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Original Article

A Novel Inspection Protocol to Detect Volatile Compounds in Breast Surgery Electrocautery Smoke

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Background/Purpose: Electrocautery procedures generate malodorous smoke. This study quantified five volatile organic compounds detected in the smoke produced during breast surgery, and elucidated the factors that affect their chemical production.
Methods: All samplers were assembled in an acrylic chamber with a Tygon tube attached to the tip of a diathermy pencil. The electrocautery smoke was quantified by gas chromatography/mass spectrometry.
Results: In all samples, toluene was identified in concentrations of 2.48–5.50 mg/m^3. Higher concentrations were observed during modified radical mastectomy procedures. Patients with high body mass index revealed high toluene concentrations. Longer duration of electrocautery tended to produce more toluene.
Conclusion: The sampling protocol enabled acquisition of smoke samples near the source without interrupting surgery. The findings suggest that type of surgery, patient body mass index and duration of electrocautery are factors that can alter production of chemicals.

Key Words: diathermy, surgical plume, volatile compounds

Electrosurgical instruments have been widely used since their first use by William T. Bovie and Harvey Cushing in 1745.[1] Varying quantities of smoke are produced when tissues are cut or coagulated by the electrosurgical unit. The smoke is known to be both biologically and chemically hazardous. The gaseous chemical contaminants create an extremely offensive odor. According to the National Institute for Occupational Health and Safety (NIOSH) health hazard evaluation reports for three hospitals in the United States, more than 50% of the surveyed operating room personnel reported annoyance with the odor of surgical smoke.[2–4]

Eighteen chemicals in surgical smoke have been quantified in several studies of operating theaters.[1,5–8] The major chemical groups are hydrocarbons, nitriles, fatty acids and phenol.[9] Benzene soluble organic compounds have been found in the smoke produced during reduction

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mammoplasty, at concentrations between 0.2 mg/m^3 and 1.2 mg/m^3.[10] A toluene concentration of 460 μg/m^3 and benzene concentration of 71 μg/m^3 have been documented in the electrocautery smoke produced during standard colorectal surgery.[6] Eleven gaseous chemicals have been identified and quantified using laser photoacoustic spectroscopy in common reduction mammoplasty. All chemical concentrations were lower than general occupational permissible exposure levels, except furfural (24 ppm), which was 12 times higher than the occupational permissible exposure levels.[1] Several volatile organic compounds (VOCs) such as hydrogen cyanide (3–51 ppm), acetylene (2–8 ppm) and 1,3-butadiene (0.15–0.69 ppm) have been identified in diathermy plumes during abdominal surgery.[11] Formaldehyde, acetaldehyde and toluene are present in the ambient air of operating rooms and within the breathing zone of surgical personnel.[2–4] The levels of these compounds were below the criteria for occupational exposure.

The primary aim of this air sampling study was to quantify potentially hazardous sniffed chemicals in the smoke produced by electrocautery. We employed a special sampling chamber to collect smoke produced near the tip of the electrocautery knife, without interrupting the surgical procedures. The second aim was to characterize the factors that affect the production of chemicals in smoke during electrosurgery.

Materials and Methods

Operating theaters

Smoke sampling was performed in the general operating theaters for mammoplasty at a medical research center in Taiwan. A laminar flow ventilation system provided 6–8 air changes per hour. The entire dissection and resection during mammoplasty was carried out using monopolar electrocautery (Sabre Electrosurgical generator; ConMed Corporation, Utica, NY, USA). The energy modes were set at 15 W for cutting and 30 W for coagulation.

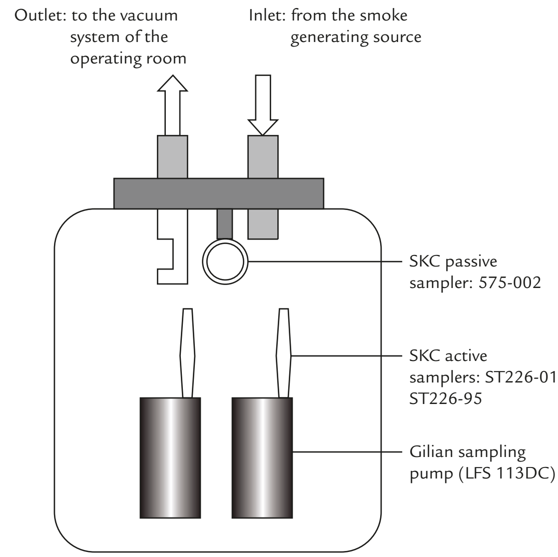

Figure 1. Sampling apparatus—acrylic sampling chamber.

Sample collection and analysis

The following five VOCs were investigated: toluene, styrene, xylene, phenol and furfural. All air samplers were arranged into a 2.5-L acrylic chamber (Figure 1). The inlet port was connected to the tip of the electrocautery pencil by a sterile Tygon tube. The open end of the tube was affixed with surgical tape 2–3 cm away from the pencil tip. The outlet port of the chamber was connected to the suction vacuum to draw the smoke into the chamber. A smoke tube (SKC Inc., Eighty Four, PA, USA) enabled observation of the air current inside the chamber so the suction force could be set. The smoke diffused uniformly when the suction pressure was set at −220 mmHg. The sampling apparatus was positioned beneath the operating table to enable sampling close to the origin of the smoke without interrupting the procedures, and avoiding possible contamination of the patients. Toluene, styrene and xylene were collected by the SKC 575-002 passive sampler with a designed sampling flow rate of 17.1 mL/min (SKC Inc.). Phenol was sampled by the SKC ST226-95 sampler at a sampling flow rate of 100 mL/min (SKC Inc.). Furfural was absorbed by the SKC ST226-01 charcoal tube at a sampling flow rate of 100 mL/min (SKC Inc.). All sampling procedures followed NIOSH recommended methods for each investigated chemical.[12–14]

All samples were analyzed with an HP 6890 gas chromatograph with an HP 5MS capillary column (30 m × 0.25 mm, internal diameter, 0.25 μm) and an Agilent 5937N mass spectrometer. For gas chromatography/mass spectrometry detection, an electron ionization system with an ionization energy of 70 eV was used. The carrier gas was helium at a linear velocity of 27 cm/sec. The chemicals in each sample were quantified using the internal standard method. The internal standards were 17.60 ng/μL ethyl benzene for toluene, styrene and xylene, 8.60 ng/μL toluene for phenol, and 21.30 ng/μL 2-heptanone for furfural in the calibration standards and samples. The lowest mass of detection (LOD) for each investigated chemical was: 1.35 μg/sample for toluene, styrene and xylene; 2.7 μg/sample for phenol; and 2.0 μg/sample for furfural.

Results

Smoke samples were collected during five different types of breast surgery. Patient body mass index (BMI) ranged from 20.8 to 27.9 (mean = 23.4). Patient age was 37–76 years (mean = 54 years). Four cases were breast cancer treated with modified radical mastectomy. One case was a breast tumor treated with partial mastectomy. The duration of electrocautery treatment ranged from 18.8 minutes to 41.1 minutes (mean = 27.5 min).

Toluene was detected in all five cases. The only case that had undergone partial mastectomy revealed the lowest toluene concentration (2.48 mg/m^3). In the other four modified radical mastectomy cases, toluene concentration exceeded 3.50 mg/m^3. Although these differences apparently indicate that the type of surgical procedure affects chemical concentrations, this was not statistically correlated according to the present study, due to the incomparable sample sizes. Additionally, as Figure 2 illustrates, the measured toluene concentrations in the four modified radical mastectomy cases tended to increase with patient BMI (correlation coefficient = 0.79). Subjects were classified as overweight if their BMI exceeded 24.99, in accordance with World Health Organization standards.[15] The BMI of two cases exceeded 24.99 and showed higher toluene concentrations in quadrant I (Figure 2). Greater attention to reduce possible exposure should be paid by the operating staff if the patients are overweight. This study is believed to be the first to reveal that patient BMI is a simple indicator for estimating exposure risk.

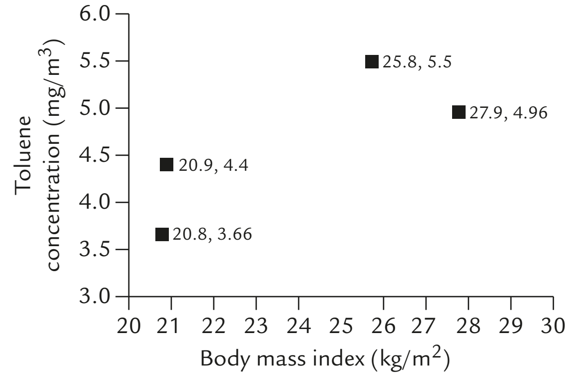

Figure 2. Effect of patient body mass index on toluene concentration.

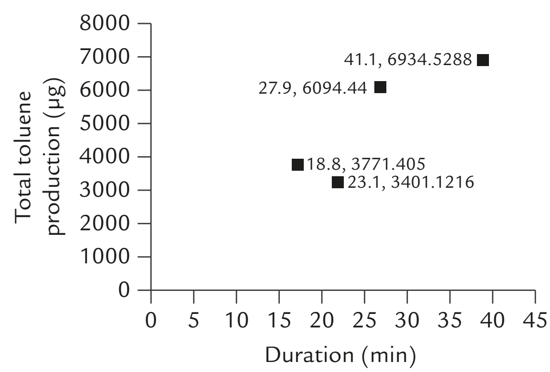

Figure 3. Correlation between duration of electrocautery and total toluene production.

To investigate the effects of varying durations on electrocautery, toluene production was plotted against duration in minutes, as shown in Figure 3. The long duration seems to lead to a high production of toluene. The correlation coefficient was 0.88.

Discussion

An acrylic chamber for sampling was developed to assemble all samplers together. The electrocautery smoke was drawn into the chamber with the operating room vacuum system. This design proved effective for collecting smoke throughout the operating procedure, without interfering with the surgical procedure. A similar sampling design was performed by Sager et al,[6] with the exception of the chamber apparatus. Our chamber design draws most of the smoke into the acrylic chamber and collects various chemicals with different collection media simultaneously. In term of the LODs of the investigated chemicals, only that of phenol at 2.7 μg/sample was higher than the United States Occupational Safety and Health Administration (OSHA) sampling and analytical method 32 (LOD = 0.97 μg/sample), which uses high-performance liquid chromatography with a UV detector as the analytical instrument.[16] The LODs of other investigated chemicals were superior to those detected by either NIOSH or OSHA methods.[12–14,17–20]

Sager et al collected smoke samples taken near the tip of the electrocautery pencil during standard colorectal surgery, and reported a maximum toluene concentration of 460 $\mu g/m^3$, which is lower than those observed in the present study.[6] This indicates that chemical concentrations in electrocautery smoke vary with the surgical tissues. Hollmann et al[1] reported a toluene concentration of 17 ppm during reduction mammoplasty, which exceeds the maximum concentration of 1.45 ppm (5.50 mg/m^3) observed in the current study. Additional patient data could have revealed the cause of this discrepancy because BMI is a possible factor in smoke composition and chemical concentration. Three NIOSH health hazard evaluation reports of Morton Plant Hospital (Dunedin, FL, USA), Ionva Fairfax Hospital (Falls Church, VA, USA), and Carolina Medical Center, (Charlotte, NC, USA) have reported various toluene concentrations associated with various breast surgery procedures. The highest concentration was 0.17 ppm during breast tissue expander surgery, and the concentrations during mastectomy were lower than 0.1 ppm.[2–4] These concentrations are lower than those observed in the present study. The different sampling positions between the two studies could explain the divergence. All NIOSH samples were typically taken within several feet of the surgical table at an average shoulder height. In the current study, surgical smoke was drawn into the collection chamber immediately after being generated. This efficient collection resulted in a high concentration. Krones et al[21] detected toluene in surgical smoke that was generated while cutting pork liver by electrocautery at 120 W for 20 minutes. The maximum concentration was 141.0 $\mu g/m^3$, which was also lower than the maximum level reported here. This difference could have been due to the varying compositions of the tissues.

Except for cigarette smokers and those who work with toluene-containing products, the United States public are generally exposed to about 300 μg of toluene daily. Those who smoke a pack of cigarettes per day are exposed to an additional 1000 μg.[22] The minimum toluene production in the present study (five cases) was 2252 μg. The toluene produced during a single breast surgery procedure exceeded that produced by smoking a pack of cigarettes. However, the sampling strategy was not intended to assess personnel exposure directly. Chronic exposure to lower toluene levels could be hazardous to operating room personnel. According to the Agency for Toxic Substance and Disease Registry, the minimal risk levels for inhalation exposure are 1 ppm (3.8 mg/m^3) for acute duration ($\leq$ 14 days) and 0.08 ppm (0.3 mg/m^3) for chronic duration ($\geq$ 365 days), for neurotoxic effects and color vision impairment, respectively.[23] From the perspective of risk assessment, the toluene concentrations observed in the present investigation exceeded both of these minimal risk levels. The health effects on operating room personnel can never be overemphasized in low-level chronic exposure situations.

The presence of styrene, xylene, phenol or furfural was not confirmed because these chemical concentrations were lower than the LODs for the methods used to analyze the five surgical smoke samples. Furfural was detected in 24 ppm during breast reduction surgery and 0.106–0.434 ppm during laparotomy for abdominal surgery.[1,11] In a study by Hollman et al, a single sample was collected during breast surgery.[1] No information regarding the electrocautery energy or the treatment duration was disclosed. It is not easy to explain the difference between the Hollman et al study and the current study, with the limited sampling information. The differences might have been due to patient BMI, imparted energy, or types of surgery. Xylene has been observed during all applications of electrocautery in a pig model, in the muscle, liver, adherent subcutaneous fatty tissue and skin.[21] The utilized energy was 120 W for cutting and coagulation modes. However, the energy settings in the current study were 15 W for cutting and 30 W for coagulation, which were lower than those reported in the study of Krones et al.[21] The chemical compositions of the plumes fluctuated widely depending on the nature and pathology of the treated tissue, the surgical technique, type of energy and application time.[10] Combined with data reported elsewhere, this study indicates that all of these factors might contribute to the variation in composition and chemical concentration of electrocautery smoke.

Electrocautery smoke samples are independent and unrepeatable. Certain factors, such as patient demographic data, duration of operation and electrocautery application time are uncontrollable. More data are needed to identify the statistically significant factors related to chemical composition and concentration. In the present study, electrocautery smoke samples were taken from as close to the source as possible. The data collected in this study might be a useful reference for investigating the chemical composition and concentration of electrocautery smoke. The NIOSH health hazard evaluation reports illustrate that the concentrations of the environmental air samples and the personal samples from a single mastectomy procedure do not significantly differ.[2–4] However, these results must be applied cautiously to personal exposure assessment, because of the different sampling strategies. Meanwhile, the long Tygon tube application before reaching the sampling chamber might underestimate VOC production as a result of absorption of VOCs by the tube. Even if operating personnel are not physically close to the electrocautery tip, and even if the laminar flow ventilation system of the operating theater dilutes the chemical concentrations in the operating room, surgical personnel might still find the odor uncomfortable.

Toluene was produced in the diathermy plume during mastectomy procedures. The toluene concentrations within the diathermy plume apparently exceeded the Agency for Toxic Substance and Disease Registry minimal risk levels. However, further studies of the long-term adverse health effects from low-level exposure are still needed. In conclusion, surgery type, patient BMI and duration of electrocautery should be considered by operating staff when assessing exposure risk.

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