

Volatile Organic Compounds Exposure During Breast Surgery in Operating Rooms of A Hospital

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Research

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Abstract

Background: The composition and concentration distribution of volatile organic compounds (VOCs) in surgical smoke had seldom reported. This study aimed to investigate the profile of VOCs and their concentration in surgical smoke from breast surgery during electrocautery in different tissues, electrosurgical units, and electrocautery powers.

Methods: Thirty-eight surgical smoke samples from 23 patients performed breast surgery were collected using evacuated stainless steel canisters. The concentrations of 87 VOCs in surgical smoke samples were analyzed by gas chromatography-mass spectrometry. The human tissues, electrosurgical units, and electrocautery power were recorded.

Results: The median level of total VOCs concentrations in surgical smoke samples from mammary glands (total VOCs: 9,953.5 ppb; benzene: 222.7 ppb; 1,3-butadiene: 856.2 ppb; vinyl chloride: 3.1 ppb) using conventional electrosurgical knives were significantly higher than that from other tissues (total VOCs: 365.7–4,266.8 ppb, $P < 0.05$; benzene: 26.4–112 ppb, $P < 0.05$; 1,3-butadiene: 15.6–384 ppb, $P < 0.05$; vinyl chloride: 0.6–1.9 ppb, $P < 0.05$). A high methanol concentration was found in surgical smoke generated during breast surgery (736.7–4,304.6 ppb) using different electrosurgical units. An electrocautery power of ≥ 27.5 watts used for skin tissues produced a higher VOCs concentration (2,905.8 ppb).

Conclusions: The surgical smoke samples collected from mammary glands using conventional electrosurgical knives had high VOCs concentrations. The carcinogens (including benzene, 1,3-butadiene, and vinyl chloride) and methanol were found in the surgical smoke samples from different electrosurgical units. The type of electrosurgical unit and electrocautery power used affected VOCs concentrations in surgical smoke.

Background

An electrosurgical machine utilizes tissue resistance to the flow of current from the electrode to convert electrical energy into heat. Tissue heating may not completely achieve during electrosurgical procedures and often accompany by surgical smoke with an unpleasant odor [1]. Surgical smoke is mainly composed of 95% water vapor, 5% suspended particles, bioaerosols, and chemical gases [2]. Hill *et al.* (2012) [3] indicated that the average daily diathermy activation time was 12 min and 43 s for surgery, and the surgical smoke production per day is equivalent to smoking 27–30 cigarettes per day.

Three factors such as human tissue, type of surgery, and electrosurgical unit influence the concentration and composition of VOCs. The increase in electrocautery power was not related to the changes in the concentrations of 1,3-butadiene, benzene, and furfural in surgical smoke [4]. A Brazil study showed that the components of VOCs in surgical smoke produced when electrocoagulating subcutaneous tissue, pork meat, and liver tissue of pigs were different [5]. The concentrations of toluene, ethylbenzene, and xylene produced from verruca extraction surgery were higher than those produced from pilonidal sinus removal surgery and abdominal surgery [6]. In addition to styrene, the mean concentrations of benzene, ethylbenzene, toluene, heptane, and methylpropene produced from electrocautery was significantly higher than those from the ultrasonic knife [7]. The National Institute for Occupational Safety and Health study indicated that the most

common components in surgical smoke were ethanol and isopropyl alcohol; other pollutants, including acetaldehyde, acetone, acetonitrile, benzene, hexane, styrene, and toluene, were also found [8]. Additionally, the electrocautery time was positively associated with the VOC concentration in the air inside the operating rooms (ORs) [9].

The United States Occupational Safety and Health Administration (OSHA) estimated that 500,000 health care personnel in ORs were exposed to surgical smoke each year [10]. A few studies have investigated the health hazards associated with surgical smoke exposure. An *in vitro* study found that surgical smoke exposure can cause apoptosis in 40% of human small airway epithelial cells and 20% of mice macrophages as well as increase the concentration of lactate dehydrogenase in both cell types, causing impairment in the cell membrane structure [11]. Moreover, a questionnaire-based study found that the risk of severe persistent asthma in OR nurses was 2.48 times higher than that in the administrative nurse after adjusting for age, body mass index, and smoking history [12]. The risk of lung cancer in OR nurses who worked for over 15 years was 0.58-fold higher than that in nurses who worked in other units of the hospital when adjusted for age, smoking history, secondhand smoke exposure, and fruit and vegetable intake. The working year had no association with the incidence of lung cancer in OR nurses [13].

To date, only a few studies have evaluated the composition and change of VOC concentration in surgical smoke under different electrocautery conditions. Therefore, this study aimed to evaluate the profile of VOCs and their concentration distribution in surgical smoke during breast surgery.

Methods

Surgical Smoke Sampling and Analysis

This cross-sectional study conducted in the breast surgery ORs of Linkuo Chang Gung Memorial Hospital in northern Taiwan. Altogether, 38 surgical smoke samples from 23 patients were collected during breast surgery (partial mastectomy, simple mastectomy, sentinel lymph node dissection, and breast reconstruction surgery) including breast skin (n = 8), breast adipose tissues (n = 6), mammary glands (n = 10), breast tumors (n = 3), abdominal skin (n = 2), and abdominal adipose tissues (n = 3) using conventional electrocautery knives as well as breast adipose tissues (n = 3) and mammary glands (n = 3) using PEAK. Additionally, background air samples (n = 3) were collected during the patients' skin disinfection procedure to evaluate the VOC concentrations from alcohol-based disinfectants.

A grab sampling technique was used with an evacuated canister for 30 s followed by the NIOSH sampling method [14]. During the sampling period, the sampling head was placed as close to the surgical site as possible, and the electrocautery unit, electrocautery power, electrocautery tissue, and indoor thermal-hygrometric conditions of the ORs were recorded. The gas chromatography mass spectrometry analysis of 87 VOCs in surgical smoke samples was performed using the NIEA A715.15B standard method of Taiwan's Environmental Analysis Laboratory [15]. Ten percent of the steel canisters were sampled for blank analysis to ensure data quality. The relative difference in duplicate measurements of the samples was below 25%, and the recovery rate of samples ranged between 70% and 130% in this study.

Statistical methods

This study used the SPSS version 25.0 (SPSS, Chicago, Illinois, USA) for statistical analysis. The figures were graphed using the GraphPad Prism 7.0 software (GraphPad Software, Inc., San Diego, CA, USA). In addition, the Matplotlib library based on Python 3.6.5 language was used for visualizing VOC profiles. The significance level was set at 0.05. The Kruskal-Wallis test and Mann-Whitney U test were used to analyze the changes in VOC concentration in surgical smoke samples in different electrocautery tissues, electrocautery units, and electrocautery power.

This study combined the VOC data from breast skin with that from abdominal skin and defined as subcutaneous tissues. In addition, VOC data from breast and abdominal adipose tissues were pooled and defined as adipose tissues.

Results

VOC Concentration Distribution During Skin Disinfection Procedures

During the skin disinfection procedure performed in surgical patients, 23 VOCs were detected in the air samples, indicating that methanol (24.9 ppb) had the highest mean concentration, followed by acetone (12.6 ppb), isopropylbenzene (4.0 ppb), toluene (3.1 ppb), and propane (1.7 ppb) (Fig. 1). Other VOCs included 2-butanone, chloromethane, (*p,m*)-xylene, alpha-methyl styrene, n-undecane, dichlorodifluoromethane, chlorodifluoromethane, n-dodecane, methylene chloride, o-xylene, benzene, trichlorofluoromethane, ethylbenzene, 1,3-dichlorobenzene, 1,2,4-trimethylbenzene, acetonitrile, m-ethyltoluene, and styrene.

Determining the Concentrations of 87 VOCs in Surgical Smoke Samples from Breast Surgeries

The thermal-hygrometric characteristics of the breast surgery ORs were 18.50–22.95°C and 41.63–56.46%. The median VOC concentration in surgical smoke samples from mammary glands (9,953.5 ppb) was significantly higher than that from breast subcutaneous tissues (2,024.4 ppb, $P < 0.01$), breast adipose tissues (1,865.9 ppb, $P < 0.01$), and breast tumors (1,308.8 ppb, $P = 0.011$) using conventional electrocautery knives as well as that from breast adipose tissues (365.8 ppb, $P = 0.011$) and mammary glands (4,266.8 ppb, $P = 0.011$) using PEAK (Fig. 2).

VOC Profile of Surgical Smoke Samples from Breast Surgeries

The mean methanol concentration (1,182.9 ppb) in surgical smoke samples from breast subcutaneous tissues using conventional electrocautery knives was the highest, followed by acetonitrile (264.7 ppb), propane (225.7 ppb), 1,3-butadiene (170.7 ppb), acrolein (82.5 ppb), acrylonitrile (77.4 ppb), acetone (65.69 ppb), 1-hexene (56.7 ppb), and benzene (52.15 ppb) (Fig. 3). The mean methanol concentration (1,088.1 ppb) in surgical smoke samples from breast adipose tissues using conventional electrocautery knives was the highest, followed by 1,3-butadiene (313.1 ppb), propane (265.5 ppb), acetonitrile (174.1 ppb), acrolein (146.7 ppb), acetone (129.5 ppb), 1-hexene (105.4 ppb), acrylonitrile (77.4 ppb), and benzene (74.1 ppb). Moreover, the median methanol concentration (4,304.6 ppb) in surgical smoke samples from mammary glands using conventional electrocautery knives was the highest, followed by acetonitrile (1,665.4 ppb), propane (1,228.2 ppb), 1,3-butadiene (1,002.8 ppb), acrylonitrile (549.6 ppb), acrolein (509.4 ppb), acetone (316.1 ppb), 1-hexene (268.4 ppb), benzene (242.5 ppb), and trans-2-butadiene (130.0 ppb). The composition of VOCs in the

surgical smoke samples from breast tumor using conventional electrosurgical knives mainly included methanol (736.7 ppb), acetonitrile (258.4 ppb), propane (88.9 ppb), acetone (83.1 ppb), acrylonitrile (68.7 ppb), acrolein (39.7 ppb), benzene (31.6 ppb), 1,3-butadiene (26.8 ppb), toluene (26.7 ppb), and chloromethane (25.3 ppb).

The predominant composition of VOCs from breast adipose tissues using PEAK included methanol (950.3 ppb), propane (243.3 ppb), 1,3-butadiene (194.2 ppb), acetonitrile (162.5 ppb), acrolein (100.2 ppb), acetone (70.0 ppb), 1-hexene (56.2 ppb), acrylonitrile (49.0 ppb), and benzene (43.6 ppb) (Fig. 2). For mammary glands, the mean methanol concentration (1,806.4 ppb) was highest, followed by acetonitrile (566.5 ppb), 1,3-butadiene (418.3 ppb), propane (299.2 ppb), acrylonitrile (183.9 ppb), acrolein (156.0 ppb), acetone (126.4 ppb), benzene (120.6 ppb), 1-hexene (88.8 ppb), and toluene (40.6 ppb).

Furthermore, this study evaluated the changes in the concentrations of carcinogenic benzene (IARC group 1) in the surgical smoke samples, indicating that the median concentration of benzene from mammary glands (222.7 ppb) was significantly higher than that from breast subcutaneous tissues (39.1 ppb, $P < 0.01$), breast adipose tissues (39.1 ppb, $P < 0.01$), and breast tumors (26.4 ppb, $P = 0.011$) using conventional electrosurgical knives, as well as that from adipose tissues (45.1 ppb, $P = 0.011$), and mammary glands (112.0 ppb, $P = 0.018$) using PEAK. In addition, the median concentration of benzene in the surgical smoke samples from mammary glands using PEAK was significantly higher than that from breast subcutaneous tissues using conventional electrosurgical knives (39.1 ppb, $P = 0.043$). For 1,3-butadiene (IARC group 1), the median concentration in the surgical smoke samples from mammary glands (856.2 ppb) was significantly higher than that from breast subcutaneous tissues (80.1 ppb, $P < 0.01$), breast adipose tissues (147.3 ppb, $P < 0.01$), and breast tumors (15.6 ppb, $P = 0.011$) using conventional electrosurgical knives as well as that from adipose tissues (210.6 ppb, $P = 0.011$) and mammary glands (384.0 ppb, $P = 0.028$) using PEAK.

With regard to IARC group 2A, no difference was observed in the median concentrations of benzyl chloride and tetrachloroethylene in the surgical smoke samples from different tissues using conventional electrosurgical knives and PEAK. The median concentrations of IARC group 2B substances, acrylonitrile (440.2 ppb) and vinyl acetate (20.2 ppb) in surgical smoke samples from mammary glands using conventional electrosurgical knives were significantly higher than that from breast subcutaneous tissues (acrylonitrile: 40.3 ppb, $P < 0.01$; vinyl acetate: 5.0 ppb, $P < 0.01$), breast adipose tissues (acrylonitrile: 43.5 ppb, $P < 0.01$; vinyl acetate: 2.9 ppb, $P < 0.01$), and breast tumors (acrylonitrile: 43.2 ppb, $P = 0.011$; vinyl acetate: 2.3 ppb, $P = 0.017$), as well as that from adipose tissues (acrylonitrile: 39.6 ppb, $P = 0.011$; vinyl acetate: 6.8 ppb, $P = 0.04$) and mammary glands (acrylonitrile: 184.0 ppb, $P = 0.018$; vinyl acetate: 8.3 ppb, $P = 0.017$) using PEAK. No differences were observed in the median levels of chloroform and carbon tetrachloride in surgical smoke samples from different breast tissues.

In IARC group 3, the median levels of acrolein (440.2 ppb), toluene (70.2 ppb), and (*p,m*)-xylene (5.1 ppb), and *o*-xylene (2.2 ppb) in surgical smoke samples from mammary glands using conventional electrosurgical knives were significantly higher than that from breast subcutaneous tissues (acrolein: 51.6 ppb, toluene: 20.9 ppb, (*p,m*)-xylene: 1.9 ppb, *o*-xylene: 0.8 ppb, $P < 0.01$), breast adipose tissues (acrolein: 64.7 ppb, toluene: 16.2 ppb, (*p,m*)-xylene: 2.2 ppb, *o*-xylene: 0.8 ppb, $P < 0.01$), and breast tumors (acrolein: 18.2 ppb, $P = 0.011$; toluene: 19.8 ppb, $P = 0.018$; (*p,m*)-xylene: 1.5 ppb, $P = 0.018$; *o*-xylene: 0.7 ppb, $P = 0.018$), as well as that

from breast adipose tissues (acrolein: 116.9 ppb, $P = 0.011$; toluene: 19.0 ppb, $P = 0.011$; (*p,m*)-xylene: 2.4 ppb, $P = 0.018$; *o*-xylene: 1.0 ppb, $P = 0.018$) and mammary glands (acrolein: 118.0 ppb, $P = 0.011$; toluene: 35.0 ppb, $P = 0.028$) using PEAK.

Effect of Electrocautery Power in the Concentrations of 87 VOCs

This study further evaluated the concentration distribution of 87 VOCs using conventional electrosurgical knives under different electrocautery power conditions (Table 1). The analytical results show that the median level of 87 VOCs from skin tissues using an electrocautery power of ≥ 27.5 watts (2,905.8 ppb) was significantly higher than that using an electrocautery power of < 27.5 watts (381.7 ppb). However, no difference was found in the median level of 87 VOCs from adipose tissues and mammary glands under different electrocautery power conditions.

Discussion

To the best of our knowledge, this study first attempted to analyze the VOC profile of surgical smoke samples from breast surgeries. The predominant component of air samples collected from the skin disinfection procedure was methanol. The source of methanol in the air samples warrants further evaluation. Moreover, the level of methanol in the surgical smoke samples from different tissues of breast surgeries using conventional electrosurgical knives and PEAK was 29.6-to-172.7-fold higher than that in surgical smoke samples during skin disinfection. Thus, the level of methanol exposure among surgeons and other medical care personnel in ORs should be evaluated. An *in vitro* experiment from NIOSH showed that the surgical smoke samples from five fibroadipose tissues from breast reduction surgeries and one below knee amputation surgery was mainly composed of ethanol (average value: $1,200 \mu\text{g}/\text{m}^3$; 37,158 ppb) and isopropanol (average value: $600 \mu\text{g}/\text{m}^3$; 18,579 ppb) [8]. In this study, ethanol and isopropanol were not included in the standard quantitative analysis of 87 VOCs. However, the semiquantitative analysis showed that the surgical smoke from breast surgery had ethanol (484–917,000 ppb) and isopropanol (11.5–62.6 ppb), which is similar to results of the NIOSH study with high percentages of ethanol (83–90%) and isopropanol (80–86%) [8]. The above difference in the concentration of two VOCs might be related to the different tissues, air sampling, and electrocautery power conditions.

Methanol can be absorbed through skin contact and inhalation. Exposure to excessive amounts of methanol vapor can suppress the central nervous system and cause optic nerve injury, such as eye irritation, headache, fatigue, and drowsiness. Exposure to 50,000 ppm of methanol causes death within 1–2 h [16]. The US OSHA recommended that the permissible exposure limits-short-term exposure limit and ceiling for methanol should not exceed 250 ppm and 1,000 ppm, respectively, to avoid the risk of developing intolerable irritation and chronic or irreversible tissue lesions, prevent accidents, or avoid the reduction in work efficiency [17]. In this study, the methanol concentration in surgical smoke samples from breast surgeries in the ORs did not exceed the recommended level set by the US OSHA [17]; the potential toxicity of methanol for humans, such as headache and vision impairment, should be investigated. The removal of surgical smoke in the operation area using a smoke evacuation system to reduce the exposure risk of medical care personnel is recommended.

A previous study showed that the concentration of 18 VOCs in surgical smoke samples from 20 surgical patients who underwent laparoscopic nephrectomy was 3,759 – 7,531 $\mu\text{g}/\text{m}^3$ (977.3 – 1,958.1 ppb) [18]. Our study indicated the concentration of 87 VOCs in surgical smoke during breast surgeries seemed to be higher than above study. The possible reasons for the concentration difference between studies might be related to the type of surgery, electrocautery power, electrocautery time, sampling period, and the number of VOCs analyzed. In this study, the substances of IARC group 1 detected in the surgical smoke samples from skin tissue, adipose tissue, mammary gland, and tumor in breast surgeries included benzene (26.35–222.65 ppb), 1,3-butadiene (15.55–112 ppb), and vinyl chloride (0.55–3.11 ppb). The levels of benzene and 1,3-butadiene in the surgical smoke samples from breast surgeries were higher than those from an *in vitro* study of pig liver tissues (benzene: 6.21 ppb, 1,3-butadiene: 2.45 ppb) and pork tissues (benzene: 19.06 ppb, 1,3-butadiene: 15.4 ppb) in Switzerland [4]. Additionally, 1,2-dichloropropane and trichloroethylene were not detected in the surgical smoke samples from breast surgeries in our study. Previous studies have found that exposure to 10 ppm of benzene for 30 years was associated with death from leukemia [19]. The incidence of lung cancer was also related to the monthly cumulative exposure to benzene and working years [20]. Moreover, long-term exposure (6 h/d, 5 d/week, 104 weeks) to 1,3-butadiene was associated with lung tumor growth in female mice [21]. Exposure to vinyl chloride (600 ppm, 4 h/d, 5 d/week, 12 months) resulted in liver tumors in male rats [22]. Therefore, the health risk of exposure to relatively low concentrations of surgical smoke in health care personnel in the ORs during breast surgery warrants further investigation.

With regard to the type of electrosurgical unit, a US study found that the mean level of benzene in surgical smoke samples from laparoscopic surgery using electrosurgical knives (85 ppb) was significantly higher than that using ultrasonic scalpels (1 ppb) [7]. Results of our study indicate that the median levels of benzene, styrene, and toluene in the surgical smoke samples from mammary glands using electrosurgical knives were significantly higher than those using PEAK, which might be due to the operation conditions and the materials of electrosurgical units. The surface temperature of PEAK (40 °C–170 °C) was lower than that of a conventional electrosurgical knife (200 °C–350 °C) [23], possibly resulting in lower VOC production from PEAK. Additionally, this study found that the changes in the concentrations of 87 VOCs in the surgical smoke samples from skin tissues in breast surgeries using conventional electrosurgical knives were associated with the electrocautery power setting. Our results differed from those reported in the Switzerland study [4], which indicated that electrocautery power was not associated with the concentrations of VOCs, including 1,3-butadiene, benzene, and furfural. The relationship between electrocautery power and the composition of VOCs in surgical smoke samples should also be evaluated further.

To avoid personal exposure to surgical smoke, effective methods should be adopted, such as using an efficient local smoke evacuation system, increasing the ventilation rate in ORs, and wearing a personal protective mask. A local smoke evacuation system and surgical masks have a limited ability to remove VOCs in surgical smokes during surgeries. Thus, this study recommends that health care settings should regularly monitor the air quality of ORs and maintain the ventilation systems to ensure the health and safety of health care personnel in the ORs. Moreover, the surgical smoke samples were collected near the surgical site to avoid interfering with the operations. The results of this study may not directly reflect the actual level of VOC exposure among surgeons and other health care personnel in the ORs, which is a limitation of this study.

Conclusions

The median level of 87 VOCs in the surgical smoke samples from mammary glands using conventional electrosurgical knives was the highest. High levels of methanol and IARC group 1 compounds, including benzene, 1,3-butadiene, and vinyl chloride were found in breast surgeries using conventional electrosurgical knives. The concentration of 87 VOCs was affected by the electrocautery power used in cutting the subcutaneous tissues.

Declarations

Ethics approval and consent to participate

- Ethics approval: Chang Gung Medical Foundation Institutional Review Board (IRB No.: 201702011B0).
- consent to participate: not applicable.

Consent for publication

YES

Availability of data and materials

- The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.
- All data generated or analyzed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization, MHC and GHW; Methodology, CHC and GHW; Investigation, MHC, HHC, CTC and GHW; Formal Analysis, CHC and CTC; Writing—original draft preparation, CHC, CTC and GHW; Writing—review & editing, MHC and GHW; Project Administration, LHP and GHW; Funding Acquisition, LHP and GHW. The authors read and approved the final manuscript.

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Tables

Table 1 Concentrations of 87 VOCs in surgical smoke from breast surgeries using electrosurgical knives under different electrocautery power conditions

ppb	Skin tissues		<i>P</i>	Adipose tissues		<i>P</i>	Mammary glands		<i>P</i>
	$\geq 27.5W$	$< 27.5W$		$\geq 35W$	$< 35W$		$\geq 35W$	$< 35W$	
	(n = 5)	(n = 5)		(n = 7)	(n = 5)		(n = 5)	(n = 5)	
Mean	3,758.8	980.4	0.047	3,189.8	1,729.3	0.462	12,275.9	9,529.6	0.602
SD	2,332.2	1,542.5		3,875.6	2,185.1		6,120.9	1,965.8	
Median	2,905.8	381.7		1,865.9	1,080.0		13,809.3	9,552.8	
25 percentiles	2,724.0	129.6		758.0	111.7		6,439.1	8,604.1	
75 percentiles	4,387.5	606.5		2,701.1	2,697.4		15,132.2	10,354.2	
Skin tissues included breast and abdominal subcutaneous tissues; Adipose tissues came from breast and abdomen.									

Figures

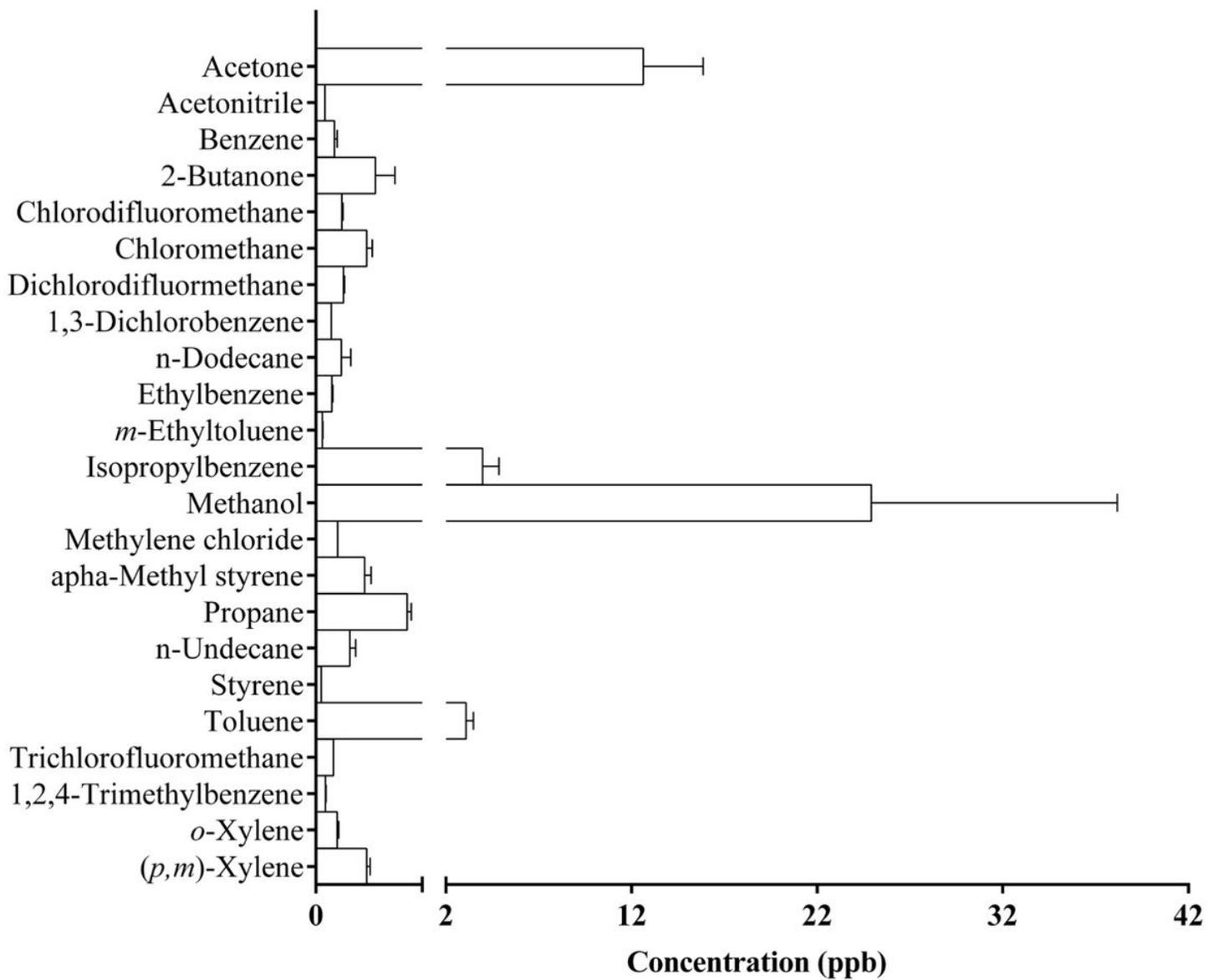


Figure 1

VOC concentration distribution in background air samples during the skin disinfection procedure. Data are represented as mean and standard error of the mean.

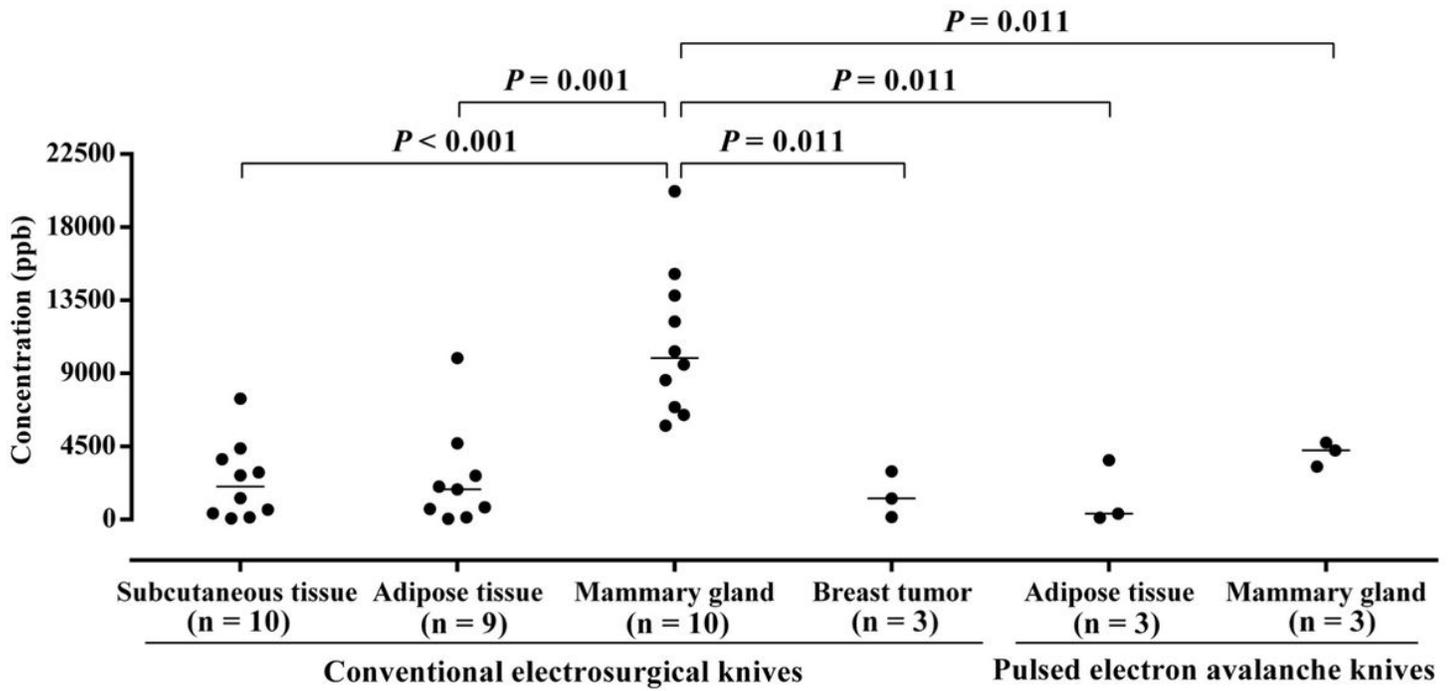


Figure 2

87 VOCs concentrations in surgical smoke samples from breast surgeries using electrocautery knives and PEAK. PEAK: pulsed electron avalanche knives

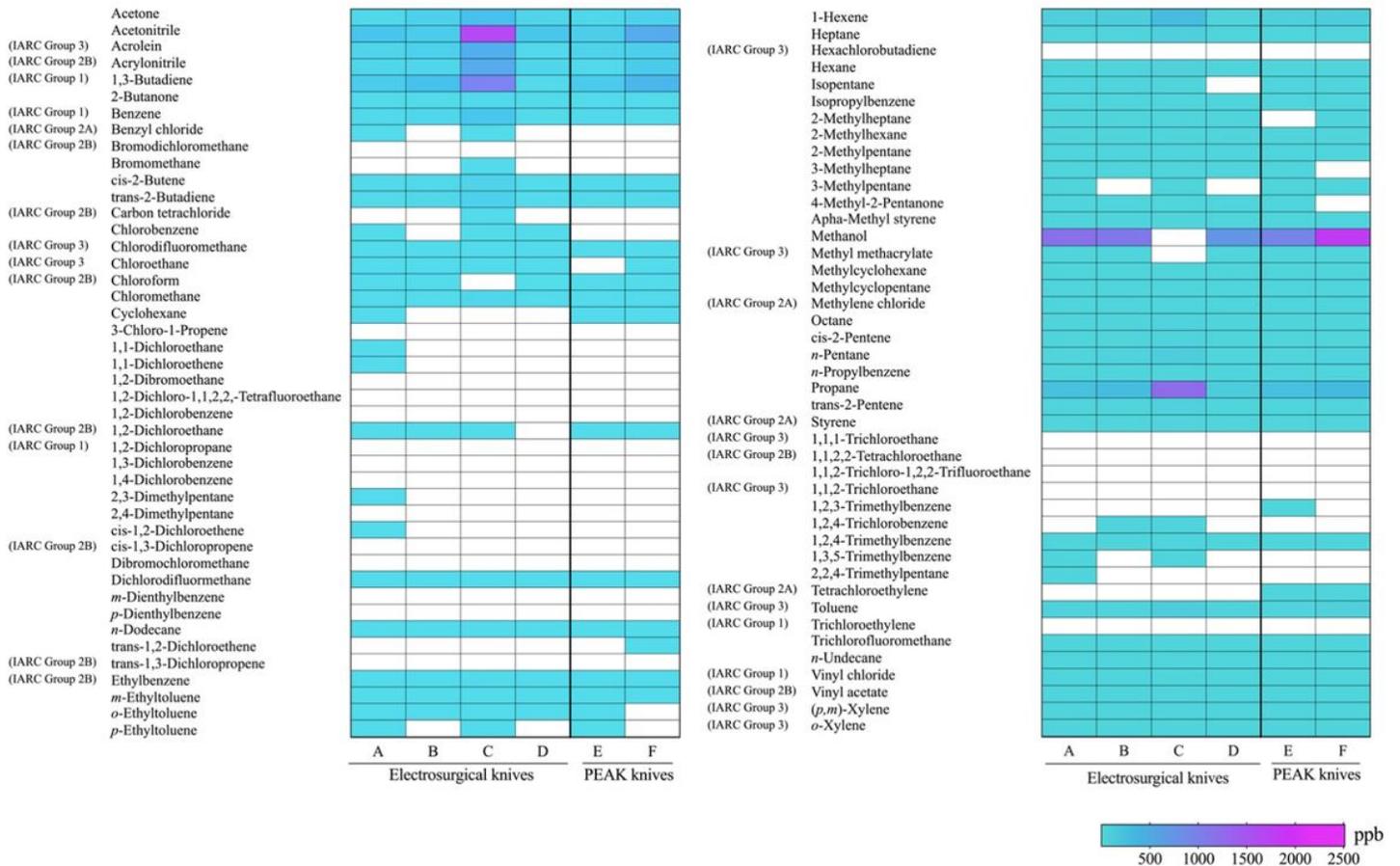


Figure 3

VOC profile in surgical smoke samples from different tissues using two electrosurgical units. A: breast subcutaneous tissue, B and E: breast adipose tissue, C and F: mammary gland, D: breast tumor.