Journal of PeriAnesthesia Nursing 37 (2022) 130–136

Contents lists available at ScienceDirect

Journal of PeriAnesthesia Nursing

journal homepage: www.jopan.org

Review

Surgical Smoke and Biological Symptoms in Healthcare Professionals and Patients: A Systematic Review

Adriane Reis Barletta Canicoba, RN[a,*], Vanessa de Brito Poveda, PhD, MSc, RN[b]

[a] School of Nursing, University of Sao Paulo, São Paulo, Brazil
[b] School of Nursing, University of Sao Paulo, The Brazilian Centre of Evidence-based Healthcare: A JBI Centre of Excellence (JBI Brazil), São Paulo, Brazil

Keywords:
electrosurgery
occupational health
occupational risk
surgical smoke

A B S T R A C T

Purpose: This study aimed to identify the evidence in the scientific literature between exposure to surgical smoke and biological symptoms in healthcare professionals and patients.
Design: A systematic review.
Methods: Electronic databases were searched, including vivo observational and experimental studies published until August 2020 in Portuguese, English, Spanish and French.
Findings: We identified 13 studies, with a predominance of cross-sectional (6; 46.15%), experimental laboratory (4; 30.76%) and cohort (3; 23.07%) studies. The main manifestations identified were related to respiratory tract and headache. There was identification of histopathological changes in the nasal mucosa of healthcare professionals and the presence of toxic substances from smoke identified in the urine of patients and healthcare professionals.
Conclusion: The scientific literature on the biological symptoms of surgical smoke is mainly composed of observational studies with a reduced sample size, thus constituting aspects which limit a broader and long-term understanding of the biological effects of surgical smoke exposure in healthcare professionals and patients.

A concentration of chemical compounds is generated when using an electric scalpel and released into the environment in the form of surgical smoke. Surgical smoke can be seen and its odor is smelled, being composed of 95% water vapor and 5% by products of combustion and cellular waste.[1] This waste includes chemical compounds such as benzene and toluene, and biological materials such as blood particles, viruses, bacteria, mutagenic and cytotoxic agents in aerosols.[2] The amounts and composition of by products can vary according to the type of surgery, target tissue and technique used by the surgeon, and exposure to these compounds can cause cumulative damage to the health of patients and healthcare professionals.

The most commonly reported symptoms in the scientific literature associated with surgical smoke exposure include headache, sore throat, coughing, eye tearing, eye and nasal mucosa irritation,[3,4] and evidence of histopathological alteration in the nasal mucosa of resident physicians exposed to smoke.[5] However, the risks of surgical smoke exposure and the biological effects caused have not yet led to the development of national regulations to prevent smoke exposure in the operating room.

Even though the dangers of exposure to surgical smoke components and the presence of bioaerosols have been investigated since the 1960s,[6] there are few experimental studies which demonstrate the absorbed dose of chemical compounds present in surgical smoke by healthcare professionals and patients, or that perform biomonitoring of the urine of these individuals.[1]

Thus, the theme presented in this review is relevant, as it has been a matter of concern and discussion by international institutions in different areas such as the Occupational Safety and Health Administration (OSHA); the National Institute for Occupational Safety and Health (NIOSH); the Association of periOperative Registered Nurses (AORN); and the Joint Commission International (JCI) for directly interfering in professionals' health due to the risk of developing occupational respiratory diseases, as well as patient safety.

Purpose

Therefore, the aim of this study was to identify the current evidence in the scientific literature between exposure to surgical smoke and biological symptoms in healthcare professionals and patients.

Conflict of interest: None to report.

Funding: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

* Address correspondence to Adriane Reis Barletta Canicoba, Nursing School of the University of São Paulo, Dr Eneas de Carvalho Avenue, 419, Cerqueira Cesar, São Paulo-SP, Brazil.
E-mail address: arbcanicoba@usp.br (A.R.B. Canicoba).

https://doi.org/10.1016/j.jopan.2021.06.106
1089-9472/

Method

This is a systematic review, performed in accordance with the principles set by the guidelines of the Joanna Briggs Institute (JBI), and following the suggested steps: formulating the research question; defining inclusion and exclusion criteria; bibliographic search strategies; selecting studies for inclusion; evaluating the methodological quality of the studies; data extraction; critically evaluating relevant studies; and finally, synthesizing and interpreting the results[7] and reporting them according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA).[8]

Research Question

The guiding research question consisted of: what is the relationship between exposure to surgical smoke and biological symptoms observed in healthcare professionals and patients exposed to surgical smoke components pointed out in the scientific literature?

Inclusion and Exclusion Criteria

The inclusion criteria were in vivo observational and experimental studies published until August 2020 in Portuguese, English, Spanish and French, and which addressed the biological implications of exposure to surgical smoke components. The exclusion criteria were: review articles, congress or conference annals, technical or scientific reports; studies which only performed a collection and analysis of the particles of the components produced by using the electric scalpel (chemical or biological); studies which evaluated the use of smoke evacuators; studies which did not specify the biological effects of surgical smoke exposure in patients and healthcare professionals.

Search Strategy

The following databases were consulted for selecting articles included in the review: the Medical Literature Analysis and Retrieval System on-line (MEDLINE), the Cumulative Index to Nursing and Allied Health Literature (CINAHL) and the *Literatura Latino-Americana e do Caribe em Ciências da Saúde* (*LILACS*), the Cochrane Central Register of Controlled Trials (CENTRAL), the Excerpta Medica Database (EMBASE), the Web of Science and Scopus.

The terms contained in the Medical Subject Headings (MeSH), in the List of Topical Subheadings of CINAHL Information Systems, Emtree, Health Sciences Descriptors (DeCS) of the Virtual Health Library were used in selecting keywords, and the combinations are described in Table 1.

Study Selection

A total of 805 articles were retrieved through the databases included in this review, of which 129 were excluded because they were duplicates, leaving 676 articles. Next, 638 were excluded after reading the titles and abstracts, leaving 38 articles which were fully evaluated. Of these, 25 articles were excluded because they did not fit the guiding question proposed for this review, thus only 13 studies were selected to compose the final sample. Figure 1 describes the selection and inclusion process for the articles.

Data Extraction

The selection, evaluation and extraction process of the obtained data was performed by two evaluators who selected the studies according to the previously-established inclusion and exclusion criteria, and who reached consensus for composing the final sample.

Table 1
Search Terms Used in the PubMed, CINAHL, Cochrane, Embase, LILACS, Scopus and Web of Science Databases

Database	Search Strategies
Medline via PubMed	("electrosurgery"[MeSH Terms] OR "monopolar electrosurgery"[All Fields]) OR "bipolar electrosurgery"[All Fields]) OR "electrocoagulation"[MeSH Terms]) OR "monopolar electrocoagulation"[All Fields]) OR "bipolar electrocoagulation"[All Fields]) OR "monopolar electrocautery"[All Fields]) OR "bipolar electrocautery"[All Fields]) AND "occupational exposure"[MeSH Terms]) OR "occupational health"[MeSH Terms]) OR "occupational hazards"[All Fields]) OR "occupational safety"[All Fields]) OR "occupational risk"[All Fields]) AND "surgical smoke"[All Fields]) OR "smoke plume"[All Fields]) OR "electrosurgery smoke"[All Fields]) OR "electrocautery smoke"[All Fields])
CINAHL	MH 'electrosurgery' OR monopolar electrosurgery OR bipolar electrosurgery OR MH 'electrocoagulation' OR monopolar electrocoagulation OR bipolar electrocoagulation AND MH ('occupational exposure or occupational risk') OR MH ('occupational health and safety') OR MH 'occupational hazards' AND MH 'surgical smoke' OR MH 'smoke plume' OR electrosurgery smoke
Cochrane	"electrosurgery" OR "electrosurgical" AND "occupational health" AND surgical smoke OR smoke plume
Embase	'electrosurgery'/exp OR 'monopolar electrosurgery' OR 'bipolar electrosurgery' OR 'electrocoagulation'/exp OR 'monopolar electrocoagulation' OR 'bipolar electrocoagulation' OR 'monopolar electrocautery' OR 'bipolar electrocautery') AND 'occupational exposure'/exp OR 'occupational health'/exp OR 'occupational hazard'/exp OR 'occupational safety'/exp OR 'occupational risk') AND 'surgical smoke'/exp OR 'smoke plume' OR 'electrosurgery smoke' OR 'electrocautery smoke'
LILACS	(electrosurgery OR bipolar electrosurgery OR monopolar electrosurgery OR electrocoagulation OR monopolar electrocoagulation OR bipolar electrocoagulation OR electrocautery OR monopolar electrocautery OR bipolar electrocautery) AND (occupational exposure OR occupational hazards OR occupational health OR occuapational safety OR occupational risk) AND ("surgical smoke" OR "smoke plume" OR "electrosurgery smoke" OR "electrocautery smoke")
Scopus	(ALL ("electrosurgery") OR ALL ("monopolar electrosurgery") OR ALL ("bipolar electrosurgery") OR ALL ("electrocoagulation") OR ALL ("monopolar electrocoagulation") OR ALL ("bipolar electrocoagulation") OR ALL ("monopolar electrocautery") OR ALL ("bipolar electrocautery") AND ALL ("occupational exposure") OR ALL ("occupational health") OR ALL ("occupational hazards") OR ALL ("occupational safety") OR ALL ("occupational risk") AND ALL ("surgical smoke") OR ALL ("smoke plume") OR ALL ("electrosurgery smoke") OR ALL ("electrocautery smoke")
Web of Science	TS=("electrocautery" OR "monopolar electrosurgery" OR "bipolar electrosurgery" OR "electrocoagulation") AND TS=(occupational exposure OR occupational health OR occupational hazards OR occupational safety OR occupational risk) AND TS=("surgical smoke" OR "smoke plume" OR "electrocautery smoke" OR "electrosurgery smoke")

CINAHL, Cumulative Index to Nursing and Allied Health Literature; LILACS, Literatura Latino-Americana e do Caribe em Ciências da Saúde.

The studies were initially evaluated by reading titles and abstracts, and subsequently by reading the selected investigations in full. An instrument developed by the authors for this review containing information such as article identification, authors, year, study location, objectives, study design, main results and the level of

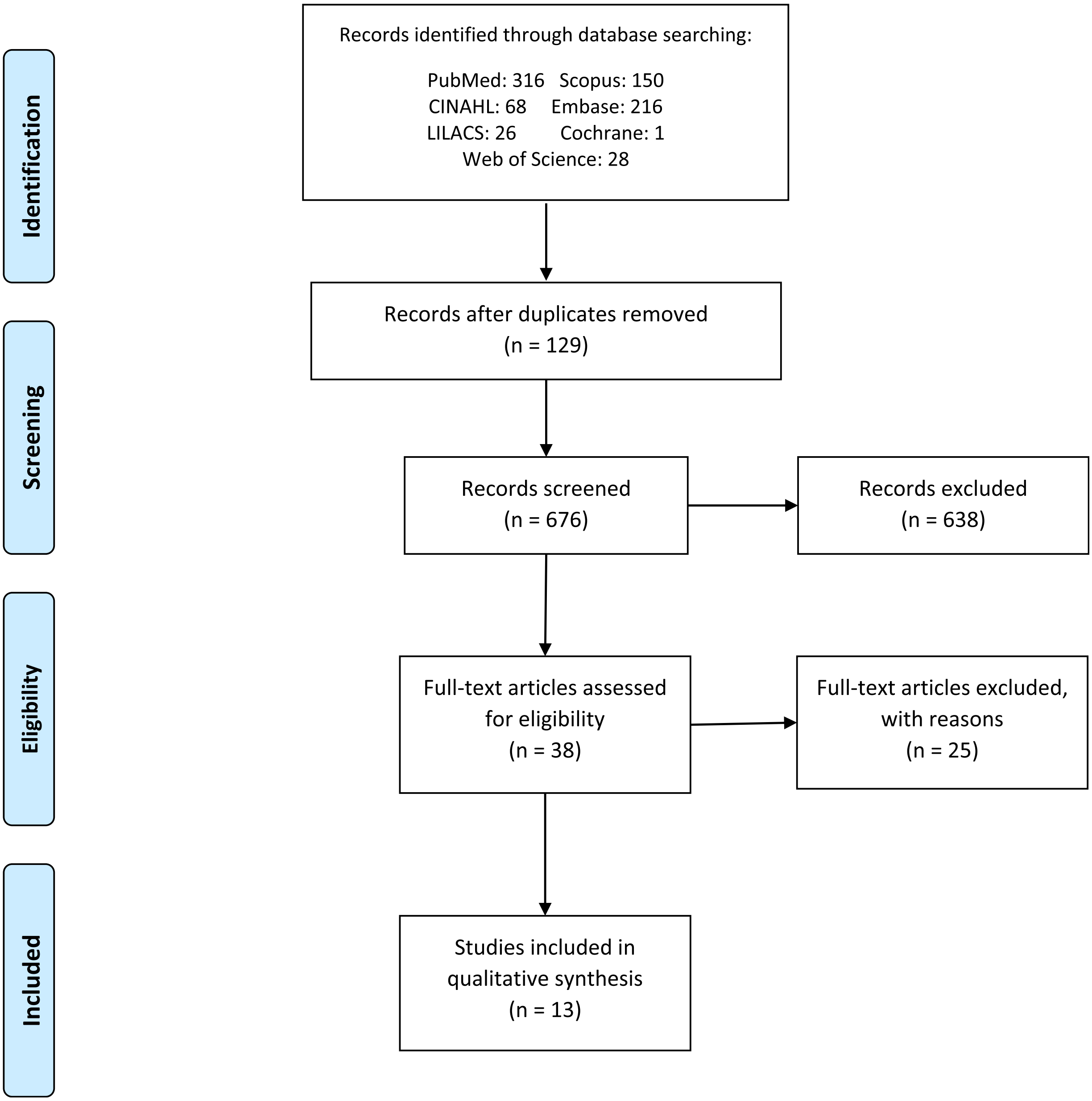

Figure 1. Selection and inclusion flowchart of studies for the systematic review. Adapted from Moher D, Liberati A, Tetzlaff J, Altman DG; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097. CINAHL, Cumulative Index to Nursing and Allied Health Literature; LILACS, Literatura Latino-Americana e do Caribe em Ciências da Saúde. This figure is available in color online at www.jopan.org.

scientific evidence was used for data extraction and analysis. The EndNote software web version was used to organize the references resulting from the bibliographic search.

Assessment of Methodological Quality and Data Analysis

The bias risk assessment in the included observational studies was conducted using the Newcastle-Ottawa Quality Assessment Scale for Cohort Studies tool, which analyzes cohort studies in three dimensions: participant selection; comparability of the study participants; and the obtained results. Next, the final evaluation is translated by the number of stars obtained, classifying the studies as good, reasonable or weak.[9] The maximum score obtained by the studies can be 9 points, representing high methodological quality. Thus, the score of the included cohort studies was calculated as follows: sample selection (0 - 4 points); comparability of study participants (0 - 2 points); and evaluation of exposure after outcome (0 - 3 points).

The Critical Appraisal instrument for studies reporting prevalence data proposed by the JBI[10] was used to assess the methodological quality of cross-sectional studies. No validated methodological quality assessment tools have been identified for laboratory studies to date.

The findings were evaluated by a qualitative approach, describing the most important results related to the aims of this systematic review.

Findings

Characteristics of the Studies

Two (15.38%) of the 13 studies selected in this review were published in 2007; one (7.69%) in 2013; one (7.69%) in 2014; two (15.38%) in 2016; one (7.69%) in 2017; one (7.69%) in 2018; three (23.07%) in 2019; and two (15.38%) in 2020.

Table 2
Methodological Quality of Cohort Studies According to the Newcastle-Ottawa Scale

Studies	Newcastle-Ottawa Scale Domains		
	Selection	Comparability	Result
Stanganelli et al (2019)[1]	**	*	**
Navarro et al (2016)[6]	***	*	***
Gates et al (2007)[9]	***	*	***

Newcastle-Ottawa quality assessment scale: The score of the included cohort studies was calculated as follows: sample selection (0 - 4 points); comparability of study participants (0 - 2 points); and evaluation of exposure after outcome (0 - 3 points).

The studies came from Europe (3; 23.07%), North America (3; 23.07%), Asia (3; 23.07%), Central America (2; 15.38%) and South America (2; 15.38%) and were predominantly published in English (11; 84.61%), although two (15.38%) studies had Portuguese versions.

There was a predominance of observational studies, namely cross-sectional studies (6; 46.15%), while the other studies were classified into: cohort studies (3; 23.07%) and experimental studies (4; 30.76%).

The methodological quality of the cohort studies included in this review was moderate, varying between 5 and 7 points according to the Newcastle-Ottawa Quality Assessment Scale[9] (Table 2). The main weaknesses of cross-sectional studies included in this review according to the JBI critical assessment instrument[10] for the methodological quality of cross-sectional studies were the small sample size and that most studies used instruments created by the authors for data collection and were therefore subject to response bias.

Table 3 presents the characteristics of observational studies according to author, year, origin, study design, number of evaluated professionals, observed biological symptoms and other relevant findings. Table 4 presents the characteristics of the experimental studies according to author (year), origin, study design, sample, data collection and main results.

A total of 11 (84.61%) of the evaluated studies reported biological effects of exposure to compounds from surgical smoke in healthcare professionals with an emphasis on headache and sore throat, watery eyes, coughing, sneezing and dizziness symptoms.[3,4,11,12] There was also evidence of histopathological changes in the nasal mucosa of healthcare professionals,[5] and changes in the blood count of neutrophils and lymphocytes.[17] The presence of benzene and toluene in the urine was observed[1,18] regarding organic absorption of toxic substances identified in surgical smoke by patients and healthcare professionals, or even increased exposure levels to formaldehyde and acetaldehyde.[6]

The main signs and symptoms identified and their frequency of appearance in the studies which compose the present review are shown in Table 5.

Discussion

The present systematic review indicated that despite the increase in the number of published studies on the chemical components present in the smoke produced by using the electric scalpel, there are few experimental or observational studies which actually assess the biological effects caused by exposure to surgical smoke, especially in the long-term.

The present review indicated that the most frequently observed biological symptoms by the studies were related to involvement of the respiratory tract and headache[3,4,11,12,16]. In this sense, studies[3,4,11,12,14] have evaluated the prevalence of signs and symptoms related to inhaling surgical smoke among healthcare professionals, with the most frequent being eye irritation with watery eyes; irritation of the nasal and oral cavity mucosa; sore throat; coughing and/or sneezing; headache and nausea[3,4,11,12,14]. It is also noteworthy that the perception of these symptoms occurs even in the first 12 months of continued exposure,[11,12] and a study points to a higher frequency of symptoms such as coughing and nausea in women.[4]

A recent Belgium experimental study which analyzed the absorbed dose of benzene, toluene, styrene and polycyclic aromatic hydrocarbons (PAHs) by healthcare professionals exposed to surgical smoke using the participants' urine samples showed an increase in the levels of O-cresol (toluene) mainly among assistants and nurses, exceeding the biological exposure indices (BEI) recommended by American Conference of Governmental Industrial Hygienists (ACGIH), which is 0.3 mg/g creatinine. In addition, it is highlighted that toluene is highly harmful to the health of workers.[1]

International occupational exposure regulations establish that the occupational exposure limit for benzene for an eight-hour workday varies between 0.1 ppm and 1.0 ppm (NIOSH), while the Occupational Safety and Health Administration (OSHA) determines limits between 1.0 ppm and 5.0 ppm for the same period.[2]

The composition of surgical smoke is documented by scientific production with toxic components such as PAHs, benzene, toluene, styrene and xylene being described. Inhalation of these compounds causes cumulative biological effects in the organism, constituting a potential health risk for healthcare professionals and patients, which in most cases can trigger respiratory symptoms.[2]

Even patients exposed for shorter periods to the surgical smoke components suffer health effects related to the exposure, as shown in previous studies that demonstrated that patients undergoing laparoscopic procedures absorb the compounds of incomplete combustion of surgical smoke through the peritoneal membrane (mainly carbon monoxide), causing an increase in the levels of carboxyhemoglobin (HbCO) and methemoglobin during the intraoperative.[19,20]

The surgical patients, due to the elevated levels of HbCO and methemoglobin, may experience in the postoperative period symptoms of dizziness, nausea, headache and weakness. In addition, a high HbCO level falsely elevates the oxygen saturation (SaO2) measurements from pulse oximetry.[19,20] Thus, all these events could directly impact the patient's care in the postanesthesia care unit.

The lack of knowledge about the use of preventive measures to decrease exposure to surgical smoke not only unnecessarily increases risk exposure, but also affects the adherence levels to the recommended practices to control smoke.[3,4] It is also interesting to highlight the findings of an Irish study which demonstrated that 58% of surgeons who participated in their study did not wish to receive any formal education or training, despite the lack of knowledge.[21]

Even though the use of Personal Protective Equipment (PPE) such as N95 masks and goggles in addition to the use of surgical smoke evacuators by the unit are able to filter 95% of biological and mutagenic agents and the toxic components present in aerosols of surgical smoke, thereby providing health protection,[22,23,24] the lack of knowledge of healthcare professionals about their use can affect adherence to these practices, or the understanding of their relevance for maintaining their health. Despite the fact that the effectiveness of using N95 masks as a measure to prevent exposure and absorption of the components of surgical smoke remains questioned,[3] a study showed that the use of these masks significantly reduced human exposure to surgical smoke in an operating room.[22]

Measures such as the use of surgical smoke evacuators have been recommended,[25] but they still represent a high cost for health institutions, which represents a limitation for their implementation. Scientific evidence shows that the average concentration of volatile organic compounds (VOCs) in the operating room is significantly reduced when the evacuation system is used.[6] Surgical smoke evacuation systems are used to remove or capture surgical smoke generated in operating rooms while using electric scalpels, thus providing additional security for healthcare staff and patients. It is believed that the improvement of equipment, as for example developing quieter

Table 3
Characteristics of the Included Observational Studies

Author (Year)	Origin	Study design	Evaluated Professionals (N)	Observed Biological Symptoms	Other Relevant Findings
Stanganelli et al (2019)[11]	Brazil	Cohort	Residents of surgical and anesthesiology clinics (N = 39)	Pharynx burning, nausea and vomiting and eye irritation.	The risk of developing pharyngeal burning was 7.765 times (P = .019) in females compared to males.
Saito et al (2019)[12]	Brazil	Cross-sectional	Instrumentalist and non-instrumentalist nursing workers (N = 48)	Irritation of eyes, nasal and oral cavity mucosa, and headache	All signs and symptoms analyzed appeared within 12 months of the beginning of the residency.
Golda et al (2019)[13]	United States	Cross-sectional	Dermatological surgeons (N = 437)	Discomfort caused by the bad odor of surgical smoke.	Of those who had symptoms, 83.9% reported having a relationship with the proximity of the operative field (higher prevalence of all signs/symptoms among instrument professionals).
Asdornwised et al (2018)[3]	Thailand	Cross-sectional	Perioperative nurses (N = 377)	Headache, sore throat, coughing/ sneezing, weakness, eye irritation, nausea/dizziness, chronic bronchitis and asthma.	Most presented discomfort caused by the bad odor of surgical smoke. Low adherence to recommended practices.
Ilce et al (2017)[4]	Turkey	Cross-sectional	Nurses (n = 45) and doctors (n = 36); N = 81	Headache, watery eyes, cough, sore throat, bad odors absorbed by the hair, nausea, drowsiness, dizziness, sneezing and rhinitis.	Higher frequency of symptoms among women (nausea and cough). Lack of knowledge and adherence to practices which can minimize the biological effects of surgical smoke exposure.
Navarro et al (2016)[7]	Mexico	Prospective cohort	Medical residents (N = 43)	Histopathological alteration in the nasal mucosa (squamous hyperplasia or metaplasia).	Association between exposure and histopathological changes in the nasal mucosa.
Navarro Meza et al (2013)[14]	Mexico	Cross-sectional	Residents of different surgical specializations (N = 61)	Feeling of a lump in the throat and sore throat	All neurosurgeons showed respiratory symptoms, which was the specialization with the highest exposure rate (24.1 min/surgical procedure).
Spearman et al (2007)[15]	United Kingdom	Cross-sectional	Surgeons, interns and nurses (N = 111)	Cough	Lack of knowledge about biological effects caused by exposure to surgical smoke.
Gates et al (2007)[16]	United States	Cohort	Nurses (N = 86,747)	Headache and respiratory irritation	Working time in the operating room was not associated with lung cancer.

Table 4
Characteristics of the Included Experimental Studies

Author (Year)	Origin	Study Design	Sample	Data Collection	Main Results
Van Gestel et al (2020)[1]	Belgium	Experimental	10 health professionals (3 surgeons, 2 assistants and 5 nurses)	Urine of healthcare professionals.	Toluene levels increased, especially among assistants and nurses in the middle and end of the shift.
Tokuda et al (2020)[6]	Japan	Experimental	Surgeons, surgical assistants, nursing assistants, circulating nurses and anesthetists	Analytical collector placed at chest level attached to surgical clothing.	The evacuation system was a factor that significantly impacted the levels of personal exposure of formaldehyde and acetaldehyde which were greatly reduced by the use of the system.
Lopez et al (2016)[17]	United States	Experimental	5 voluntary participants (healthy men and women, without current pulmonary or cardiovascular diseases or diseases, self-declared as non-smokers, sedentary and aged between 35 and 55 years).	Markers of pre- and post-exposure changes in exhaled nitric oxide, spirometry, FVC (forced vital capacity) and systemic inflammation blood markers.	Neutrophil and lymphocyte counts increased and fibrinogen levels decreased in four of the five individuals.
Dobrogowski et al (2014)[18]	Poland	Experimental	79 women and 13 men, randomly selected patients, aged between 18 and 77 years.	Surgical patient urine before and after surgery.	The average benzene and toluene concentrations in the urine of patients undergoing laparoscopic cholecystectomy were significantly higher after surgery.

Table 5
Signs and Symptoms Related to Surgical Smoke Exposure Identified in Studies

Studies	Airway Involvement/Respiratory Symptoms (Nasal Mucosa Irritation, Sore Throat/Burning, Coughing/Sneezing, Chronic Bronchitis and Asthma)	Headache	Eye Irritation	Weakness	Nausea/ Dizziness
Stanganelli et al (2019)[11]	x		x		x
Saito et al (2019)[12]	x	x	x		
Golda et al (2019)[13]	x				
Asdornwised et al (2018)[3]	x	x	x	x	x
Ilce et al (2017)[4]	x	x	x		x
Navarro Meza et al (2013)[14]	x				
Spearman et al (2007)[15]	x	x			
Gates et al (2007)[16]	x				

devices, may favor the adhesion of institutions and professionals in the operating room regarding the use of these systems.[26]

Study Limitations

This systematic review found that the scientific literature on the biological symptoms of surgical smoke is mainly composed of observational studies with reduced sample size, impairing the ability to perform a metanalysis. These aspects limit a broader understanding of the biological effects of surgical smoke exposure in healthcare professionals and patients, mainly related to the potential effects from long-term involvement.

Implications For Clinical Practice

Over 500,000 perioperative workers are estimated as exposed to the hazard of surgical smoke each year. However, there is a lack of preventive practices that minimize the biological effects caused by exposure to the dangerous by-products of surgical smoke since the standard surgical masks offer little protection.[27] In addition, patients undergoing surgical procedures absorb the compounds of incomplete combustion of surgical smoke, causing an increase in the levels of carboxyhemoglobin and methemoglobin during the intraoperative, which could cause symptoms of dizziness, nausea, headache, weakness, and falsely elevates the oxygen saturation measurements from pulse oximetry during the postoperative period.[19,20]

Therefore, it is of the highest importance for all health professionals involved during the perioperative period to know and recognize the biological effects caused by exposure to surgical smoke to protect their health and the patient's health.

Conclusion

This systematic review revealed that the scientific evidence that analyzes the impact of surgical smoke on healthcare workers' (HCW) and patients' health is based on low-quality studies that show the relationship between exposure and the major health events. The results point out new possibilities of investigation and the major symptoms and signals related to surgical smoke exposure to be observed among HCW and patients.

The main manifestations identified were related to the respiratory tract, headache, and histopathological changes in the nasal mucosa of healthcare professionals. Concerning experimental studies, urine analysis was the most frequent method to determine the concentration of toxic compounds or biomonitoring of the absorbed dose of chemical compounds present in the smoke by healthcare professionals and patients.

Thus, it is necessary to develop research that expands the evidence on the topic and evaluates the long-term effects, thereby providing more accurate information about the real risk of exposure to surgical smoke, since it would determine the absorption of these compounds by bodies of healthcare workers in the perioperative setting.

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