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ORIGINAL ARTICLE

Chemical composition of smoke produced by high-frequency electrosurgery

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Abstract

Background Exposure to surgical smoke during electrosurgery may be harmful to theatre personnel. This study quantified toxic compounds present and we were particularly interested in isolating toluene, ethylbenzene and xylene due to their putative carcinogenic effects.

Methods A variety of surgical procedures were studied. Smoke samples emitted during electrosurgery were collected in charcoal tubes and analysed by gas chromatography coupled with mass spectrometry.

Results Surgery involving mainly thermal decomposition of adipose tissue produced greater quantities of aldehydes and lower concentrations of toluene. In contrast, smoke generated during epidermal tissue ablation produced higher levels of toluene, ethyl benzene and xylene.

Conclusion This study demonstrated the presence of irritant, carcinogenic and neurotoxic compounds in electrosurgical smoke. This may have considerable implications for the health and safety of all involved in surgical practice, as exposure to these compounds pose potential risks to health.

O.S. Al Sahaf and I. Vega-Carrascal contributed equally to this work. Aspects of this work were presented at the 31st Sir Peter Freyer Memorial Lecture and Surgical Symposium (*Irish J Med Sci* 2006; 175(3)S1:87).

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Introduction

The potential hazard of surgical smoke has been a source of concern over recent years. Numerous studies have attempted to determine the risks that these aerosols pose both to patients and surgeons [1]. As a result, protective measures such as the use of masks and surgical smoke evacuation systems have been recommended [2]. Unprotected exposure to electrosurgical by-products is still a common practice in many operating theatres. The long term effects of surgical smoke on surgeons and theatre personnel have not been determined. Furthermore, the mutagenicity of benzene cannot be underestimated.

The composition of surgical smoke is markedly variable. The nature and size of the particles generated depend greatly on the type of procedure, energy used and power levels employed [1]. This study focused on its chemical composition. Smoke created both with laser and electrocautery contains mainly hydrocarbons, nitriles, fatty acids and phenols [3]. Of these, formaldehyde, acrolein, mixtures of benzene, toluene, ethylbenzene, xylene (BTEX), and polyaromatic hydrocarbons are of most concern. The presence of chemical toxins may result in pulmonary irritation and inflammation of the respiratory tract [4, 5]. In addition to contributing to the noxious odour of the smoke, these chemicals are known irritants. In the case of polyaromatic hydrocarbons, benzene and formaldehyde, they are known carcinogens. The toxicity of surgical smoke has been estimated to be similar to cigarette smoke. The mutagenic potential of thermal destruction of 1 g of tissue has been calculated to be equivalent to three cigarettes with tissue ablation and up to six cigarettes with electrocautery [6].

The aim of this study was to measure the volatile compounds of smoke produced during surgery employing tissue ablation and electrocauterisation using gas chromatography coupled with mass spectrometry.

Materials and methods

Sample collection and preparation

Sorbent sample tubes were constructed in the laboratory by filling glass Pasteur pipettes with 0.85 g activated carbon (DGK 0.2–0.6, Rütgers, Carbotech GmbH) and plugging both ends with cotton wool. Each sorbent tube was wrapped individually in tin-foil to prevent contamination and stored at room temperature prior to use.

The sorbent tubes were placed in the evacuation system while the smoke was generated during surgical procedures. Once the volatiles were trapped on the charcoal tubes, the tubes were removed from the system, sealed in tin-foil and returned to the laboratory for analysis. Charcoal tubes not processed on receipt were stored at −15°C. To analyse the volatiles, each sample of charcoal was emptied into a stoppered glass bottle. Two by 1 ml of dichloromethane (DCM) were added and vortexed for 2 min. The solvent phase was pipetted into a clean millifuge tube with a glass Pasteur pipette. The sample was then centrifuged for 1 min and the supernatant transferred into a clean glass tube. For chromatographic analysis of contents, 1 µl of the supernatant was injected onto the chromatographic column. Samples obtained at surgery were concentrated after extraction to half the original volume by allowing evaporation at room temperature. Values were calculated using extracted calibration curves obtained for certified BTEX during the validation of the method. The remaining compounds were identified and estimated by extrapolation using toluene standards. Results were expressed as microgram per millilitre of DCM.

Gas chromatography-mass spectrometry analysis

Sample analysis was performed using a 5890 Series II (Hewlett Packard) gas chromatograph, coupled to a 5971A mass spectrometer (Hewlett Packard). Compounds were separated using a 30 m HP5 column (30 m 0.32 μ ID, 0.25 µm film) (Agilent Technologies). Each sample (1 µl) was manually injected into the gas chromatograph. The oven was programmed at 30–300°C, ramped at 20°C/min, after initial maintenance for 7 min at 30°C and finally held for 5 min at 300°C with helium as a carrier gas (0.5 ml/min). The injector and detector temperatures were 120°C and 280°C, respectively. The detector was routinely started after 2 min to prevent overloading. The lower limit of mass detection was set at 50, unless the compounds suspected to be present in the extract required lower limits of detection due to the formation of ions with mass below 50. All the results were processed by library mass spectral data comparison to identify compounds eluted (Wiley 275). Quantitative analysis was performed by integration of selected ion chromatographic peaks. The programme described above was a modification of the one previously described by Stankiewicz [7], which was found to provide excellent separation of toluene, ethylbenzene and xylene as well as other organic compounds present in surgical smoke. Quantitation was validated using certified standards for benzene, toluene, ethylbenzene and xylenes (BTEX) and other compounds were quantified using toluene as reference standard.

Samples from patients undergoing surgery were collected at Our Lady's Hospital, Navan. Charcoal cartridges prepared in the laboratory were provided for sample collection. A sample sorbent tube was inserted into the suction extraction system attached to a standard diathermy pencil. The suction extraction system consisted of a diathermy needle with a circular opening on its distal surface. This opening communicated with suction tubing on the end of the pencil. The smoke generated was directed into the mouth, followed by a standard suction canister, and then into the suction unit (−40 Kpa). A diathermy setting of 70 W was used to ablate tissue and to ensure haemostasis by cauterisation. After the volatile compounds were collected, the charcoal tubes were removed from the system, wrapped in tin-foil, and sent to the laboratory for analysis.

Clinical samples were collected during the cauterisation of tissue on excision of verrucae ($n = 2$), excision of pilonidal sinuses ($n = 2$) and also during abdominal procedures such as reversal of ileostomy ($n = 9$). This involves incision through the skin and adipose tissue with ablation of these tissues. The use of diathermy was stopped upon fascia and/or muscle encounter. Electrocauterisation was carried out to ensure homeostasis. Smoke was collected throughout the procedure for a total duration of approximately 20 min, depending on the adipose layer size. Verruca excision involved mainly skin ablation. The smoke generated was collected throughout the procedure. The duration of the procedure was 10 min on average but varied depending on the amount and size of the verrucae. Pilonidal sinus excision involved incision through the skin, adipose tissue ablation and cauterisation to ensure homeostasis. Smoke was collected throughout the procedure for a total duration of approximately 15 min.

Results

Different types of tissues yielded varying chromatographic profiles after being subjected to electrosurgery. Clinical samples analysed in this study identified the presence of *n*-alkanes, *n*-alkenes and aldehydes as well as toluene, ethylbenzene and xylene. Other potential toxic or irritant compounds identified in surgical smoke were cyclohexanone, and perchloroethylene (PCE) in lower amounts. The production of cyclohexanone seemed to be inversely proportional to the toluene concentration. Table 1 lists the compounds of greatest concern identified in electrosurgical smoke.

Discussion

Despite numerous studies, the composition of smoke produced by electrosurgery remains unclear and a number of studies report the difficulties in obtaining reproducible results from real electrosurgical smoke investigations [2, 5]. Some researchers report the presence of BTEX compounds [1, 5] whereas others could not identify benzene or other BTEX components in vivo [8] or in simulation studies [9].

Table 1 Compounds identified in electrosurgical smoke

Compound	Verruca extraction (μg/ml DCM)	Pilonidal sinus removal (μg/ml DCM)	Abdominal surgery (μg/ml DCM)
Cyclohexanone	6.13	19.9	48.6
Decene	ND	1.86	4.79
Decane	2.20	0.6	3.00
Dodecene	ND	1.21	4.01
Dodecane	23.06	0.95	4.35
Ethylbenzene	3.23	D	D
Heptanal	ND	ND	0.31
Nonanal	ND	ND	6.06
n-propylbenzene	ND	ND	D
Pentadecane	ND	0.6	D
Perchloroethylene	0.35	D	0.03
Tridecane	0.50	0.72	0.11
Tetradecane	1.86	0.95	0.19
Tetradecene	ND	0.31	0.58
Toluene	4.39	2.11	0.80
Undecane	2.09	0.68	5.76
Undecene	ND	1.17	1.00
Xylene	6.06	D	D

ND not detected, *D* detected below detection limit

Verruca extraction ($n = 2$), pilonidal sinus removal ($n = 2$), abdominal surgery ($n = 9$)

It has been reported that the nature of the surgical procedure determined the smoke content. The cauterisation process had been demonstrated to generate more complex and toxic gaseous mixtures [1]. In contrast, ultrasonic (harmonic) scalpels produce less noxious plume since the process is carried out at low temperature vaporisation [1]. In this study, standard diathermy equipment was used for all surgical interventions (verruca extraction, removal of pilonidal sinus and reversal of ileostomy).

The samples analysed show a high degree of similarity according to the type of surgery undertaken. Toluene was consistently identified and other BTEX compounds were detected at smaller concentrations during verruca extraction. Cyclohexanone was found as a major component during abdominal surgery. Other compounds identified in surgical smoke include *n*-alkanes, *n*-alkenes, aldehydes and aromatic compounds in smaller quantities. These findings suggest that the type of surgery determined whether toluene or cyclohexanone are produced preferentially. In previous studies, pyrolysis of human foot skin was shown to produce predominantly toluene [7], whereas human fat thermal decomposition produced toluene in small amounts [10, 11].

Cyclohexanone is a potent respiratory irritant. It is classified as a suspected carcinogen for humans and suspected neurotoxicant. The airborne exposure limit is set at 50 ppm by OSHA. PCE was identified in both verruca extraction and abdominal surgery. PCE exposure limits are set at 25 ppm by OSHA. Epidemiological studies suggest increased risk on exposure to PCE for several types of cancer, therefore, it is classified by the EPA as potentially carcinogenic for humans. Additionally, reproductive and neurological adverse effects have been reported.

In this study, the presence of irritant, carcinogenic and neurotoxic compounds in electrosurgical smoke was demonstrated. Toluene, ethylbenzene and xylene were quantified and other volatile compounds were estimated using standard toluene. The content of these compounds had been estimated to be similar to cigarette smoke [12]. Surgeons and operating room personnel should be informed about the potential hazards of surgical smoke. Measures should be implemented to reduce this potentially serious occupational risk. This study may contribute to heightening the awareness of the potential risks that exposure to surgical smoke poses to the health of all involved in surgical practice.

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