhalation and infection of operating room personnel.

More data are required to better understand the risk associated with surgical smoke exposure. Due to the effectiveness of electrocautery, smoke evacuation, suction, and N95 masks, these are likely the best mitigation strategies to reduce potential toxic human health effects. Although these mitigation strategies prove to be the best current option, until further study is done on the long-term health effects of electrocautery smoke exposure, limiting the use of electrocautery can decrease smoke production and protect health personnel. Several studies, as discussed later, have examined surgical outcomes excluding the use of electrocautery without an increase in negative outcomes.

Other Mitigation Strategies

Alternative to electrocautery use, procedures can be performed by sharp dissection and/or with laser, such as Nd:YAG laser and CO_2 laser. One study found that sharp dissection showed superior outcomes of stronger wound healing and less drainage compared with other modalities.[33] In one prospective study of two abdominoplasty cohorts, one with cautery dissection and the other utilizing sharp dissection, there was no change in operative time, systemic complications, or hematoma incidence.[34] The sharp dissection group had a 54.5% reduction in total drain output and a 2.65 reduction in days to drain removal, without seroma or healing issues.[34] Conversely, in a study of bariatric post–weight loss patients undergoing abdominoplasty with cautery versus sharp dissection, the sharp dissection group had increased hematoma formation and increased wound infections rates.[35]

There are alternative operative techniques designed to decrease blood loss, which would necessitate less electrocautery use. The use of tumescence has been well described in plastic surgery to decrease blood loss. This technique involves creation of firm and tense tissue via local anesthetic injection combined with epinephrine and sodium bicarbonate.[36] The goal is to create a local anesthetic effect and vasoconstriction. This technique has been effectively used in abdominoplasty, gluteal augmentation, breast reduction, and facelift procedures.[36–41] A controlled study evaluated the maximum hemostatic effects of epinephrine and found that the maximum effects occur after 25 minutes.[42] Epinephrine should not be used in patients with hyperthyroidism, pheochromocytoma, or severe hypertension, and should be used cautiously in cardiac disease and peripheral vascular disease.[43,44] It should be mentioned that the classic teaching of epinephrine inducing vasocontraction to the level of ischemia and necrosis in fingers has not been supported by research. Tissue ischemia has been historically attributed to injection of expired acidic procaine into fingers.[45]

The use of hemostatic and antithrombolytic agents in surgery have been extensively described.[46–56] The use of tranexamic acid (TXA) in reduction of blood loss during surgery has been demonstrated to be safe and effective.[57–59] TXA is a synthetic lysine analogue that augments the clotting cascade by inhibiting the conversion of plasminogen to plasmin, preventing the degradation of fibrin.[60,61] It can be administered topically, orally, or intravenously.[46–51] Recent reports cite advantages of TXA's use in plastic surgical procedures, including rhinoplasty, microsurgery, rhytidectomy, liposuction, and breast reconstruction.[52–56,62–75] Indicated benefits include reduction of intraoperative and postoperative bleeding, reduced blood transfusion requirements, reduced postoperative edema and ecchymosis, and reduced hematoma risk.[52–56,62–75]

Other hemostasis-inducing topical agents are also routinely utilized. There are three broad categories: hemostatic agents, sealants, and adhesives. In the hemostatic category, there are further subcategories of mechanical, active, and flowable. Mechanical hemostatic agents include cellulose, bovine collagen, and porcine gelatin, such as Gelfoam; active hemostatic agents include various compositions of thrombin; and flowable hemostatic agents combine thrombin with a gelatin, such as Surgiflo.[76] They function best in the presence of blood, as they assist in clotting. The mechanical hemostatic agents provide a physical barrier to blood flow.[76] Active hemostatic agents work as thrombin derivatives.[76] Flowable hemostatic agents are the most efficacious, and they consist of lyophilized thrombin with a preparation of free-standing thrombin; this combination is then mixed with a stand-alone porcine gelatin matrix.[76] Sealants are accessible in fibrin composition and in synthetic form. They function by creating a barrier, and they are most effective without the presence of blood. Finally, adhesives include cyanoacrylate (Surgiseal), albumin, and glutaraldehyde. These work by sealing tissue together, functioning best without the presence of blood.[76,77] Adhesive hemostatic products include agents from various categories for a combined mechanism of action. Studies have shown a reliable, significant reduction in surgical site drainage and ecchymosis formation with their use.[77–85]

The simple concept of applying pressure is undervalued. One dermatologic study used patient-applied pressure for 5 minutes after biopsies and lesion excision, with 16 of 25 (64%) patients demonstrating no bleeding.[86] The effectiveness of attaining hemostasis by pressure alone is evidenced by its efficacy upon vascular access sites or after removal of central catheters. In the case of vascular access sites, the literature has shown time to hemostasis with a range of 10–30 minutes.[87–90]

Tourniquet use has also been reliably shown to reduce blood loss in burn surgery, without affecting skin graft take.[91–93] Successful tourniquet use has also been described in a panniculectomy case report.[94] The use of tourniquet in free flap harvest has been shown to reduce operative time by improving visualization.[95,96] These findings are consistent with results found during orthopedic procedures.[55,97,98] Tourniquet use is not without downsides in cases of peripheral vascular disease and should be utilized with caution alongside standard techniques of good hemorrhagic control.[99]

Inevitably, there are limitations to the conduction of this review. One limitation is a risk of bias, such as selection bias. When conducting a literature review, the articles selected for inclusion are ones that meet criteria originally set in place by the researchers. Our research team set in place the search constraints utilized for this review. In setting these constraints, we could have inadvertently caused selection bias, as our choice of search terms and date ranges are influenced by our personal beliefs, ideas, and career experiences. Additionally, publication bias is an important limitation to address when performing a systematic review.[100] Publication bias, or the tendency for studies with positive results to be overrepresented in the literature, is most common when a large number of studies have been published on a topic, such as surgical smoke.[100] Finally, the overall quality of research on the topic was low, with 41 of the listed studies being basic science studies, 21 cross sectional studies, four animal studies, two surveys, and one prospective cohort study.

CONCLUSIONS

Electrocautery is a useful tool in surgery and has been utilized effectively in hemostasis since its development. Its effect on human health is yet to be fully demonstrated. Standard precautions including local exhaust systems, smoke suction, and the use of N95 surgical masks can be used to limit exposure to surgical smoke. Additional studies on the dangers of electrocautery smoke exposure and inhalation are needed. Meanwhile, surgeons can use the adjuncts in reducing hematoma and/or improving visualization during surgery with tourniquet use, epinephrine injection, tumescent techniques, applied pressure, TXA, and topical hemostatic agents.

Madison Rose Tyle, BS
Department of Plastic Surgery
University of South Florida Morsani College of Medicine
560 Channelside Drive
Tampa, FL 33602
E-mail: mrtyle@usf.edu

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