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Research Article

Determination of Benzene, Toluene, Ethylbenzene and Xylene Compounds in Surgical Smoke and Its Relationship with Body Mass Index and Duration of Surgery

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ABSTRACT

Background and objectives: Electrosurgical units produce the highest level of surgical smoke. Therefore, the present study aimed to determine concentration of surgical smoke compounds produced in orthopedic surgeries.

Methods: The present study was performed on 20 patients in the operating room units of 5 Azar Hospital in Gorgan, Iran. Twenty smoke specimens were collected from electrosurgical units during orthopedic surgeries. The concentration of benzene, toluene, ethylbenzene, and xylene (BTEX) was determined using an air-sampling pump and SKC charcoal sorbent tubes. The collected data were analyzed using frequency distribution as well as generalized linear and ranked logistic regression tests in SPSS software (version 17).

Results: Most patients had a body mass index (BMI) level of >24 kg/m^2. The mean age of patients was 25.28 years. The average concentrations of benzene, toluene, ethylbenzene, and xylene were 540 µg/m3, 430 µg/m3, and 340µg/m3, and 390µg/m3, respectively. The concentration of particles with an aerodynamic diameter of 2.5 µm or less (PM2.5) was 22.75 µg/m^3. Benzene values were higher than the National Institute for Occupational Safety and Health limit. The PM2.5 values were unhealthy for sensitive groups according to the Air Quality Index. Moreover, BMI had a significant association with the amount of benzene produced intraoperatively (p=0.016). The findings also showed that the surgery duration had a significant association with toluene production (p=0.049).

Conclusion: The concentration of BTEX compounds was low, but the PM2.5 values are high in the studied operating rooms. Long-term exposure to BTEX compounds can be considered as a health risk for operating room personnel

Keywords: Electrosurgery; Smoke; BMI; PM2.5; BTEX

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Introduction

The development of medical technology and applying surgery as an essential treatment process have led to the emergence of new risk factors for health personnel (1). Surgical smoke has been known as an integral part of the operating room atmosphere since 1926, when Harvey Williams used electrosurgical units (ESUs) during surgical operations (2). During surgery and tissue cutting, the temperature of the cellular content is increased to 100°C, leading to breakdown of the cell membrane and release of gases from the dissolution of the cellular content into the air (3). Edwards and Reiman demonstrated the presence of hazardous components in surgical smoke and documented the potentially harmful consequences of exposure to these airborne contaminants (4). Many studies have shown that surgical smoke contains complex constituents of chemical pollutants and biological hazards (5-7). Within hazardous volatile organic compounds, special attention has been paid to emission of benzene (C6H6), toluene(C7H8), ethylbenzene (C6H5CH2CH3), and xylene (C_8H_{10}) (BTEX) to the atmosphere from both anthropogenic and biogenic sources (8), which poses a serious threat to human health (8) as benzene is a known carcinogen (9). These compounds were identified in surgical smoke based on the results of numerous studies (10-12). The above compounds have been included in the list of hazardous compounds by the United States Environmental Protection Agency. According to the National Institute for Occupational Safety and Health (NIOSH), occupational exposure limit is 0.1 parts per million (ppm) for benzene, 0.1 ppm for toluene, and 100 ppm for ethylbenzene and xylene. The permissible limit for benzene, toluene, ethylbenzene, and xylene in ambient air is 0.003, 0.23, 0.116, and 0.92 ppm, respectively (8). Particulate matter (P.M2.5) is also one of the most important indices, and average particle size of major environmental pollutants range from 68.3 to 994 nm. Unfortunately, these particles can penetrate directly into small airways and alveoli, thereby exerting their adverse effects.

Surgical smoke is an environmental pollutant due to the presence of BTEX (13). According to annual reports, more than half a million operating room staff were in contact with surgical smoke, at least 7 hours of day, for several consecutive years (14). Lindsey et al. (2015) also reported that ESUs smoke chemicals, in addition to irritating the respiratory tract and eyes, could be teratogenic and carcinogenic, which also affects the central nervous system (15). In addition, the surgical team inhales gases released by the dissolution of cancer cell particles during ESU-assisted removal of cancerous skin tissue (16). Considering the results of many studies on the adverse and toxic effects of surgical smoke on human health, the present study was designed to determine concentration of compounds present in surgical smoke produced during orthopedic surgeries in the operating rooms of 5 Azar hospital in Gorgan, Iran.

Materials And Methods

This was a descriptive-analytical study designed to analyze the monopolar ESUs smoke compounds during orthopedic surgeries (coagulation and cutting). Samples were taken from the operating rooms of 5 Azar Hospital, a surgical center in the Golestan Province, northeastern Iran. Approximately 60 surgical operations are performed in this the hospital daily. Samples were taken via the convenience sampling method. In order to increase the accuracy of the results, 20 patients (10 men and 10 women) were selected from orthopedic patients with coagulation problems and underlying diseases such as hypertension, diabetes, morbid obesity, and cardiovascular diseases.

Table 1. The AQI for PM2.5 breakpoints (13)

$PM_{2.5}$ breakpoints (μg/m^3)	AQI category
0.0-12.0	Good
12.1-35.4	Moderate
35.5-55.4	Unhealthy for sensitive groups
55.5-150.4	Unhealthy
150.5-250.4	Very unhealthy

Table 2. Recommended guideline for concentration of BTEX compounds in indoor air (μg/m3)(18)

Guideline		Benzene	Toluene	Ethylbenzene	Xylene
NIOSH[A]	TWA[B]	320	375×10 ^{3}	435×10 ^{3}	435×10 ^{3}
	STEL[C]	3750	560×10 ^{3}	545×10 ^{3}	655×10 ^{3}

[A] National Institute of Occupational Safety and Health
[B] Time Weight Average
[C] Short- term Exposure Limit

Demographic information including gender, age, body mass index (BMI), type of surgery, and duration of surgery were recorded using a researcher-made checklist.The concentration of hazardous gases (BTEX), PM2.5, and their relationship with patients' BMI and duration of surgery were studied. All measurements were repeated three times. For sample collection, a charcoal adsorption tube (SKC, USA) was connected to air-sampling pump (Model NR346, Negretti Co., UK). The charcoal adsorption tubes were used to collect surgical smoke samples at a distance of 2 to 3 cm from the surgical site and near the cutting pen. The pump was set at 50-200 ml/minute. This sampling method consisted of continuous extraction of gases from surgical smoke throughout the surgical operation (17). After the sampling, formalin tablets were used for sterilizing the smoke suction tube for 6 hours. Next, BTEX compounds were extracted from charcoal tubes by using 2 ml of carbon disulfide (CS2). The vials containing CS2 and charcoal were gently shaken for 20 minutes. The solvent was transferred into GC vials, and BTEX compounds were quantified by using a gas chromatograph equipped with flame ionization detector according to the NIOSH method number 1501 (18). The measurement of suspended particles with a size of 2.5 μm was carried out by a suspended particle measuring device (Hi-Volume). As shown in table 1, the Air Quality Index (AQI) and the National Ambient Air Quality Standards for Particle Pollution by the United States Environmental Protection Agency were used for comparing PM2.5 values with standard limits (13).

There are few published guidelines for BTEX levels in residential environments, but in this study, the results were compared with the NIOSH guidelines (Table 2) (18).

All samples were analyzed using frequency distribution, a generalized linear regression (GLR) model, and a ranked logistic regression (RLR) model in SPSS software (version 17), in order to determine the relationship between dependent and independent variables. Confidence level of all analyzes was set at 95% ($p<0.05$).

Results

The mean age of the patients was 48.65±19.24 years. Most patients (60%) had a BMI of >24 kg/m2 (range 15.4-37.8 kg/m2). The surgery duration was less than 1 hour in 55% of cases (Table 3). Analysis of smoke compounds from ESUs revealed the presence of BTEX during surgery. The average concentrations of benzene, toluene, ethylbenzene, and xylene were 540 μg/m3, 430 μg/m3, 340 μg/m3, and 390 μg/m3, respectively. In addition, the average PM2.5 concentration was 22.75 μg/m3 (Table 4).

In this study, the GLR and RLR models were applied to determine the relationship of BTEX concentrations with duration of surgery and BMI. The statistical analysis showed that benzene and PM2.5 had a non-

Table 3. Demographic characteristics of the patients

Variable	Category	Number (%)
Sex	Female Male	10 (50%) 10 (50%)
BMI (Kg/m2)	<19 19-24 >24	2(10%) 6(30%) 12 (60%)
Surgery duration (minutes)	<60 60-120 >120	11(55%) 5(25%) 4(20%)
Frequency of surgery (number)	First Second Third	11(45%) 5(35%) 4(20%)
Age (years)	<25 25-50 >50	2(10%) 6(30%) 12(60%)

Table 4. Concentration of BTEX compounds (μg/m3) and P.M2.5 (μg/m3) in operating rooms

Variable	Minimum	Maximum	Average
Benzene	400	800	540
Toluene	280	600	430
Ethylbenzene	200	600	340
Xylene	300	600	390
$P.M_{2.5}$	4	52	22.75

Table 5. Estimation of regression coefficients for benzene and PM2.5 by BMI and surgery duration according to the GLR model

Type of gas	Variable	Value of β coefficient	Coefficient of error Std. Error	95% confidence interval		*p*-value
				Upper	Lower	
Benzene	BMI Surgery duration	0.025 0.001	0.0104 0.0013	0.005 0.001	0.045 0.004	0.016 0.3
$P.M_{2.5}$	BMI Surgery duration	0.01 0.003	0.0289 0.0041	0.046 0.005	0.067 0.011	0.727 0.53

normal distribution; therefore, simultaneous effect of BMI and duration of surgery on concentration of benzene and P.M2.5 was analyzed using the GLR model. In this model, if the response variable is quantitative, Gaussian function, gamma, normal distributions, and fit with appropriate link function (linear, logarithmic, and inverse, etc.) could be used. After fitting different models, the best model could be obtained according to fitting criteria, such as the Akaike Information Criterion. The obtained results showed that the best model had an inverse Gaussian distribution with logarithmic link function for benzene and gamma distribution with logarithmic link function for PM2.5 (Table 5). Based on the results, BMI had a significant association with the benzene production rate (p=0.016), and as BMI increased, the benzene production rate also increased. The surgery duration had no significant association with the PM2.5 production rate (p=0.3). We observed no significant correlation between BMI and P.M2.5 (p=0.727) or between duration of surgery and P.M2.5 (p=0.52) in the operating rooms. The RLR model was applied to determine correlation of patients' BMI and duration of surgery with the concentrations of BTEX gases. Based on the results, duration of surgery and BMI had no significant association with ethylbenzene and xylene concentrations (p>0.05), but the

Table 6. Estimation of regression coefficients for toluene, ethylbenzene, and xylene by BMI and surgery duration according to the RLR model

Type of gas	Variable	Value of β coefficient	Coefficient of error Std. Error	95% confidence interval		*p*-value
				Upper	Lower	
Ethylbenzene	BMI Surgery duration	-0.048 0.009	0.095 0.011	-0.234 -0.013	0.138 0.031	0.611 0.422
Toluene	BMI Surgery duration	-0.166 0.037	0.123 0.019	-0.406 0.000	0.075 0.075	0.178 0.0493
Xylene	BMI Surgery duration	-0.073 0.002	0.101 0.012	-0.27 -0.021	0.124 0.025	0.467 0.845

surgery duration had a significant positive association with toluene production (p=0.049) (Table 6).

Discussion

The highest value of BTEX (540 µg/m3) during orthopedic surgeries was related to benzene, which is one of the major chemical materials of the hydrocarbon group. This value is higher than the time weighted average value of the NIOSH limit (320 µg/m3). In recent years, several studies have shown that benzene is one of the main gases produced during orthopedic surgeries (2- 7- 19). This gas can irritate the eyes, nose as well as the respiratory tract, and cause headaches, dizziness, and nausea. Exposure to benzene in the workplace can lead to various blood disorders, such as anemia and leukemia, even at very low concentrations (8- 20). Benzene is also the only compound within the BTEX group that has been proven to be carcinogenic to humans according to the International Agency for Research on Cancer (13). The lack of awareness of operating room staff might be an important reason for increasing the effects of this compound. Our results showed that there was significant association between benzene concentration and patients' BMI. Due to these destructive effects, it is necessary to measure this compound continuously in the operating rooms.With an average dynamic diameter of < 2.5 µm, PM2.5 particles are considered as one of the main pollutants of ambient air (17).

These particles can increase the mortality risk of cardiovascular disease, especially in people with heart failure or recurrent arrhythmia. According to a cohort study by the American Cancer Society, cardiovascular diseases and mortality rate from lung cancer are increased by 6% and 8%, respectively, for each 10 µg/m3 average annual exposure to PM2.5 (21- 22). Based on our results, the average PM2.5 concentration was ranging between 4 and 52 µg/m3, which is unhealthy for sensitive groups according to the AQI standards. This indicates that inadequate control of surgical smoke can cause serious complications for operating room personnel in short term and long term. Due to the dangerous effects of PM2.5 for the operating room personnel, it is essential to monitor the ventilation of the operating room and use appropriate face masks during surgery. In addition, an empirical study of Suwa et al. (2002) showed that the presence of PM2.5 in the operating room air can have detrimental effects on humans and cause cardiovascular disease among operating room personnel (23).

The average levels of released toluene, xylene, and ethylbenzene were 430 µg/m3, 390 µg/m3, and 340 µg/m3, respectively. According to the NIOSH standard, the permissible limit for toluene, xylene, and ethylbenzene is 375×103 µg/m3, 435×103 µg/m3, and 435×103 µg/m3, respectively. Our obtained values were lower than the NIOSH standard limit. There was also no significant relationship between duration of surgery and concentration of xylene and ethylbenzene, but there was a significant relationship between duration of surgery and concentration of toluene (p=0.04). Exposure to some organic solvents such as toluene can have detrimental effects on some organs including they eyes and nose, and may lead to the development of diseases such as leukemia, bladder cancer, and central nervous system disorders (24). In general, toluene, xylene, and ethylbenzene can be released from substances such as anesthetics, solvents, medical equipment, chemical and biological compounds, and surgical smoke. Zhou et al. (2014) have shown that these gases cause congenital defects in the fetus and increase the risk of leukemia in children as well as infertility and preterm labor in women (25). Although the concentration of surgical gases in the present study was in the optimal range, it seems that increasing the surgery duration may increase the indoor concentration of the above gases. Assessing the patient's conditions and the complexity of the surgical procedure preoperatively and choosing the appropriate room with larger open space and better ventilation can be effective in facilitating the safety management of the operating room staff, especially female operating room technicians.

The BMI of patients ranged between 15.4 and 37.8 kg/m2 (mean = 25.28 kg/m2). This index is one of the most effective indicators related to surgical smoke in the operating rooms (26). According to the World Health Organization, patients are classified as overweight if their BMI exceeded 24.99 kg/m2 (27). In our study, 60% of patients had a BMI level of >24.99 kg/m2, which is higher than the standard limit. The mean BMI level (25.28 kg/m2) was near the normal range and slightly close to the overweight range. Twelve cases had BMI level of >24.99 kg/m2 and also a higher benzene concentration in ESUs. Moreover, benzene production increased with patients' BMI during electrosurgery. Greater attention to reduce possible exposure should be paid by the operating staff if the patients are overweight. Therefore, due to the aforementioned facts, it can be said that BMI is a simple indicator for estimating exposure risk. Other studies have also found a direct relationship between the concentration of surgery smoke and duration of surgery and BMI of patients (26-28-29).

Conclusion

Although the overall concentration of toxic and irritating volatile organic compounds in our study was low, but cumulative concentrations of BTEX compound in the operating rooms can be a serious health threat for surgeons and operating room personnel. Standardization of the operating rooms and providing a suitable laminar airflow ventilation system can be effective for removing these carcinogenic gases form the operating rooms atmosphere. The PM2.5 concentration in the studied center is out of the standard limit, which can be unhealthy for sensitive groups. Due to the dangerous effects of PM2.5 for the operating room personnel, it is essential to monitor the ventilation of the operating room and use appropriate face masks during surgery. Our findings indicate that the inadequate control of surgical smoke can have serious short-term and long-term complications for operating room personnel. Therefore, it is suggested to conduct studies on operating room personnel's awareness level about the health risks of these gases.

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Declarations

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Ethics approvals and consent to participate

The study was approved by the Ethics Committee of the Golestan University of Medical Sciences, Iran (ethical approval code: IR.GOUMS.REC.1395.260).

Conflict of Interest

The authors declare that there is no conflict of interest regarding publication of this article.

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