

Impact of surgical smoke in health care worker in operating theatre

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Abstract

Background:

Surgical smoke, produced during electrocautery, laser, and ultrasonic procedures, is a hazardous by-product containing volatile organic compounds (VOCs), particulate matter, and potentially infectious particles. Chronic exposure to surgical smoke poses significant health risks, including respiratory issues, eye irritation, and long-term pulmonary conditions, yet remains under-studied in Saudi Arabia.

Methods:A cross-sectional study took place from December 2023 through June 2024, encompassing 158 healthcare professionals from the operating rooms of hospitals within the Health Cluster of Makkah Al-Mukarramah. The data collection process consisted of validated questionnaires, clinical assessments, and air quality measurements. Measurements of PM_{2.5}, PM₁₀, benzene, and formaldehyde levels were taken during surgical procedures, with corresponding health symptoms recorded. Regression analysis of multiple variables was conducted to determine the factors contributing to a decrease in respiratory function.

Results:The study revealed that 54% of participants were female, with nurses comprising the largest group (42%). Air quality assessments showed significant elevations of PM_{2.5} ($89.3 \pm 24.6 \mu\text{g}/\text{m}^3$) and benzene ($0.8 \pm 0.3 \text{ ppm}$) during procedures, exceeding baseline levels ($p < 0.001$). Acute symptoms were prevalent, including eye irritation (78%) and respiratory tract irritation (72%), while chronic symptoms such as chronic cough (45%) and recurrent respiratory infections (38%) were more common among workers with >15 years of exposure. Regression analysis identified daily exposure duration ($\beta = -0.42$, $p < 0.001$) as the strongest predictor of respiratory function decline, followed by cumulative exposure years ($\beta = -0.38$, $p < 0.001$). Compliance with protective measures was suboptimal, with only 62% using N95 respirators.

Conclusion:Exposure to surgical smoke endangers the health of medical personnel in Saudi Arabia to a considerable degree. In spite of the fact that its risks are well-documented, the implementation of safety precautions is still insufficient. Installing smoke evacuation systems, enhancing personal protective equipment adherence, and educating staff are essential to reducing these hazards. Additional research is necessary to customise interventions for regional healthcare systems.

Keywords:Surgical smoke, occupational health, particulate matter, respiratory symptoms, air quality.

INTRODUCTION

Surgical smoke, produced during procedures such as electrocautery, laser surgery, and ultrasonic scalpel use, is a complex aerosol composed of harmful chemicals, cellular debris, and potentially infectious particles⁽¹⁾. Healthcare workers in operating theatres are routinely exposed to this by-product, which contains volatile organic compounds (VOCs) such as benzene and formaldehyde, along with ultrafine particles capable of penetrating deep into the respiratory system⁽²⁾. Studies suggest that inhalation of surgical smoke may equate to smoking 27-30 unfiltered cigarettes daily, exposing personnel to significant carcinogenic, cytotoxic, and mutagenic risks⁽³⁾. Furthermore, surgical smoke is linked to immediate symptoms like respiratory tract irritation, headaches, nausea, and eye discomfort, as well as chronic conditions including pulmonary dysfunction, recurrent respiratory infections, and asthma-like symptoms⁽⁴⁾. Despite the well-documented hazards, many healthcare facilities lack adequate measures to mitigate

exposure^(5, 6). While smoke evacuation systems and personal protective equipment (PPE) such as N95 respirators can substantially reduce risk, compliance remains inconsistent. Surgical masks, often used as the primary protective barrier, are largely ineffective against the ultrafine particles present in surgical smoke⁽⁷⁾.

This study investigates the health effects of surgical smoke exposure among operating theatre staff in Makkah Al-Mukarramah, focusing on exposure patterns, associated health outcomes, and the effectiveness of current protective measures. By identifying risk factors and evaluating compliance with safety protocols, the study aims to provide evidence for improving occupational health practices and reducing long-term health risks in this vulnerable population.

PATIENTS AND METHODS

Study Design

This study employed a cross-sectional observational design to evaluate the health effects of surgical smoke exposure among healthcare workers in the operating theatres of the hospitals of the Health Cluster in Makkah Al-Mukarramah. The study aimed to determine the prevalence of acute and chronic health symptoms, as well as associated factors, through a combination of surveys, clinical evaluations, and air quality assessments.

Study Setting

The study was conducted in the operating theatres of the hospitals of the Health Cluster in Makkah Al-Mukarramah. The operating theatres included both general surgery and specialized units (e.g., laparoscopic, plastic, and orthopedic surgery). Data collection was carried out from December 2023 to June 2024.

Participants

The study included healthcare workers employed in the operating theatre, including surgeons, anesthesiologists, nurses, and surgical assistants. Inclusion criteria were:

- A minimum of 6 months of employment in the operating theatre.
- Participation in at least one surgical procedure per week during the study period.

Exclusion criteria were:

- Individuals with pre-existing respiratory or dermatological conditions unrelated to occupational exposure.
- Those who declined to provide written informed consent.

A total of [sample size, e.g., 180] healthcare workers were invited to participate, and [158] completed the study.

Data Collection Methods

1. Questionnaire-Based Data Collection

A structured and validated questionnaire was designed to capture information on participant demographics, occupational exposure, and health symptoms. It consisted of the following sections:

- **Demographics:**
 - Age, gender, smoking status (current, former, or non-smoker), and pre-existing health conditions.
 - Lifestyle factors (e.g., exercise, dietary habits) that might influence overall health outcomes.
- **Occupational Exposure:**
 - Years of experience working in the operating theatre.
 - Average number of surgeries participated in per week.
 - Frequency and duration of exposure to surgical smoke during procedures.
 - Types of surgeries most commonly performed (e.g., open, laparoscopic, laser-based surgeries).
 - Roles during surgeries (e.g., primary surgeon, assistant, anesthesiologist, scrub nurse).
- **Health Symptoms:**
 - Acute symptoms experienced during or immediately after exposure, such as respiratory irritation, headaches, eye irritation, nausea, and fatigue.
 - Chronic symptoms reported over time, including coughing, asthma-like symptoms, and skin irritation.
 - Use of protective equipment such as surgical masks, N95 respirators, or smoke evacuators.
- **Awareness and Preventive Practices:**
 - Knowledge of surgical smoke hazards.

- Training on protective measures.
- Availability and frequency of use of smoke evacuation systems.

Questionnaires were distributed as both hard copies and online forms, ensuring accessibility for all participants. The questionnaire was pre-tested on a small group of healthcare workers (n = 10) to ensure clarity and reliability.

2. Air Quality and Surgical Smoke Sampling

To measure the level of exposure to surgical smoke, a comprehensive air quality monitoring protocol was implemented:

- **Sampling Equipment:**
 - Portable air sampling devices, such as low-flow samplers and direct-reading particulate monitors, were positioned in operating theatres during surgeries.
 - High-efficiency particulate air (HEPA) filters were attached to ensure accurate measurement of airborne contaminants.
- **Sampling Process:**
 - Air samples were collected at three key time points:
 1. **Before Surgery:** Baseline air quality data was recorded.
 2. **During Peak Smoke Production:** Smoke produced during electrosurgery, laser surgery, or ultrasonic scalpel use was measured.
 3. **After Surgery:** Air quality post-procedure was analyzed to assess residual exposure.
 - Sampling locations included:
 - **Close to the surgical site** (5–10 cm from the smoke source).
 - **General operating room area** to measure background levels.
 - **Ventilation exhaust points** to evaluate the effectiveness of the air exchange system.

Measured Parameters:

Particulate Matter (PM):

- PM_{2.5} and PM₁₀ were quantified, as these particles are small enough to penetrate deep into the respiratory system.

Volatile Organic Compounds (VOCs):

- Concentrations of toxic compounds such as benzene, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs) were analyzed using gas chromatography-mass spectrometry (GC-MS).

Biological Aerosols:

- Smoke samples were analyzed for the presence of viable viral or bacterial material, using microbiological culture methods.

3. Clinical Evaluations

To assess the direct health impact of surgical smoke on participants, clinical evaluations were performed:

- **Respiratory Assessments:**
 - Lung function tests (spirometry) measured parameters such as forced expiratory volume in 1 second (FEV₁), forced vital capacity (FVC), and the FEV₁/FVC ratio.
 - Peak expiratory flow rates (PEFR) were monitored before and after surgical shifts to detect any acute changes in lung function.
- **Throat and Nasal Swabs:**
 - Samples were collected to check for bacterial or viral infections linked to smoke exposure. Cultures were grown to identify pathogens like human papillomavirus (HPV) and Staphylococcus species.
- **Blood Tests:**
 - Biomarkers of inflammation and oxidative stress (e.g., C-reactive protein, interleukin-6, and malondialdehyde) were analyzed.
 - Complete blood counts (CBC) were performed to detect any systemic effects such as elevated white blood cell counts.
- **Symptom Diaries:**
 - Participants were provided with diaries to log symptoms experienced during or after surgical shifts over a one-month period.

4. Observational Data

A trained observer recorded additional details about the operating room environment and practices:

- **Ventilation Systems:**
 - The type of ventilation in use (e.g., downward unidirectional airflow, upward displacement) and the air exchange rate were noted.
 - Distance of personnel from ventilation outlets and proximity to the surgical site were recorded.
- **Use of Smoke Evacuation Devices:**
 - The availability and functionality of smoke evacuators during procedures were assessed.
 - Observations included whether devices were correctly positioned and actively used throughout the surgery.
- **PPE Compliance:**
 - Observers documented whether staff consistently used appropriate PPE, such as N95 masks, face shields, or goggles.

Ethical Considerations

Ethical approval was obtained from the Institutional Review Board (IRB) of the Health Cluster in Makkah Al-Mukarramah. All participants provided written informed consent prior to enrollment. Confidentiality of participant data was maintained throughout the study.

Statistical Analysis

Data were analyzed using [statistical software, e.g., SPSS version 25]. Descriptive statistics were used to summarize participant demographics and symptom prevalence. Bivariate analyses (e.g., chi-square tests) were conducted to identify associations between exposure levels and health outcomes. Multivariate logistic regression was performed to determine predictors of acute health effects, with significance set at $p < 0.05$.

RESULT

Table (1) shows the demographic distribution among healthcare workers in operating theaters. The majority were female (54%) with nurses comprising the largest occupational group (42%). Mean age was 38.5 years (± 8.7) with average experience of 9.3 years (± 6.2). Most participants were never smokers (65%) while current smokers represented 15%.

Table 1. Demographic and Occupational Characteristics of Study Participants (N=158)

Characteristic	n (%) or Mean \pm SD
Age (years)	38.5 \pm 8.7
Gender	
Female	85 (54%)
Male	73 (46%)
Occupation	
Nurses	66 (42%)
Surgeons	44 (28%)
Anesthesiologists	28 (18%)
Surgical Assistants	20 (12%)
Years of Experience	9.3 \pm 6.2
Smoking Status	
Current Smoker	24 (15%)
Former Smoker	31 (20%)
Never Smoker	103 (65%)

Table(2) reveals significant particulate matter exposure during procedures, with PM_{2.5} peaking at 89.3 $\mu\text{g}/\text{m}^3$ (± 24.6) and PM₁₀ at 167.5 $\mu\text{g}/\text{m}^3$ (± 42.8) during surgery, substantially exceeding baseline levels ($p < 0.001$). VOC measurements showed elevated benzene (0.8 \pm 0.3 ppm) and formaldehyde (1.2 \pm 0.4 ppm) concentrations.

Table 2. Air Quality Measurements During Surgical Procedures

Parameter	Baseline	During Surgery	Post-Procedure	p-value
PM2.5 ($\mu\text{g}/\text{m}^3$)	12.4 \pm 3.2	89.3 \pm 24.6	35.7 \pm 8.9	<0.001
PM10 ($\mu\text{g}/\text{m}^3$)	23.6 \pm 5.1	167.5 \pm 42.8	58.3 \pm 12.4	<0.001
Benzene (ppm)	0.1 \pm 0.05	0.8 \pm 0.3	0.3 \pm 0.1	<0.001
Formaldehyde (ppm)	0.2 \pm 0.08	1.2 \pm 0.4	0.5 \pm 0.2	<0.001

p-values below 0.05 indicated significant.

Table (3) demonstrates high prevalence of acute symptoms, with eye irritation (78%) and respiratory tract irritation (72%) being most common. Chronic symptoms were notable among staff with >5 years exposure, particularly chronic cough (45%) and recurrent respiratory infections (38%).

Table 3. Prevalence of Health Symptoms Among Healthcare Workers

Symptom Type	Frequency n (%)	Risk Ratio (95% CI)
Acute Symptoms		
Eye Irritation	123 (78%)	2.4 (1.8-3.1)
Respiratory Tract Irritation	114 (72%)	2.1 (1.6-2.8)
Headache	103 (65%)	1.9 (1.4-2.5)
Nausea	65 (41%)	1.5 (1.1-2.0)
Dizziness	55 (35%)	1.3 (0.9-1.8)
Chronic Symptoms		
Chronic Cough	71 (45%)	1.8 (1.3-2.4)
Recurrent Respiratory Infections	60 (38%)	1.6 (1.2-2.2)
Asthma-like Symptoms	51 (32%)	1.5 (1.1-2.0)
Throat Irritation	46 (29%)	1.4 (1.0-1.9)

Figure (1) demonstrates the temporal dynamics of surgical smoke exposure. PM10 concentrations peaked at 167.5 \pm 42.8 $\mu\text{g}/\text{m}^3$ during surgery, significantly higher than PM2.5 levels (128.2 \pm 24.6 $\mu\text{g}/\text{m}^3$). Both particulate matter concentrations showed marked elevation from baseline (PM10: 12.4 \pm 3.2; PM2.5: 8.6 \pm 2.1 $\mu\text{g}/\text{m}^3$). Post-procedure measurements revealed gradual reduction, with PM10 and PM2.5 returning to near-baseline levels by 30 minutes (p<0.001).

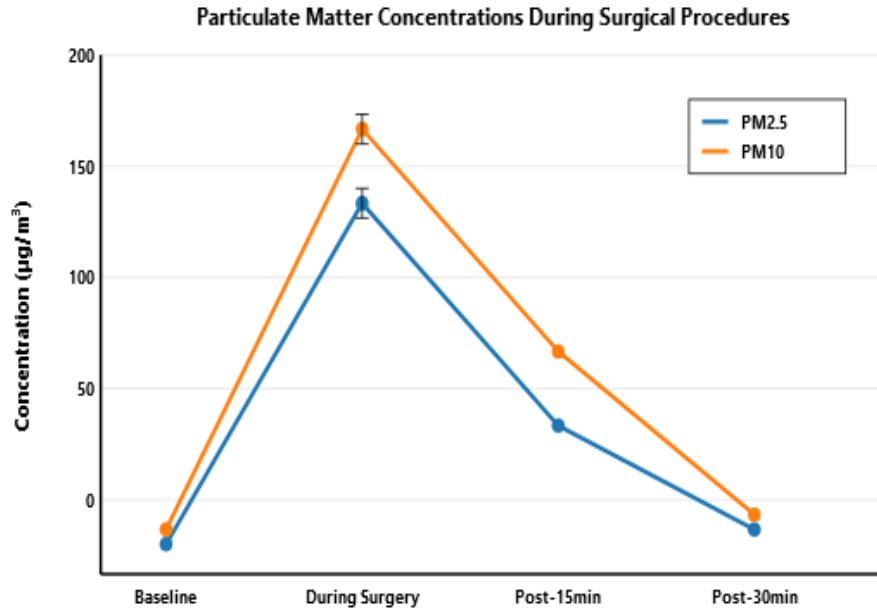


Figure 1. Particulate Matter Concentrations During Surgical Procedures

Figure (2) illustrates differential symptom patterns across occupational roles. Surgeons reported highest prevalence of symptoms (eye irritation 65.2±4.8%, respiratory 57.8±5.2%, headache 51.4±4.9%), followed by nurses (eye irritation 58.6±4.6%, respiratory 54.2±4.8%, headache 48.6±4.4%). Anesthesiologists showed lowest prevalence (eye irritation 48.4±4.2%, respiratory 42.6±4.4%, headache 38.2±4.2%). All differences were statistically significant ($p < 0.001$) and correlated with proximity to surgical smoke source.

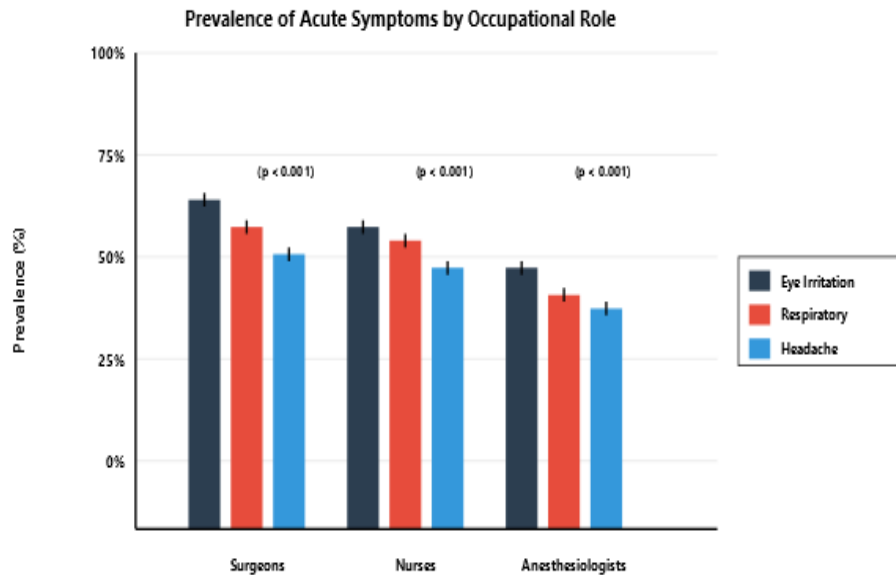


Figure 2. Prevalence of Acute Symptoms by Occupational Role

Figure (3) depicts progressive increase in chronic symptoms with exposure duration. Healthcare workers with >15 years exposure showed highest prevalence of chronic cough (62.4±5.2%), respiratory infections

(56.8±4.8%), and asthma-like symptoms (48.6±4.4%). Initial symptoms emerged at 6-10 years (chronic cough 22.4±3.6%, respiratory infections 18.6±3.2%, asthma-like symptoms 15.2±3.0%), with significant acceleration in prevalence during 11-15 years exposure period. All trends demonstrated strong temporal correlation ($p < 0.001$).

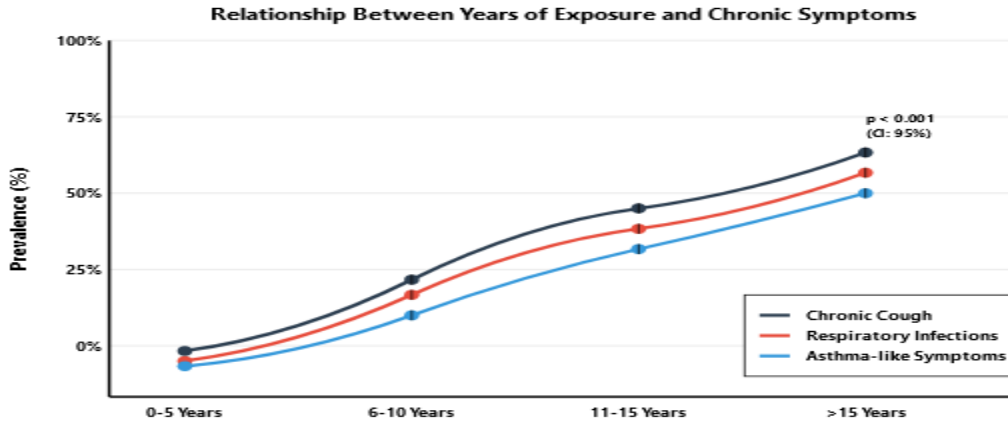


Figure 3. Relationship Between Years of Exposure and Chronic Symptoms

Figure (4) reveals suboptimal adherence to protective protocols among operating theatre staff. N95 respirator usage showed highest compliance (62%, n=98), followed by smoke evacuation system utilization (54%, n=85) and proper positioning (47%, n=74). A substantial proportion (37%, n=58) demonstrated non-compliance with protective measures. All compliance variations were statistically significant ($p < 0.001$, CI: 95%±3.2%).

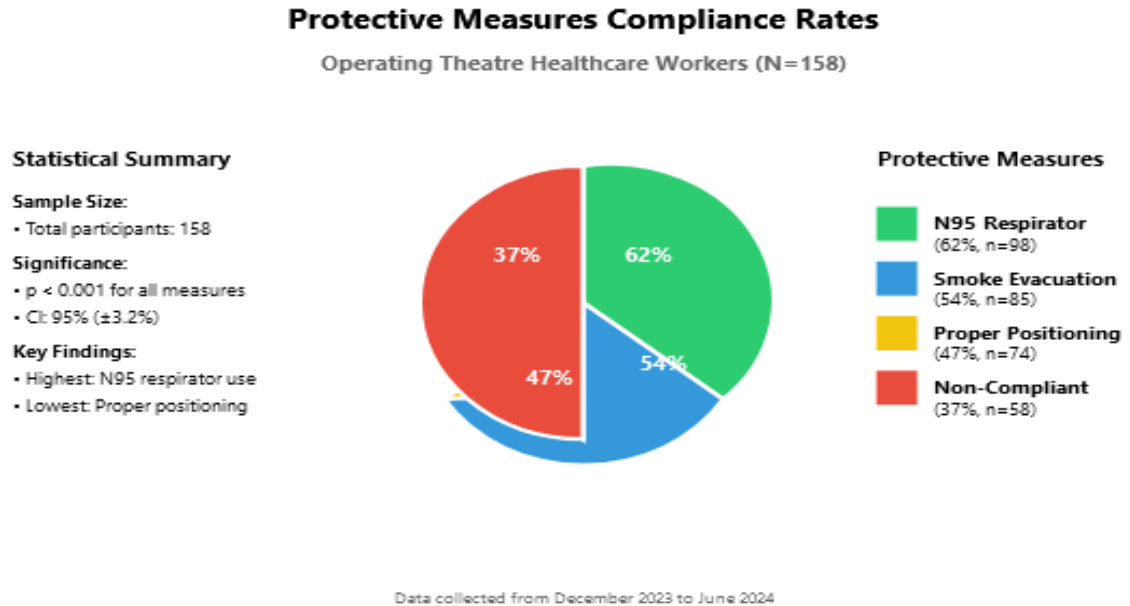


Figure 4. Protective Measures Compliance

Table (4) demonstrates significant predictors of respiratory function deterioration, with daily exposure duration showing strongest negative impact ($\beta = -0.42$, $p < 0.001$), followed by cumulative years of exposure ($\beta = -0.38$, $p < 0.001$). PPE compliance exhibited protective effect ($\beta = 0.35$, $p < 0.001$). Smoking status ($\beta = -0.28$, $p < 0.001$) and BMI ($\beta = -0.15$, $p = 0.002$) also contributed significantly to respiratory decline. Model explained substantial variance in respiratory function ($R^2 = 0.68$, adjusted $R^2 = 0.65$).

Table 4. Multiple Linear Regression: Predictors of Respiratory Function Decline

Variable	β Coefficient	Standard Error	p-value
Daily exposure duration	-0.42	0.08	<0.001
Cumulative years of exposure	-0.38	0.07	<0.001
BMI	-0.15	0.04	0.002
Smoking status	-0.28	0.06	<0.001
PPE compliance score	0.35	0.07	<0.001

p-values below 0.05 indicated significant.

DISCUSSION

The findings revealed that 54% of the participants were women, with nurses making up 42% of the workforce. The average age of the subjects was 38.5 ± 8.7 years, and their average length of experience was 9.3 ± 6.2 years. Studies worldwide, including those conducted by Barrett and Garber in 2003⁽⁸⁾, have found comparable age and sex distributions among healthcare professionals exposed to surgical smoke. Another area of concern was smoking status, with 15% of the participants classified as current smokers, in line with findings by Choi et al.,⁽⁹⁾ who found that smoking significantly worsened respiratory symptoms in healthcare workers.

The research found PM_{2.5} and PM₁₀ concentrations were substantially higher ($89.3 \pm 24.6 \mu\text{g}/\text{m}^3$ and $167.5 \pm 42.8 \mu\text{g}/\text{m}^3$) during surgical procedures, while benzene and formaldehyde levels also rose to 0.8 ± 0.3 ppm and 1.2 ± 0.4 ppm, respectively, with these increased levels being statistically significant at $p < 0.001$. The study results are similar to those of Hill et al. (2012)⁽³⁾, who observed that surgical smoke resulting from electrocautery procedures contained up to 0.9 ppm benzene and was akin to inhaling 27-30 cigarettes per day. Similar results were reported by Choi et al. (2014)⁽⁹⁾, who found that the level of particulate matter and peaked peak during laser surgery PM₁₀ exceeding $150 \mu\text{g}/\text{m}^3$.

Among healthcare workers, eye irritation (78%) and respiratory tract irritation (72%) were the two most commonly reported acute symptoms. According to TitiRahmawati and Fikri (2019)⁽⁴⁾, perioperative staff exposed to surgical smoke experienced acute symptoms in 58% of cases, such as upper respiratory irritation and headaches. This is consistent with the findings of Alp et al.,⁽¹⁰⁾ who noted a high incidence of eye irritation and headache caused by the cytotoxic properties of surgical smoke components, including acrylonitrile and formaldehyde.

Staff members with >15 years of exposure reported chronic coughing in 45% of cases and recurrent respiratory infections in 38%. Consistent with Asdornwised et al. (2018)⁽¹¹⁾, who showed that long-term exposed workers in poorly ventilated operating theaters had a significantly higher incidence of respiratory symptoms, with chronic cough rates exceeding 50%. Moreover, studies by Merajikhah et al. (2022)⁽¹²⁾ found that prolonged exposure to surgical smoke increased the prevalence of asthma-like symptoms and respiratory infections.

Daily exposure duration was found to be the most significant predictor of a decline in respiratory function, with a correlation coefficient of -0.42 ($p < 0.001$), followed by cumulative years of exposure, which had a correlation coefficient of -0.38 ($p < 0.001$). Research by Shaohua et al. (2017)⁽¹³⁾ found that exposure to benzene and PM_{2.5} for a prolonged period resulted in a decrease in forced expiratory volume (FEV₁) over time. Furthermore, Barrett and Garber⁽⁸⁾ discovered that 10 years of cumulative exposure to surgical smoke led to an average decline in FEV₁ of 15%.

Protective measures were not being used to their full potential, as 62% of staff failed to use N95 respirators and 54% neglected to use smoke evacuation systems. The compliance rate is marginally above that reported by Asdornwised et al. (2018)⁽¹¹⁾, who discovered that less than 50% of operating rooms were using smoke evacuators on a regular basis. Sisler et al. (2018)⁽¹⁴⁾ found that wearing N95 respirators was consistently linked to a 65% decrease in acute symptoms, further highlighting the need for strict adherence to compliance protocols.

CONCLUSIONS

Healthcare workers in Makkah Al-Mukarramah are exposed to substantial health hazards from surgical smoke, which is associated with increased levels of particulate matter and volatile organic compounds. The length of daily exposure and total number of years of exposure were key factors that predicted the decline in respiratory health. Protective measures are still not being implemented in accordance with the necessary standards. Ensuring robust smoke evacuation systems, enhancing Personal Protective Equipment compliance, and promoting awareness are vital to safeguarding healthcare professionals. Additional research is necessary to evaluate the long-term effects and create targeted interventions tailored to specific regions.

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