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Review Article

Impact of Surgical Smoke on the Surgical Team and Operating Room Nurses and its Reduction Strategies: A Systematic Review

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Abstract

Background: Surgical smoke is an integral part of surgical operations that the surgical team has been exposed to for so long. This study aimed to investigate the effects of smoke, on members of the surgical team.

Methods: A systematic review was conducted focusing on the complexity of surgical smoke. PubMed, Scopus and web of science databases were searched until May 2020 without any time or language limitation. All documents were reviewed by title or abstract according to the search strategy. The screening process of articles was performed by two independent authors. The articles were selected according to the inclusion and exclusion criteria.

Results: Overall, 37 studies in this systematic study were investigated. The effects of many surgical smokes were found in a nutshell including complications such as carcinogenic, toxicity, mutation, irritant, transmission of tumor cells, virus transmission, headaches, dizziness, sleepiness, headache, the bad odor in head hair, the tearing of the eye on the surgical team and staff.

Conclusion: Surgical smoke, produced during surgical operations, is one of the risks and threats to which the surgical team and operating room staff are at risk then can affect the organs of different bodies from the body of all operating room staff and surgical team.

Keywords: Surgical smoke; Electrosurgery; Electrocautery; Ultrasonic scalpel

Introduction

Using tools such as electrocautery, laser and harmonic scalpel for cutting and tissue dissection and bleeding control used by coagulating small blood vessels (1). Diathermy is also used during surgery to manipulate tissues as well as control bleeding (2). When dissecting or burning tissue by heat-generating devices such as lasers, electrosurgery, ultrasonic devices and electrical devices, drills and saws are performed, some smoke produced, named surgical smoke, and among these devices, the most prevalent sources of production is electrocautery and lasers (3, 4) that commonly used by surgical team members.

Electrosurgery is commonly used in surgery for homeostasis during surgery (5) and it is mostly used in all operating rooms and people who work there, especially doctors and surgical technologists, are unprotected from surgical smoke (6).
Surgical smoke is one of the unavoidable products of surgical energy devices, which contains carcinogens and harmful substances and is a significant occupational hazard in the operating room (7) that is as mutagenic as cigarette smoke (4). Surgical smoke is a type of dangerous aerosol that is specific to the operating room and on the other hand, due to the position of personnel around the patient, surgical smoke is directly in their airway (8) and on the other hand, it has different stinking and dangerous contents (9). The smoke contains chemicals, blood and tissue particles, bacteria, and viruses; due to prolonged exposure to smoke, the smoke poses potential risks to surgeons, nurses, anesthesiologists, and the operating room. (10). Due to operating room nurses reported respiratory problems, including nasal congestion, increased cough, allergies, and sinus infections or problems (11). Nurses and physicians were exposed to surgical smoke from headaches, watery eyes, coughs, sore throats, nausea, bad breath, drowsiness, dizziness, sneezing, and rhinitis (6) and even this smoke carries many potential risks, such as direct physical injury, mutagenesis, and transmission of infectious diseases, especially HPV transmission, to the gynecological surgery team (10).
The purpose of this study was to interrogate the complications and effects of surgical smoke inhalation on the surgical team so that these complications can be used for awareness and prevention of the harms of surgical smoke. Since surgical smoke generators are widely used during surgeries and all members of the surgical team are exposed to the dangers of this smoke, we decided to examine systematically the effects of surgical smoke.

Methods

The PRISMA statement was used to expound the present report (12). PRISMA is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. PRISMA but can also be used as a basis for reporting systematic reviews of other types of research, particularly evaluations of interventions used to improve transparency in systematic reviews. These items cover all aspects of the manuscript, including title, abstract, introduction, methods, results, discussion, and funding.
The main question of study was raised: What are the complication of surgical smoke inhalation in surgical team members? The search was performed based on ("Surgical Smoke" OR "Surgical plume" cautery OR Electrosurgery) AND (complication OR risk OR hazard OR hazardous) keywords in PubMed, Scopus and web of science databases until May 2020 without any time or language limitation. The authors also reviewed the reference lists of qualified studies.
Authors screened titles and abstracts of all identified articles. All irrelevant, duplicate and non-original essays were excluded. According to the inclusion criteria, full text of the remaining articles was reviewed. All these actions were performed by 2 authors independently.

Ethics approval

Not applicable as this study did not involve direct human intervention. Code of Ethics: IR.UMSHA.REC.1399.552 (Hamadan University of Medical Sciences)

Results

The Fig.1 shows a process of searching and selecting articles. Totally, 2812 articles were found in 3 variant databases and its references during the prime searches. After the removal of duplicates by Endnote software, 1956 articles remained for reviewing title and abstract and 14 articles extracted from the study of references were added to them. By checking title and abstract, 1889 records were excluded and 82 records remained for screening by full text. In stage of deleting articles based on full text, 45 full texts were removed and 37 full-text articles, that had the necessary criteria for the systematic review, were reviewed which shown in

(Fig. 1). These studies were compiled from 1981 to 2020. Complications from the studies seen in Tables 1, 2 and 3 are divided into three categories: Complications related to toxicity, carcinogenicity and irritability; Complications related to Respiratory illness; Complications related to Microorganism transmission; Complications related to Mutagenicity 5_ Complications related to the head (Tables 1-5).

Moreover, the hazardous contents of surgical smoke that were identified in studies included in systematic review are summarized in Table 6 (3, 7, 9, 13-23).

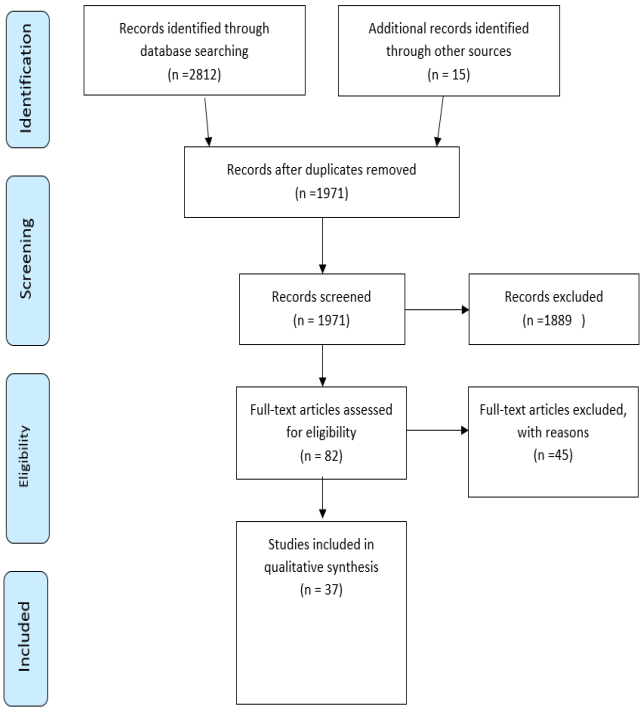

Fig. 1: Flow diagram of the study selection for the review process

Table 1: Complications related to toxicity, carcinogenicity and irritability

Author	*Type of surgery*	*Device*	*Article Findings*	*Main Complications*
Hensman, C (2)	In vitro	Electrosurgery	Surgical smoke generated contains various toxic chemicals.	Toxic
Al Sahaf, O. S. (23)	• Pilonidal sinus removal • Verruca extraction • Abdominal surgery	Electrosurgery	This paper identified of neurotoxic, toxic, carcinogenic compound in surgical smoke.	• Toxic • Neurotoxic • Carcinogenic • irritant
Choi, D. H. (14)	• Laparoscopic surgeries • Robotic surgery	• Laser • Electrosurgery	Surgical smoke contained many volatile organic Contents that the rates of benzene and toluene are very high.	Toxic
Choi, S. H. (15)	Transperitoneal laparoscopic nephrectomy	Electrocautery	The carcinogens, so as 1, 2-dichloroethane, benzene, and ethyl benzene, were recognized.	• Toxic • Carcinogenic
Choi, S. H. (38)	Transperitoneal laparoscopic nephrectomy	Electrocautery	Five of the 18 volatile organic Contents recognized were carcinogenic.	carcinogenic

Bratu, A. M. (13)	In vitro	CO2 laser	Effects of acetonitrile, acrolein, ammonia, benzene, ethylene, and toluene were identified in surgical smoke.	• Toxic • carcinogenic
Chung, Y. J. (16)	Transurethral resection of the prostate (TURP)	Electrocautery	Three of the toxic and carcinogenic compounds produced in Transurethral resection of the prostate and evaporation are carcinogens.	• Toxic • Carcinogenic
Dobrogowski, M. (17)	Laparoscopic cholecystectomy	Electrocautery	Many of surgical smoke compounds are toxic, Carcinogenic, and genotoxic.	• Toxic • Genotoxic • Carcinogenic
Hahn, K. Y. (7)	Rectal cancer resection	1_Electrocautery 2_Ultrasonically activating scalpel	Benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isovaleraldehyde, and valeraldehyde were detected in the surgical smoke.	Toxic
Kocher, G. J. (18)	In vitro	Electrocautery	Many toxic and carcinogenic fugacious organic contents consist 1,3-butadiene, benzene and furfural were found.	• Toxic • Carcinogenic
Krones, C. J. (20)	In vitro	• Electrocautery • Harmonic scalpel • Argon beaming	Surgical smoke produced from all instruments Contains toxic and carcinogenic components.	• Toxic • Carcinogenic
Sisler, J. D. (39)		Electrocautery	surgical smoke is toxic in vitro	Toxic
Lin, Yu-Wen (21)	Mammoplasty	Electrocautery	Toluene was detected in surgical smoke.	Toxic
Kokosa, John M (19)	In vitro	Laser	Compounds chemicals, containing benzene, formaldehyde and acrolein were in surgical smoke.	Toxic
Hyeong In Ha (9)	• Laparoscopic • Robotic	Electrocautery	Surgical smoke in gynecologic surgery contains dangerous hydrocarbons containing formaldehyde.	Toxic
Oganesyan, G (22)	Dermatologic surgery	Electrosurgery	Surgical smoke included carcinogenic compounds, so as benzene, butadiene, and acetonitrile.	Carcinogenic
Fitzgerald, J. E. F. (3)	Laparoscopic intraabdominal surgery	1_Electrocautery 2_ultrasonic scalpel	Benzene, ethylbenzene, styrene, toluene, heptane, and methylpropane were identified in surgical smoke that they are carcinogenic or irritant.	• Carcinogenic • irritant
Tseng, H. S. (40)	Mastectomy	Electrocautery	There is a risk of carcinogenicity for anesthetists payable to the longer working time in surgery rooms.	Carcinogenic
Hill, D. S. (4)	In vitro	Diathermy	Surgical smoke is mutagenic and carcinogens.	Carcinogenic

Table 2: Complications related to respiratory illness

Wenig, Barry L (41)	***In vitro***	***1_Nd:YAG Laser 2_Electrocautery***	***Analysis showed alveolar congestion and emphysematous changes***	• ***Alveolar congestion*** • ***Emphysematous changes***
Atar, Y. (42)	In vitro	Electrocautery	Surgical smoke causes tissue inflammation due to irritation.	• inflammation in the larynx
Ilce, A. (6)	Non applicated	Electrocautery	The problems due to surgical plume contained: headache, watering of the eyes, cough, sore throat, bad odor attracted in the hair, nausea, drowsiness, vertigo, sneeze and rhinitis	• Cough • Sore throat • Sneezing • Rhinitis
Sarkarizi, H. K. (26)	In vitro	Electrosurgery	study showed complications included vascular congestion, epithelial vacuolation, acute inflammation, and the presence of necrotic cells	Damage the nasal mucosa
Baggish, Michael S. (43)	In vitro	Laser	The compounds produced of the surgical smole was which constructed pneumonia, bronchiolitis, and emphysema.	• Pneumonia • Bronchiolitis • Emphysema
Navarro-Meza, María Cristina (44)	Not identified	Electrocautery	The sensation of a lump in the pharynx and a sore throat were due to surgical smoke Inhalation.	• lump in the throat • sore throat

Table 3: Complications related to microorganism transmission

McKinley, I. Blake (45)	***Dental surgery***	***Argon laser***	***The whole of the cultures was shown that E.coli growth on them.***	***Bacterial dissemination***
Capizzi, Peter J (29)	Aesthetic surgery	CO2 laser	The potential risk exists for health care workers to be exposed to viable bacteria during laser surgery.	Viable bacterial dissemination
Taravella, Michael J. (46)	In vitro	Excimer laser	The oral poliovirus can be alive during laser surgery.	Live virus dissemination (Oral polio virus human immunodeficiency virus)
Neumann, K. (24)	Gynecosurgery and Obstetrics	Electrosurgery	Four cases of surgical plume produced from LEEPs shown contamination with HPV.	live viruses (HPV) transmission
Zhou, Q. (47)	Gynecosurgery	Electrocautery	HPV deoxyribonucleic acid was showed in LEEP-induced surgical smoke and the risk of HPV DNA transmission during surgery.	HPV DNA transmission
Garden, Jerome M (27)	In vitro	Laser	Accumulated laser plume included papillomavirus deoxyribonucleic acid in the whole of cases.	HPV DNA transmission
Sawchuk, William S (28)	Gynecosurgery	1_Laser 2_Electrocoatery	Laser and electrocautery smoke contained papillomavirus DNA.	HPV DNA transmission
Fletcher, J. N. (48)	In vitro	Electrocautery	Melanoma cells were present alive in a culture medium	Melanoma cells releases in plume
In, S. M. (49)	In vitro and in vivo	Electrocautery adiofrequency ablation Ultrasonic scalpels	Ultrasonic scalpel smoke contained live tumor cells	Viable tumor cells in plume
Han Deok Kwak (25)	Laparoscopic or robotic abdominal surgeries	Laparoscopic surgery(Electrocautery)	Hepatitis B virus was identified in the surgical smoke.	Hepatitis B virus (HBV) transmission

Table 4: Complications related to Mutagenicity

Dobrogowski, M. (17)	***Laparoscopic cholecystectomy***	***Electrocautery***	***Many of surgical smoke compound are Mutagenic.***	***Mutagenic***
Hill, D. S. (4)	In vitro	Diathermy	Surgical smoke is mutagenic and carcinogens.	Mutagenic
Yoshifumi, Tomita (50)	In vitro	1_ CO2-laser 2_ Electrocautery	Smoky condensate produced from the mucous membrane of the dog's tongue under CO2 laser irradiation showed mutagenicity.	Mutagenic
Gatti, John E (51)	Mammoplasty	Electrocautery	Surgical smoke contained mutagenic compounds that produced in during reduction mammoplasty.	Mutagenic

Table 5: Complications related to Related to the head

Hyeong In Ha (9)	• ***Laparoscopic*** • ***Robotic***	***Electrocautery***	***Volatile organic compounds and aldehydes had unsightly odours.***	***Unpleasant odors***
Ilce, A. (6)	Non applicated	Electrocautery	The problems due to surgical smoke contained: headache, watering of the eyes, cough, sore throat, bad odor attracted in the hair, nausea, drowsiness, vertigo, sneeze and rhinitis	• Headache • Watering of the eyes • Bad odours absorbed in the hair • Nausea • Drowsiness • Dizziness

Table 6: Components discovered in surgical smoke

Pentadecane	***Benzene***	***Ethylbenzene***	***Styrene***	***Heptane***	***Toluene***
Propionaldehyde	Isobutylene	Allene	Propylene	Dioxins	Aldehydes
Valeraldehyde	Acrylamide	Acrolein	Acetonitrile	Isovaleraldehyde	Furfural
Methylpropene	Propylene	valeraldehyde	Acetaldehyde	Formaldehyde	Xylene
1, 3-Methylpropene	Tetradecene	Undecene	Undecane	Tetradecane	Tridecane
Ethylene	n-propylbenzene	Nonanal	Decane	Perchloroethylene	Heptanal
Acetone	Cyclohexanone	Decene	Dodecane	Dodecene	acrylnitrile
n-hexadecane	o-xylene	n-decane	n-nonane	p-xylene	n-tetradecane
n-tridecane	n-heptane	Hexane	2-butanone	n-undecane	Ammonia
1,2-dichloroethane	Ethanol	propenylacetylene	cyclopentadiene	butyrolactone	1,4-pentadiene
Piperylene	1-pentene	vinyl acetylene	diacetylene	ethyl acetylene	EtOH
Mecaptomethane	Butyraldehyde	Butadiene	1,3-butadiene	Ozone	dioxins

Studies on carcinogenicity, toxicity and irritability included 19 studies and studies on respiratory complications including 6 studies and 10 studies on microorganism transmission complications, 4 studies on mutagenicity complications and 2 studies on complications related to the head.

Discussion

Complications related to the effects of surgical smoke from electrosurgery and electrocautery on the surgical team

Exposure to surgical smoke from these devices can have side effects that affect different organs and parts of the surgical team. In this case, several fugacious or carcinogenic fugacious organic compounds were found including butadiene, benzene and furfural in concentrations well upper standard in electrocautery-induced surgical fumes (18) other studies in line with these results demonstrate the importance of carcinogenicity and toxicity (14-16, 20) and in addition to the complications of toxicity, genetic toxicity and carcinogenicity, also mentioned the mutagenic complication and also stated that it is better to eliminate surgical smoke from the operating room (17). However, this problem persists and even the surgical team, other personnel in other operating rooms can inhale the odor. In the following, surgical smoke from electrosurgery could transmit the live HPV virus (24) and Hepatitis B virus has been observed in surgical smoke (25). In a study, short-term exposure to electrocautery smoke had little effect but long-term exposure to smoke could damage the nasal mucosa (26) and because the surgical team has been exposed to the smoke for many years, the nasal mucosa of these people is damaged.

Complications of the effects of laser-induced surgical smoke on the surgical team

Lasers are relatively common tools used for tissue burning as well as healing but they can produce smoke that has toxic properties (14) as well as in connection with surgical smoke caused by CO2 laser; in addition to toxic properties, carcinogenicity was also considered as a complication of this category (13). Laser smoke can also transmit HPV DNA (27, 28). Other studies have also shown that laser smoke can transmit live bacteria (29).

Complications of surgical smoke from harmonic and ultrasonic scalpel and diathermy on the surgical team

The use of harmonic scalpel and ultrasonic scalpel can cause smoke production and subsequent complications to be exposed to it. This smoke can have toxic properties (7) and Fitzgerald expressed the carcinogenic effect of this smoke (3). On the other hand, sometimes the use of this tool may be limited but the surgical team of hospitals that use this tool are exposed to this smoke for a long time and are not completely safe from complications. In a study, in connection with surgical smoke caused by diathermy stated that the average smoke production by diathermy is equivalent 27 to 30 cigarettes per day and smoke from diathermy has side effects such as mutagenicity and carcinogenicity (4).

How to preserve surgical team against surgical smoke during endoscopic, robotic and open surgeries?

Due to the COVID-19 epidemic, the need to implement these recommendations is felt more than ever.

1) Ventilation systems: A) General room ventilation (GRV)

General ventilation of operating rooms alone is not sufficient to absorb contaminants produced by surgical smoke (30) but the density of surgical smoke can reduce in the operating room because the smoke can be transferred between operating rooms in the operating room.

B) Local exhaust ventilation (LEV)

The two main LEV methods used to reduce surgical smoke for the surgical team are portable surgical smoke evacuators and operating room suction systems. Portable surgical smoke vacuum cleaners should have a speed of 100 to 150 feet per minute and the filter should be HEPA (High-efficiency particulate air) or more powerful. Moreover, these filters should be replaced regularly and disposed of as an infectious waste (30) LEVs must also be equipped with Ultra Low Penetration Air (ULPA) and Charcoal (31) filters to prevent particles from re-entering the surgical site (32). New filters and tubing must be installed on the smoke evacuator for each surgery (30). Surgery room suction systems are designed to absorb fluids and blood at the surgical site, so they suck the smoke of the surgery at a slower rate. If this device is used, a suitable filter must be installed in it and replaced regularly and then destroyed (30). Finally, the use of LEV is more effective than room suction systems (30). The nozzle inlet of portable surgical smoke evacuators and operating room suction systems should be located 2 inches from the surgical site to be effective (30).

2) Laparoscopic surgery

A) Filters

HEPA, ULPA, Charcoal filters must be used at the output of endoscopic ports to filter the CO2 gas used for pneumoperitoneum. On the other hand, these filters in endoscopic applications can filter the surgical smoke caused by tissue coagulation.

B) General strategies in endoscopic and robotic surgeries include the following (33):

1. Reduce the regulation of electrocautery power as much as possible.
2. Ensuring the airtightness of all trocars throughout the procedure.
3. Reduce intra-abdominal pressure as much as possible
4. Use of insufflation devices with smoke evacuation and filtration during surgery. Integrated insufflation devices (eg, the ConMed Air-

seal or Stryker Pneumoseal) can keep the pneumoperitoneum pressure low while filtering the pneumoperitoneum.

5. Ensure disinfection of pneumoperitoneum at the end of surgery.

3) Respiratory protection

Masks N95 and N99, N100, P95, P99, P100, R95, R99 and R100 can be used for protection during surgery, but it is a noteworthy point that elastomeric half-mask and (powered air-purifying respirators)PARPs should not be used during surgical procedures because exhalations Unfiltered endangers the sterile position (34), but care should never be taken to use a respirator instead of a LEV to control surgical smoke (35) because surgical smoke is not removed and may spread to other parts of the operating room. Surgical masks and laser masks cannot protect against surgical smoke (36).

4) Education

One of the best solutions for controlling surgical smoke is to educate continuously all members of the surgical team about the risks and ways to reduce and eliminate surgical smoke (31) teachings should be given from the beginning of the student's entry into the relevant fields and should be taught to the staff frequently.

5) Disposal of filters

In caring for patients with COVID-19, all biological waste should be safely collected and disposed of in special containers, preferably in the same place. All personal protective equipment (such as boots, thick gloves, aprons, long-sleeved clothing, goggles and masks) should be used by people who dispose of waste and after that, take off personal protective equipment. Washout yourself and hands (37) because filters are also considered infectious waste.

Limitation

In this study, some articles were not available.

Conclusion

Surgical smoke generated by surgical instruments such as electrocautery, laser and so on is one of the dangers and threats. The surgical team and operating room staff are always exposed to it and this smoke can harm the health of these people. Surgical smoke generators are widely used in the operating room and are almost an integral part of surgery. Complications such as carcinogenicity, toxicity, mutagenicity, irritants, respiratory diseases, spread of pathogenic microorganisms, HPV DNA transfer, HBV transfer, tumor cell transmission, headache, dizziness, drowsiness, bad hair odor and runny eyes. They affect the surgical team and operating room staff. Therefore, surgical smoke is a health threat to the surgical team, the effects of which affect different organs and systems in the body of surgical team members and operating room personnel. The protective strategies expressed in the discussion section of this article can be used to control and prevent the complications of surgical smoke. Universities and hospitals teach these complications, their importance, and the stated strategies to the staff of the surgical team as well as the students.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflicts of interest

There are no conflicts of interest with this review.

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