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Top 5 Articles
to
Promote Surgical Smoke

Listing of Top 5 Articles

1. **Surgical smoke- A health hazard in the operating theatre: A study to quantify exposure and a survey of the use of smoke extractor systems in UK plastic surgery units**
   - Published: Journal of Plastic, Reconstructive & Aesthetic Surgery (2012) 65, 911e916
   - Link: http://buffalofilter.com/files/6814/1409/2676/Surgical_smoke_e_A_health_hazard_in_the_operating.pdf

   Article Summary:
   This study looked at the contents of surgical plume in the United Kingdom from plastic surgery centers. Their results revealed the equivalent mutagenicity and other hazards as smoking 27-30 cigarettes per day for OR staff. The contents of the plume were very similar to those of tobacco smoke and have the same disease causing capability.

   - Key Points:
     - The total daily duration of diathermy use in a plastic surgery theatre was electronically recorded over a two month period
     - Data was collected over 44 operating days and it was found that the mean daily diathermy activation time was 12 min and 43 seconds
     - On average the smoke produced daily was equivalent to 27-30 cigarettes
     - The World Health Organization states that non-smokers who are exposed to passive (tobacco) smoke are exposed to the same carcinogenic risk as the active smokers themselves

2. **Chemical Composition of Surgical Smoke Formed in the Abdominal Cavity During Laparoscopic Cholecystectomy Assessment of the Risk to the Patient**
   - Published: International Journal of Occupational Medicine and Environmental Health 2014;27(2):314 – 325
   - Link: http://buffalofilter.com/files/9414/1502/4548/ChemicalCompSurgicalSmokeAbdominalLaparoscopicCholecystectomy.pdf

   Article Summary:
   This article discusses the finding of various xenobiotics in patient urine following laparoscopic cholecystectomy. These chemicals, including benzene, xylene and toluene, were absorbed by the patient from surgical smoke in their abdomen during laparoscopy and found by urinalysis post operatively. They also discuss various risk factors to the patient from the absorption of these chemicals, including the possibility of fetal harm.

   - Key Points:
     - The selected biomarkers of exposure to surgical smoke included benzene, toluene, ethylbenzene and xylene
     - Their concentrations in the urine samples collected from each patient before and after the surgery were determined by SPME-GC/MS.

- The average concentrations of benzene and toluene in the urine of the patients who underwent laparoscopic cholecystectomy, in contrast to the other determined compounds, were significantly higher after the surgery than before it, which indicates that they were absorbed.
- The source of the compounds produced in the abdominal cavity during the surgery is tissue pyrolysis in the presence of carbon dioxide atmosphere.
- All patients undergoing laparoscopic procedures are at risk of absorbing and excreting smoke by-products.
- Exposure of the patient to emerging chemical compounds is usually a one-time and short-term incident, yet concentrations of benzene and toluene found in the urine were significantly higher after the surgery than before it.
- Benzene diffuses across the placenta and is considered to be fetotoxic.
- It appears that laparoscopic procedures in pregnant women may be a subject to some risk to the fetus.
- The second chemical compound for which we revealed a significant increase in the urine of the operated patients was toluene.
- Toluene, unlike benzene, does not have carcinogenic effect. There are a number of developmental consequences particularly neurodevelopmental changes that have been reported in children of the women who abused toluene during pregnancy.

3. HPV Positive Tonsillar Cancer in Two Laser Surgeons

- Published: Rioux et al. Journal of Otolaryngology - Head and Neck Surgery 2013, 42:54 http://www.journalotohns.com/content/42/1/54
- Link: http://journalotohns.biomedcentral.com/articles/10.1186/1916-0216-42-54

Article Summary:

A 53 year-old male gynecologist presented with human papillomavirus (HPV) 16 positive tonsillar squamous cell carcinoma. He had no identifiable risk factors with the exception of long term occupational exposure to laser plumes, having performed laser ablations and loop electrosurgical excision procedures (LEEP) on greater than 3000 dysplastic cervical and vulvar lesions over 20 years of practice. The second patient is a 62 year old male gynecologist with a 30 year history of laser ablation and LEEP who subsequently developed HPV 16 positive base of tongue cancer. He also had very few other risk factors for oropharyngeal cancer or HPV infection. HPV is a probable causative agent for oropharyngeal squamous cell carcinoma and has been reported as being transmittable through laser plume.

- Key Points:
    - A 53 year-old male gynecologist presented with human papillomavirus (HPV) 16 positive tonsillar squamous cell carcinoma.
    - He had no identifiable risk factors with the exception of long term occupational exposure to laser plumes.
    - Had performed laser ablations and loop electrosurgical excision procedures (LEEP) on greater than 3000 dysplastic cervical and vulvar lesions over 20 years of practice.
    - A 62 year old male gynecologist with a 30 year history of laser ablation and LEEP who subsequently developed HPV 16 positive base of tongue cancer.
    - Had very few other risk factors for oropharyngeal cancer or HPV infection.
    - The association of his diagnosis with workplace exposure warranted his receipt of worker's compensation.
    - There is now a strong body of evidence supporting a causal relationship between oncogenic HPV types and head and neck squamous cell carcinomas.
    - It is also recognized that HPV may be transmitted through laser plume.
    - Long term occupational exposure to laser plumes may lead to HPV infection and oropharyngeal squamous cell carcinomas.

4. Bovie Smoke: A Perilous Plume

- Published: 10 Vol. 17, No. 1 • 2008 • AANS NEUROSURGEON
- Link: http://www.aans.org/bulletin/pdfs/Vol%2017_1_08.pdf

Article Summary:
Surgical smoke plume, often referred to as Bovie smoke, is examined in this article from a number of different facets. Taken from the American Association of Neurological Surgeons Journal, the author outlines the hazards by first making the comparison of plume contents, both laser and electrosurgical, to that of cigarette smoke in potential toxicity. Furthermore, he examines the mutagenic, carcinogenic, and neurotoxic compounds that reside within surgical plume. Finally, he concludes his discussion with an examination of inert and biologically active particles that are propelled in to the air space when cellular disruption takes place, either through laser or electrosurgical means.

- Key Points:
    - A comparison of laser plume and electrosurgical smoke shows little difference in terms of the health risk, and in some respects the electrosurgical smoke poses a greater risk
    - A study that directly compared electrosurgical smoke with laser plume and tobacco smoke showed that electrosurgical smoke is

more toxic than laser plume or tobacco smoke *(Dikes CN: Is it safe to allow smoke in our operating room? Today's Surg Nurse 21(2):15–21, 1999)*

- Surgical smoke behaves as:
  - A carcinogen
  - A mutagen
  - An infectious vector
  - Can induce inflammatory and allergic responses in some people.
- Regulations suggest that a smoke evacuator nozzle be kept within two inches (5.08 cm) of the surgical site to maximize effective capturing of airborne contaminants.
- Evacuation of surgical smoke near the source has the greatest likelihood of preventing exposure and any health consequences associated with it.

5. Surgical Smoke and Infection Control

- Published: Journal of Hospital Infection (2006) 62, 1–5
- Link: http://www.journalofhospitalinfection.com/article/S0195-6701%2805%2900077-0/abstract

Article Summary

Gaseous byproducts produced during electrocautery, laser surgery or the use of ultrasonic scalpels are usually referred to as 'surgical smoke'. This smoke, produced with or without a heating process, contains bio-aerosols with viable and non-viable cellular material that subsequently poses a risk of infection (human immunodeficiency virus, hepatitis B virus, human papillomavirus) and causes irritation to the lungs leading to acute and chronic inflammatory changes.

- Key Points:
  - Gaseous by-products produced during electrocautery, laser surgery or the use of ultrasonic scalpels are usually referred to as surgical smoke.
  - This smoke, produced with or without a heating process, contains bio-aerosols with viable and non-viable cellular material that subsequently poses a risk of infection (HIV, HBV, and HPV) and causes irritation to the lungs leading to acute and chronic inflammatory changes.
  - Surgical smoke causes:
    - Acute and chronic inflammatory changes in respiratory tract (emphysema, asthma, chronic bronchitis)
    - Hypoxia/dizziness
    - Eye irritation
    - Nausea/vomiting
    - Headache

- Sneezing
- Weakness
- Lightheadedness
- Carcinoma
- Anxiety
- Anemia
- Leukemia
- Dermatitis
- Colic
- Throat irritation
- Cardiovascular dysfunction
- Lacrimation (watery eyes)
- Nasopharyngeal lesions
- Human immunodeficiency virus
- Hepatitis

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Surgical smoke — A health hazard in the operating theatre. A study to quantify exposure and a survey of the use of smoke extractor systems in UK plastic surgery units

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KEYWORDS
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Diathermy;
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Risk;
Extractor

Summary Surgeons and operating theatre personnel are routinely exposed to the surgical smoke plume generated through thermal tissue destruction. This represents a significant chemical and biological hazard and has been shown to be as mutagenic as cigarette smoke. It has previously been reported that ablation of 1 g of tissue produces a smoke plume with an equivalent mutagenicity to six unfiltered cigarettes. We studied six human and 78 porcine tissue samples to find the mass of tissue ablated during 5 min of monopolar diathermy. The total daily duration of diathermy use in a plastic surgery theatre was electronically recorded over a two-month period. On average the smoke produced daily was equivalent to 27–30 cigarettes. Our survey of smoke extractor use in UK plastic surgery units revealed that only 66% of units had these devices available. The Health and Safety Executive recommend specialist smoke extractor use, however they are not universally utilised. Surgical smoke inhalation is an occupational hazard in the operating department. Our study provides data to quantify this exposure. We hope this evidence can be used together with current legislation to make the use of surgical smoke extractors mandatory to protect all personnel in the operating theatre.

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Introduction

Surgeons and operating theatre personnel are routinely exposed to pollution from the surgical smoke plume generated through thermal tissue destruction. The most common source of surgical smoke is electrocautery ablation, with laser ablation and harmonic dissection also contributing. The term *'smoke'* describes the by-products of combustion that are a chemical hazard and *'vapour'* describes suspended particles that may be a biological hazard. In this context the term *'plume'* describes both the by-products of combustion and non-combustion processes. The heat of a cutting diathermy causes intracellular water to boil, cells to be ablated, and tissues destroyed. Although coagulation diathermy current develops less heat, it still causes cell drying and thus coagulation. Surgical smoke plume consists of 95% water vapour and 5% combustion by-products and cellular debris.[1] It is the latter that represent a chemical and biological hazard. Electrocautery ablation creates the smallest mean particle sizes (which travel the greatest distances[2]), laser ablation creates larger particles, and harmonic scalpels create the largest mean particle size. Regardless of production method larger particles are more of a biological concern, whereas the smaller particles are more of a chemical concern.[1,3]

In vitro experimentation has identified many chemicals in the surgical smoke plume (Figure 1).[3,4] It is known to be at least as mutagenic as cigarette smoke,[5] in addition to being associated with considerable potential morbidity[6] (Figure 2). An analysis of surgical smoke, using an animal model, found that the mutagenic potency of condensates from 1 g of tissue destroyed through electrocautery ablation was the equivalent of smoking six unfiltered cigarettes.[7] The chemicals present in greatest quantity in surgical smoke are hydrocarbons and nitriles, with hydrogen cyanide, formaldehyde and benzene representing the greatest hazards.[4] The non-combusted fraction of the plume is a bioaerosol of viable and non-viable cellular material.[8] Infectious viral genes and viruses, and viable cells (including malignant cells) are clearly demonstrated in surgical smoke plumes.[9] Although pathogen transmission through surgical smoke is possible, documented cases are rare. It has been reported that a surgeon contracted laryngeal papillomatosis after treating anogenital condyloma with a surgical laser.[10]

Factors previously identified to effect the amount and content of the surgical smoke plume include; type of procedure, surgeons technique, pathology of target tissues, type of energy transferred, power levels used, and amount of cutting, coagulation or ablating performed.[5]

Through determining the duration of diathermy use in a dedicated full time plastic surgery theatre over a 2 month period, we set out to experimentally quantify the mass of tissue converted into a surgical smoke plume over the same time. We also sought by telephone questionnaire to determine the prevalence of specialist surgical smoke extractors in plastic surgery units in the United Kingdom.

Acetonitrile Furfural (aldehyde)
Acetylene Hexadecanoic acid
Acroloin Hydrogen cyanide
Acrylonitrile Indole (amine)
Alkyl benzene Isobutene
Benzaldehyde Methane
Benzene 3-Methyl butenal (aldehyde)
Benzonitrile 6-Methyl indole (amine)
Buladiene 4-Methyl phenol
Butene 2-Methyl propanol (aldehyde)
3-Butenenitrile Methyl pyrazine
Carbon monoxide Phenol
Creosol Propene
1-Decene (hydrocarbon) 2-Propylene nitrile
2,3-Dihydro indene Pyridine
Ethane Pyrrole (amine)
Ethene Styrene
Ethylene Toluene (hydrocarbon)
Ethyl benzene 1-Undecene (hydrocarbon)
Ethynyl benzene Xylene
Formaldehyde

Figure 1 Chemicals identified within surgical smoke.[3]

Methods

Duration of diathermy use during a two-month period

The total duration of diathermy use in our dedicated full time elective plastic surgery theatre was recorded over a two-month period. The elective nature of this theatre meant that this encompassed 44 operating days. A dedicated *Valley Lab Force FX* electrosurgical generator[11] was allocated to the plastic surgery theatre. With the permission of the manufacturer, our medical electronics department accessed built in service functions of the device both before and after the study period. This allowed the number of device activations and total duration of activation of each setting to be determined for the study period.

Experimental estimation of surgical smoke plume generation

An experiment was devised to estimate the amounts of tissue destroyed through electrocautery ablation using a porcine animal tissue model. Local research and ethics committee approval was granted to study human muscle samples removed during surgical procedures. An initial pilot

Acute and chronic inflammatory changes (emphysema, asthma, chronic bronchitis)
Hypoxia/dizziness
Eye irritation
Nausea/vomiting
Headache
Sneezing
Weakness
Light-headedness
Carcinoma
Dermatitis
Cardiovascular dysfunction
Throat irritation
Lacrimation
Colic
Anxiety
Anaemia
Leukaemia
Nasopharyngeal lesions
Human immunodeficiency virus
Hepatitis

Figure 2 Potential risks of surgical smoke inhalation.[25]

study was undertaken to compare human tissue samples with the animal model. No difference was found between the two tissue types and therefore the study was completed using the porcine model. Porcine tissue is the most physiologically similar to human tissue.[12] A large para-spinal muscle block was obtained from a freshly slaughtered organic pig. The samples were vacuum packed to minimise tissue degradation. Experimentation began within 4 h of animal slaughter. (Figure 3A).

A calibrated *Mettler AE163* weighing instrument with an accuracy of 0.0001 g was used to determine tissue sample mass before and after experimentation. A standard earth plate was placed on a flat surface and the tissue sample applied, and attached to a *Valley Lab Force FX* electrosurgical generator. We elected to investigate both the cutting and coagulation features of the monopolar aspect of this device. The device was set to a power of 25 W, with the cutting option set to 'pure' and the coagulation option set to 'fulgurate'. We selected 25 W as the setting for study as this is the setting most commonly used by the senior author and other surgeons within out department. A monopolar finger switch diathermy probe was continuously applied to the tissue sample in a uniform fashion for a 5-min period. Further ablation of charred tissue was avoided. The cutting and coagulation functions were each assessed on 39 independent tissue samples. The probe was used to dissect the tissues in a uniform linear fashion (Figure 3B) using the cutting function on separate samples. When assessing the coagulation function the probe was held just above the tissue surface and moved in a uniform fashion (Figure 3C) to ablate the maximal tissue surface area of independent tissue samples. For both settings the finger switch remained depressed for the entire 5-min period. A surgical smoke extractor was utilised to protect the investigator, and the experiments were performed in a well ventilated room. The tissue sample mass was then re-determined following ablation, allowing the change in mass to be calculated.

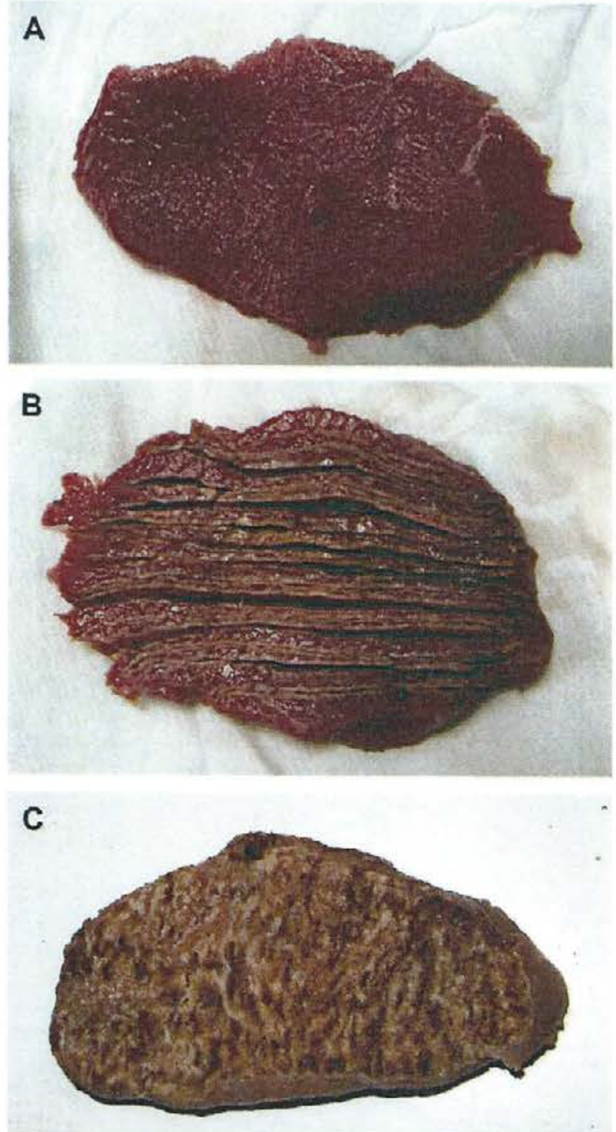

Figure 3 A — standard porcine tissue sample, B — porcine tissue sample following continuous application diathermy probe (cutting setting), C — porcine tissue sample following continuous application of coagulation diathermy (coagulation setting).

Statistical analysis

A statistician performed a descriptive analysis. The data were tested for normality using the Shapiro—Wilks test. If shown not to deviate significantly from a normal distribution, then data were summarised using mean and standard deviation and 95% confidence intervals were calculated. If not, they were expressed using medians and interquartile ranges.

Use of smoke extractors

A list of 56 British plastic surgery units was obtained from the British Association of Plastic Reconstructive and Aesthetic Surgeons (BAPRAS).[13] A plastic surgery theatre

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nurse was contacted in each unit via telephone. We specifically asked, *"are purpose designed surgical smoke extractors used in the plastic surgery theatres in your unit?"* Specific probing questions were asked in order to avoid confusion between specialised extractors and standard suction to evacuate the plume.

Results

Human tissue model

Six human muscle tissue samples were subjected to electrocautery ablation (three cutting and three coagulation). The mass of electrocautery tissue ablation following 5 min of continuous cutting ablation was 2.4132 g (SD 0.3929), while the same for coagulation ablation was 1.5817 g (SD 0.3782).

Porcine tissue model

There was no significant deviation from a normal distribution in the data collected. For change in the weight of the tissue ablated with cutting diathermy, $W = 0.9671$, $p = 0.3038$ and for coagulated tissue, $W = 0.9515$, $p = 0.0923$. The mean mass of electrocautery tissue ablation following 5 min of continuous cutting ablation was 2.3721 g (SD 0.3537) with the lower and upper limits of the 95% confidence interval being 2.2574 g and 2.4867 g respectively. The mean mass of electrocautery tissue ablation following 5 min of continuous coagulation ablation was 1.5406 g (SD 0.2573) with the lower and upper limits of the 95% confidence interval being 1.4569 g and 1.6237 g respectively.

Diathermy device use

The cutting function was activated 4790 times with a total activation time of 3 h, 43 min, and 49 s. The coagulation function was activated 8433 times with a total activation time of 5 h, 35 min, and 30 s. Combining the cutting and coagulation functions, there was a total use of 9 h, 19 min, and 19 s. In addition the bipolar function was activated 3782 times with a total activation time of 2 h, 45 min, and 52 s creating additional generation of surgical smoke plume.

Smoke extractor use

BAPRAS list 56 plastic surgery units. We achieved responses from 89% (50) of units. 66% (33) had specialised smoke extractors available for use in plastic surgery theatres and 34% (17) did not. In units with such devices a common comment was that their use was not universal in plastic surgery theatres, and indeed varied between surgeons and procedures.

Discussion

Tobacco smoke exposure is known to cause cardiovascular and respiratory disease, together with a number of malignancies including carcinoma of the lung, oral cavity, pharynx, larynx, oesophagus, pancreas, and bladder.[14] The surgical smoke plume has been shown to be as mutagenic as cigarette smoke,[5,7] however there is currently no evidence of human carcinogenicity. Laboratory rodent experimentation has reported that pulmonary congestion and lung abnormalities occur when exposed to surgical smoke for between 32 and 224 min duration over a 7- or 14-day period.[6,15] Histopathological examination in such studies revealed a spectrum of pathologies including inflammatory lung disease, pneumonia, bronchiolitis and chronic obstructive changes.[16,17] Despite the mutagenic effects and presence of carcinogens in the surgical smoke plume being known for over 20 years,[7] scientific consensus on the dangers of long-term human exposure is lacking. It was the large numbers of cigarette smokers that made proving significant association between smoking and pulmonary pathology possible. The comparatively small numbers of theatre personnel chronically exposed to passive surgical smoke means that it is more difficult to reach statistically significant findings. Confounding factors such as cigarette smoking and general environmental pollution along with the time lag between exposure and disease also make association difficult to prove.

Data was collected over 44 operating days and it was found that the mean daily diathermy activation time was 12 min and 43 s. This is however an overall mean and does not take into account large individual procedures such as raising a muscle flap. We used experimental data to estimate the mass of tissue destroyed during the 44 operating days of the study period and extrapolated this to calculate the mean together with lower and upper confidence intervals of the amount of tissue destroyed per operating day. Given that ablation of 1 g of tissue creates a surgical smoke plume with the mutagenic effect of smoking 6 unfiltered cigarettes[7] we can quantify the environmental theatre air pollution with surgical smoke in real terms. The World Health Organisation states that non-smokers who are exposed to passive (tobacco) smoke are exposed to the same carcinogenic risk as the active smokers themselves.[14] Therefore the equivalent of between 27 and 30 unfiltered cigarettes would need to be smoked in our theatre on a daily basis to generate a *passive* air pollution with an equivalent mutagenicity.

A number of systems exist to minimise risks of surgical smoke exposure. All operating theatres have ventilation systems to capture and extract bacteria and dust particles. British theatres must have air exchanged at least every 3 min through the generation of a positive downward pressure.[18] This equates to the surgical smoke plume being drawn towards the outlet 20 times per hour. This alone, however, is ineffective at removing the smoke plume, simply dissipates the plume elsewhere, and does not extract the plume at the site of generation. We acknowledge some impact on air recycling, however the highest concentration of toxic gas still passes directly into the operating surgeons facial field. So although other theatre personnel are exposed over a greater time period, it is the surgeon at a working distance of 20–40 cm from the point of smoke generation who is exposed to the highest concentrations of the plume. Standard surgical masks are inadequate in filtering either smaller smoke particles or the larger non-combusted cellular components.[19] Although ultra-filtration surgical masks are available, the increased work of breathing means their use is rare.

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Tubing attached to a mechanical suction device (with an exhaust outlet) directed at the source of combustion is common practice. Although this method has been reported as better than standard theatre air clearance[20] such devices have insufficient suction power to remove the majority of smoke from the operating field. The use of tubing attached to the electrocautery device has been described to increase the capture of smoke from the operating field.[21] Again however this system lacks sufficient suctioning power or filtering. Specialised mechanical surgical smoke evacuating and filtration systems evacuate surgical smoke through high-powered suction, filter virtually all contaminants, and return filtered air to the operating theatre. A multi-speciality survey performed by the Royal College of Surgeons reported that only 3% of surgeons used smoke extracting devices in their practice.[6] Although we report that 66% of plastic surgery units have smoke extraction devices available for use, clearly this is surgeon specific.

Current legislation protects people in the workplace by making smoking in enclosed public and work places illegal (Health Act 2006).[22] This applies to National Health Service (NHS) buildings. This legislation however does not protect those who work in operating theatres as it only applies substances that can be smoked. Employers are required to carry out an assessment of the risks from hazardous substances under the Control of Substances Hazardous to Health Regulations (COSHH).[23] Moreover these regulations state that employers are required to *"always attempt to prevent exposure at source"*. We directly quote recommendations from the Health and Safety Executive (HSE) in relation to surgical smoke: *"If exposure to diathermy emissions can't be prevented then it should be adequately controlled. This is usually achieved by effective local exhaust ventilation (LEV). Typically this takes the form of extraction incorporated into the electrosurgery system to remove emissions at source, known as 'on-tip' extraction"*.[24] The legal department at our hospital were unable to identify a case precedent of an employee taking legal action against their employer for not providing adequate surgical smoke extraction, however in the light of the above legislation this is a real possibility.

Conclusion

The long-term effects of chronic surgical smoke exposure remain unproven. However, it is known to be as mutagenic and contain the same carcinogens as tobacco smoke for which the dangers of passive exposure are well documented. Although the generation of the surgical smoke plume is unavoidable the use of purpose-built surgical smoke extractors is recommended. Use of these is not universal. Through estimating the mass of tissue ablated in a busy plastic surgery theatre and by quantifying this in real terms we hope to contribute to this controversial debate. In keeping with current legislation employers should carry out risk assessments and provide appropriate and provide effective local exhaust ventilation to allow surgical teams to work in a smoke free environment. Further research is required to determine which device will be most effective.

Conflict of interest

None. We have not made any discussion or mentioned any manufactures of specific devices that could/should be utilised to minimise exposure to surgical smoke.

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South West Regional research and ethics committee for both the use of human and porcine tissue for the purpose of this research.

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CHEMICAL COMPOSITION OF SURGICAL SMOKE FORMED IN THE ABDOMINAL CAVITY DURING LAPAROSCOPIC CHOLECYSTECTOMY – ASSESSMENT OF THE RISK TO THE PATIENT

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Abstract
Objectives: The aim of this study was to assess the exposure of patients to organic substances produced and identified in surgical smoke formed in the abdominal cavity during laparoscopic cholecystectomy. **Material and Methods:** Identification of these substances in surgical smoke was performed by the use of gas chromatography-mass spectrometry (GC-MS) with selective ion monitoring (SIM). The selected biomarkers of exposure to surgical smoke included benzene, toluene, ethylbenzene and xylene. Their concentrations in the urine samples collected from each patient before and after the surgery were determined by SPME-GC/MS. **Results:** Qualitative analysis of the smoke produced during laparoscopic procedures revealed the presence of a wide variety of potentially toxic chemicals such as benzene, toluene, xylene, dioxins and other substances. The average concentrations of benzene and toluene in the urine of the patients who underwent laparoscopic cholecystectomy, in contrast to the other determined compounds, were significantly higher after the surgery than before it, which indicates that they were absorbed. **Conclusions:** The source of the compounds produced in the abdominal cavity during the surgery is tissue pyrolysis in the presence of carbon dioxide atmosphere. All patients undergoing laparoscopic procedures are at risk of absorbing and excreting smoke by-products. Exposure of the patient to emerging chemical compounds is usually a one-time and short-term incident, yet concentrations of benzene and toluene found in the urine were significantly higher after the surgery than before it.

Key words:
Risk factor, Surgical smoke, Xenobiotics, Absorbtion, Urine analysis, Laparoscopy

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INTRODUCTION

Laparoscopic operations are beginning to dominate in most areas of operational treatment, and in the case of some of them they have become standard procedures. Indications for their application expand and new technical tools are continuously being refined and implemented to perform more and more complex procedures. Patients are also more likely to opt for this type of operation because of a shorter hospital stay and a faster recovery. Also, the cosmetic effect is more favorable (small scars). One of the most commonly performed laparoscopic surgery is resection of the gallbladder (cholecystectomy). This method has now become standard. During this operation, in order to prevent bleeding, coagulation of tissues is necessary as well as cutting them in the coagulation zone in the peritoneal cavity filled with carbon dioxide to the pressure of about 10–15 mm Hg. For this purpose, the apparatus for mono- or bipolar coagulation and an ultrasonic knife or other coagulating-cutting devices are used. These devices consist of an electric generator and high-frequency mono- and/or bipolar endings. Electric current is applied with a frequency that does not stimulate neuromuscular activity. Temperatures reached at the coagulating endings range from 100°C to 500°C, and the zone of thermal injury to tissues reaches 4–5 mm. During typical laparoscopic operations thermocoagulation of tissues in the atmosphere of carbon dioxide occurs. During this process, in the oxygen-free atmosphere a number of different chemical compounds, which can be potentially harmful to the health of both, patients and medical personnel, are formed and released. The characteristic sharp smell of the smoke released from abdominal cavity can be smelt in the operating theatre and it is also visible on the screen. The particular risk of exposure to the substances that are formed during such treatment is connected with the possibility of their direct absorption through peritoneum and their penetration into blood and other body fluids [1,2].

The proof of their absorption may be the presence of these compounds or their metabolites in blood and urine. Urine is a filtrate of blood and it contains toxic substances and their metabolites present in blood. Therefore, analysis of urine samples is an important source of information concerning functioning of the body, as well as its exposure to harmful substances. Whereas smoke production during laparoscopic surgeries is well documented in world literature [1–7], the analysis of urine samples of patients undergoing laparoscopic procedures in order to assess the potential exposure to such substances has not been performed yet.

A number of studies, such as those conducted by Barrett et al. [7], show the presence of chemical compounds of different structure and toxicity, which mostly occur in low to trace concentrations, in the smoke produced as a result of tissue thermocoagulation. The identified compounds include aliphatic hydrocarbons, aromatic hydrocarbons (including carcinogenic benzene), aldehydes, nitriles, amines, phenols and others. During a laparoscopic surgery patients breathe with the help of anesthetic equipment that sucks clean air from the outside of the operating theatre. Therefore, exposure of the patient depends only on the concentration of compounds released from the fat tissue or produced during tissue pyrolysis and the efficiency of their absorption into the bloodstream through peritoneum. Biological monitoring remains the only way to assess exposure of the patient and the tremendous progress and development of new analytical methods make it possible to measure quantitatively small, or even trace amounts of these substances. Similar studies to the one we performed have not been done before. This study offers us a glimpse into the threat posed by new surgical techniques, such as minimally invasive operations, which are becoming more and more popular. We have confirmed the presence of many chemical compounds, which are released during the pyrolysis of tissues, in the abdomen. Next, we have proved that some of these compounds are absorbed by peritoneum into the body of the operated patients. For the first time, we have identified dioxins in the surgical smoke created during laparoscopic cholecystectomy.

We have proved that the concentrations of benzene and toluene were significantly higher in patients after the surgery than before it. Our results showed that urine samples are a good source of information on occupational exposure as well as the dangers posed by modern medicine.

OBJECTIVES

1. Identification of the main chemical compounds produced in the abdomen during laparoscopic cholecystectomy.
2. Quantitative measurement of the concentrations of toxic chemicals excreted in the urine after the surgery.
3. Selection of exposure biomarkers useful for assessing the health risk of the patients exposed to these compounds.

MATERIAL AND METHODS

Ethical issues

The study was approved by the Ethics Committee of the Medical University of Lodz, Poland (approval No. RNN/195/08/K). The patients were informed before the surgery about the conduct of the research and voluntarily agreed to have samples of their urine collected for analysis.

Sixty nine women and 13 men were randomly selected for the study. The age of the operated patients ranged from 18 to 77 years. The average operation time was 80 min. Based on the survey, occupational and environmental exposure to aromatic hydrocarbons was excluded.

The operating theater of the hospital in Zgierz consists of 4 operating rooms, which make an enclosed space together with the preparation rooms, the sterilization room, etc. The study was conducted in the operating theater during laparoscopic procedures.

The first step of the study was performed according to Figure 1.

For identification purposes, gas samples were taken directly from the cable connected to the main working trocar through which, during operations, the gases escape from the abdominal cavity. The samples were taken by the use of measuring sets appropriate for the expected groups of substances. The expected substances included carbonyl compounds (aldehydes, ketones), volatile organic compounds (aliphatic hydrocarbons, aromatic hydrocarbons, alcohols) and polychlorinated dibenzodioxins and furans (PCDD/PCDF). In front of each measuring set, a humidity capacitors were installed, and their content was analyzed with respect to the presence of volatile substances by the use of the SPME technique.

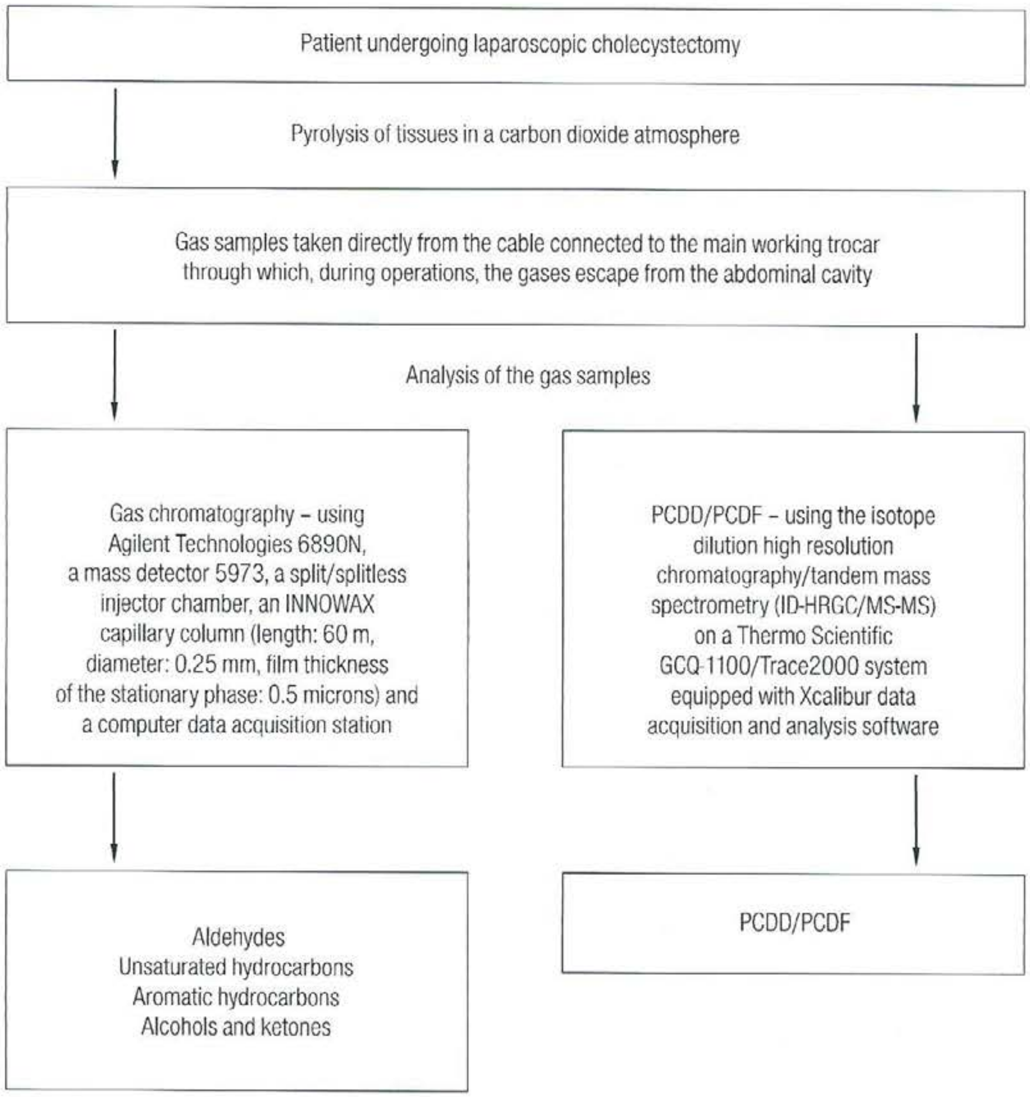
To perform determinations of volatile organic compounds, a measurement set was used, consisting of a gas chromatograph manufactured by Agilent Technologies 6890N, a mass detector 5973, a split/splitless injector chamber, an INNOWAX capillary column (length: 60 m, diameter: 0.25 mm, film thickness of the stationary phase: 0.5 microns) and a computer data acquisition station. The analyses were performed using a programmable oven temperature of the column (40°C (2 min), 5°C/min → 80°C (0 min), 20°C/min → 180°C (15 min)), the temperature of the split/splitless injection chamber – 200°C.

Data acquisition was performed in the selective ion monitoring (SIM) mode and scanning at the same time. The scanning range ranged from 10 Da to 250 Da. The signal for the SIM was collected for specific masses of aromatic hydrocarbons:

- Group 1 (benzene) – 50.0, 51.0, 52.0, 78.0.
- Group 2 (toluene) – 65.0, 91.0, 92.0.

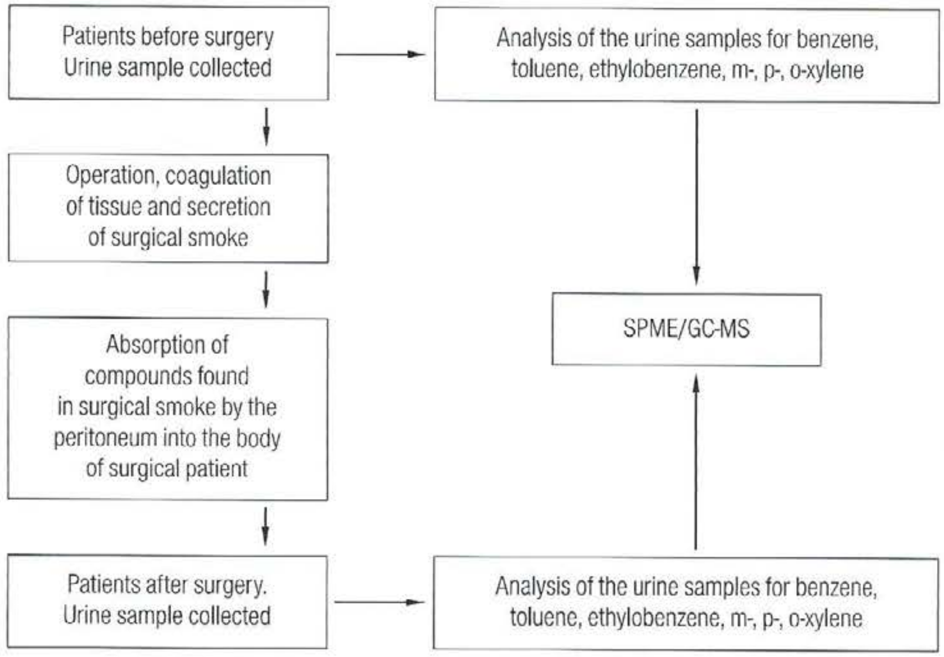
- Group 3 (ethyl benzene, xylene) – 51.0, 65.0, 91.0, 105.0, 106.0.
- Group 4 (naphthalene, biphenyl, alkyl derivatives of benzene C9-C10) – 105.0, 120.0, 128.0, 134.0, 154.0.

Determination of PCDD/PCDF was conducted using isotope dilution high resolution chromatography/tandem mass spectrometry (ID-HRGC/MS-MS) on a Thermo Scientific GCQ-1100/Trace2000 system equipped with Xcalibur data acquisition and analysis software. Separation was performed on a 30 m × 0.25 mm i.d. DB5MS J&W capillary column of 25 μm film and DB17 30 m × 0.25 mm i.d. DB5MS J&W capillary column of 25 μm film. A sample of 2.5 μl volume was injected into the SSL injector at 260°C. The GC oven was programmed as follows: the initial temperature of 130°C was held for 3 min, then temperature jump of 50°C/min to 180°C, then another temperature jump – 2°C/min to 270°C. Finally, the temperature jump was 20°C/min to 300°C and it was held



PCDD – polychlorinated dibenzodioxins; PCDF – polychlorinated dibenzofurans.

Fig. 1. Qualitative identification of the composition of gases formed in the peritoneal cavity during laparoscopic cholecystectomy



SPME/GC-MS – soild-phase microextraction / gas chromatography – mass spectrometry.

Fig. 2. Urine sampling and analysis

for 5 min. PCDD/PCDF were determined only in 20 randomly collected gas samples.

The next stage of the study (Figure 2) was to test whether the chemicals produced in the abdomen are absorbed into the body of a surgical patient and excreted in the urine.

Upon admission to the hospital for the planned surgery, the patients had urine samples collected. Volume and specific gravity measurements were performed. Then, 2 ml of urine were taken in 3–4 min using a glass pipette – and it was dispensed to the previously prepared chromatographic vials containing 1 g of NaCl. After capping, the vials were placed in a refrigerator at 4°C until analysis. During their hospital stay, the patients did not smoke cigarettes and were not exposed to cigarette smoke. The hospital is not situated near a busy street. All operations were conducted in the same operating theater using identical sets of tools. All patients were anesthetized using the same method and the same set of anesthetic equipment.

Immediately after the surgery, each patient was taken to the specially designated recovery room, where he/she stayed until the next day. The urine first excreted after the surgery (5–12 h after the surgery) was collected into a clean glass container. The volume and specific gravity of the urine given to analysis were measured. Then, similarly as before, 2 ml of urine were measured with a glass pipette, into previously prepared chromatographic vials containing 1 g of NaCl. The capped vials containing samples of urine were stored in a refrigerator at 4°C until analysis.

Methodology for quantitative determinations of urine samples collected before and after the surgery

The content of volatile organic compounds (benzene, toluene, ethylbenzene, xylene) was determined in urine by the use of solid phase microextraction gas chromatography (SPME-GC-MS). The analyses were conducted on a HP 6890 gas chromatograph with a HP 5973 mass detector, split injector, and capillary column (HP-INNOWAX) using the method described by Fustinioni et al. [8].

Methods of statistical analysis

For statistical evaluation of the research results the non-parametric Wilcoxon test for paired observations was used [9]. The decision to use the non-parametric test was taken after verification with the Shapiro-Wilk test and its result being abnormal distributions of the tested variables. The level of significance used for statistical tests was $\alpha = 0.05$.

Quality control

Internal quality control (IQC) procedures implemented in the laboratory were based on the use of control and calibration of samples which were included in the analytical procedures and which were prepared in the same way as the samples. They were also based on the use of internal standard (ISTD). Because of the fact that reference material was not commercially available, quality control samples were prepared in the laboratory by spiking a sample from the volunteers. Internal quality samples (IQS) were always injected at the beginning, every 10 samples and at the end of a sequence.

RESULTS

The results of the qualitative chromatographic analysis of surgical smoke are shown in Table 1.

As presented in the table, during coagulation in the abdominal cavity, about 40 substances, different in terms of their chemical structure, such as: aldehydes, unsaturated and saturated hydrocarbons having conjugated double and triple bonds (e.g., alcohols, ketones) as well as aromatic hydrocarbons and dioxins, were formed and identified. Aromatic hydrocarbons found in the surgical smoke include benzene and its alkyl derivatives (e.g., toluene, ethylbenzene, xylenes). Also, the presence of polychlorinated dioxins and furans was reported, including 2,3,7,8-TCDD. Mass spectra of the selected compounds confirming their chemical structure are presented in Figure 3.

For some toxic substances identified in the laparoscopic smoke, biological monitoring was carried out based on the measurement of the concentrations of these xenobiotics in the urine of the patients, collected before and after the

Table 1. The main components identified in the samples of laparoscopic smoke

Aldehydes*	Unsaturated hydrocarbons	Aromatic hydrocarbons	Alcohols and ketones	Other	PCDD/PCDF***
Formaldehyde	but-1-en-3-yn (vinylacetylene)	benzene	isopropyl alcohol	acrylonitrile	2,3,7,8-TCDD
Acetone	butane-1,3-diyn	ethylbenzene	ethyl alcohol	acetonitrile	1,2,3,7,8-PCDD
Acetaldehyde	phenylacetylene	etylobenzen	acetone		1,2,3,4,7,8-HxCDD
Propionaldehyde	1-phenylcyclohexene	m-, p-, o-xylene			1,2,3,4,6,7,8-HpCDD
Methacrolein		cumene**			OCDD
Butyraldehyde		o-, m-, p-ethyl toluene**			2,3,7,8-TCDF
Benzaldehyde		mesitylene**			1,2,3,7,8-PCDF
Valeraldehyde		pseudocumene**			1,2,3,6,7,8-HxCDF
Hexyl aldehyde		hemimeliten**			OCDF
		naphthalene			

PCDD – polychlorinated dibenzodioxins; PCDF – polychlorinated dibenzofurans.
TCDD, PCDD, HxCDD, HpCDD, OCDD, TCDF, PCDF, HxCDF, OCDF – congeners of PCDD/PCDF (dioxins).
* Identified based on the retention time of the derivative with 2,4-dinitrophenylhydrazine.
** Identified based on the retention time of the signal recorded in the selective ion monitoring (SIM) mode.
*** Identified based on the retention time of the signal recorded in the SIM mode using isotopic patterns.

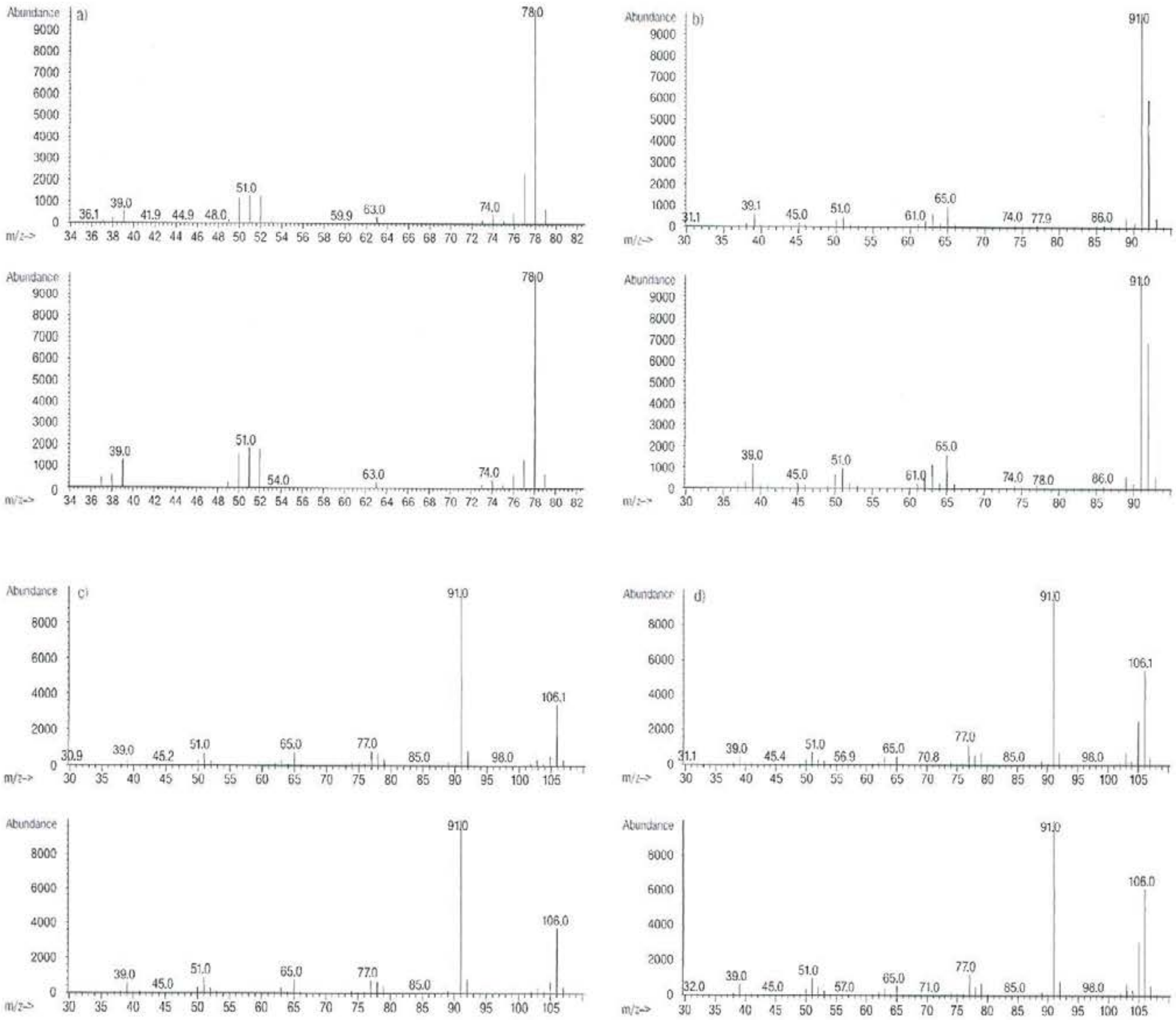


Fig. 3. Peak identification protocols tested (up) with a reference mass spectrum of the library Willey7 (bottom), respectively for a) benzene, b) toluene, c) ethylbenzene, and d) p-xylene

surgery. This study included substances for which the assay methods in the urine were validated and which provide a satisfactory level of determination.

Results concerning the urine samples analyzed with respect to the presence of benzene, toluene, xylene and ethylbenzene are shown in Table 2 and in Figure 4.

As shown in Table 2 and Figure 5, concentration of benzene in the urine of the patients after the surgery was on average 0.867 ± 0.143 and it was about 3 times higher than before the surgery (0.280 ± 0.045). In the case of toluene, the average concentrations of the compound in the urine of the patients after the surgery were also significantly higher than before it, although this difference was not so emphatic: 0.718 ± 0.110 (before the surgery) compared to 1.051 ± 0.188 (after the surgery).

No significant differences were found between the concentrations of ethylbenzene and xylenes (m, o, p) determined pre- and postoperatively.

Table 2. Average concentrations of the selected substances in the urine samples taken from the 82 patients before and after the surgery

Tested substance	Concentration (µg/l)			p in the test comparing the averages for dependent variables
	M±SEM	Me	range	
Benzene				
before surgery	0.280±0.045	±0.150	0.000–2.240	< 0.0005
after surgery	0.867±0.143	±0.310	0.020–6.060	
Toluene				
before surgery	0.718±0.110	±0.450	0.080–6.850	0.039
after surgery	1.051±0.138	±0.675	0.140–7.660	
Ethylbenzene				
before surgery	1.518±0.104	±1.480	0.110–4.900	0.100
after surgery	1.765±0.164	±1.480	0.090–6.220	
M-, p-xylene				
before surgery	2.082±0.173	±1.880	0.150–6.560	0.268
after surgery	1.876±0.233	±1.260	0.110–9.000	
O-xylene				
before surgery	1.042±0.114	±0.785	0.060–6.060	0.883
after surgery	1.064±0.112	±0.725	0.050–4.720	

M – mean; SEM – standard error of measurement; Me – median.

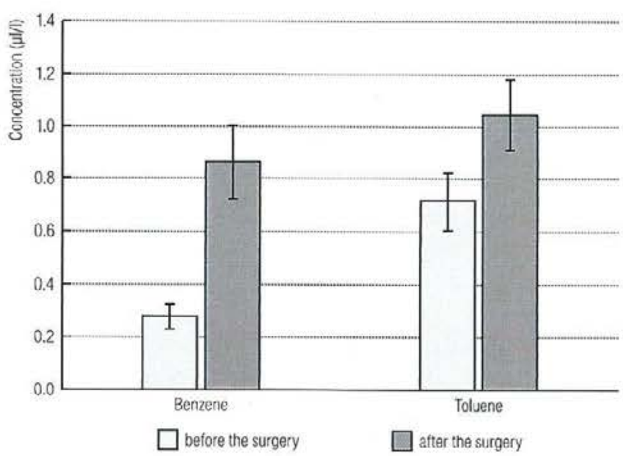


Fig. 4. Average concentrations of benzene and toluene in the urine samples collected from the patients before and after the surgery

DISCUSSION

Surgical smoke from abdominal cavity may pose a hazard to both, the operating room staff and the patients since it contains chemical compounds. There are many documented studies, which show that the smoke plume contains a vast array of chemical compounds, including aliphatic hydrocarbons, aromatic hydrocarbons such as benzene and its alkyl derivatives, as well as aldehydes, nitriles, amines, and other substances [4–7]. In contrast to other authors, we have also found traces of polychlorinated dioxins and furans, including the highly toxic 2,3,7,8-TCDD. Some xenobiotics identified in the laparoscopic smoke may have mutagenic and carcinogenic effect.

There is a risk of their direct or indirect impact on genetic material. In the case of patients undergoing laparoscopic procedures who breathe with anesthesia equipment, which draws in fresh air from the outside of the operating theatre, the exposure to these potentially harmful compounds is associated with the risk of direct absorption (into the bloodstream through peritoneum) of a number of substances that are either released from the fat tissue or produced in the pyrolysis process during thermocoagulation of the tissues.

Therefore, the only way to assess the exposure of the patients is biological monitoring. So far such tests have not been performed, hence the assay results described in our work concerning the selected compounds in the urine collected from the patients before and after the operation are novel and they indicate that toxic compounds present in the smoke are absorbed into the body. Previous studies carried out by various authors included only the analysis of the air (surgical smoke).

In the literature, there are few works on biological monitoring based on the measurement of unchanged compounds excreted in the urine, but they refer only to occupationally exposed workers [10–14]. These works have demonstrated a high correlation between concentrations of various solvents in the air of the working environment, and their concentration in the urine. Biological monitoring of the exposure to benzene and toluene is particularly well-documented. In the past, it was based on the concentration measurements of the metabolites of these substances in the urine. Great progress and development of new analytical methods now allow for a quantitative measurement of even very small (trace) amounts of unchanged compounds, including benzene and toluene [10–14].

It has been reported by other authors that in the smoke produced during laparoscopy more than 40 different compounds of different structure and belonging to different groups, such as aldehydes, unsaturated and saturated hydrocarbons having conjugated double and triple bonds (e.g., alcohols and ketones), as well as aromatic hydrocarbons such as benzene and its alkyl derivatives (toluene, ethylbenzene, xylenes), may be detected. Our study confirmed formation of compounds from these groups.

Then for the selected toxic compounds identified in the surgical smoke, we performed biological monitoring based on the examination of the concentrations of the selected xenobiotics in the urine samples collected before and after the surgery.

The study showed that the concentrations of benzene and toluene identified in the urine of the patients after the surgery were significantly higher than their concentrations before the surgery, which is direct evidence that during such operations these compounds are produced and absorbed into the blood. The obtained results indicate the possibility of implementing biological monitoring to assess the potential risk for the patients undergoing this type of surgery.

In theory, the absorbed compounds may pose a potential risk of distant health effects. It should be borne in mind that benzene, concentration of which in the urine of the patients after the laparoscopic surgery was more than 3 times higher than before the operation, is classified by the International Agency for Research on Cancer (IARC) as Group 1 human carcinogen and its role as a leukemogen has been clearly demonstrated through a number of epidemiological studies. Other effects on the hemopoietic system include leukopenia, agranulocytosis, anemia, pancytopenia and the myelodysplastic syndrome. Benzene is also considered a leukemogenic factor in humans. Benzene is a human clastogen: chronic exposure leads to consistent structural and numerical chromosomal aberrations in lymphocytes and bone marrow cells which may be recorded for at least 5 years after cessation of (occupational) exposure [15–22].

Benzene diffuses across the placenta and is considered to be fetotoxic. It is not thought to be a teratogen and there is currently no evidence that it causes reproductive effects in humans. Therefore, it appears that laparoscopic procedures in pregnant women may be a subject to some risk. Laparoscopy, as a diagnostic-operation technique, is currently regarded as a method safe in pregnant women and is increasingly being used in obstetrics [23,24]. The scope of indications for laparoscopy in pregnancy relates mainly to lithiasis and cholecystitis (the so-called acute abdomen).

Most of these procedures are performed in the first (33%) and second trimester of pregnancy (56%) [24]. Although in all the cases there is obligatory pre- and post-operative monitoring of the wellness of the fetus and the maternal end levels of the expiratory carbon dioxide concentration, no additional risk has ever been taken into consideration for the substances that are present in the surgical smoke, such as benzene or 2,3,7,8-TCDD, which are carcinogenic compounds with a proven harmful effect on the fetus.

The second chemical compound for which we revealed a significant increase in the urine of the operated patients was toluene. Although toluene, unlike benzene, does not have carcinogenic effect, there is a number of developmental consequences, particularly neurodevelopmental changes, that have been reported in children of the women who abused toluene during pregnancy. The effects recorded in children exposed in utero to toluene include central nervous system (CNS) dysfunction, attention deficits and developmental delay/mental deficiency [25].

Since some experimental tests have shown the possibility of interaction between benzene and other chemicals, including toluene, such interaction cannot be ruled out in the exposed patients [26,27].

Summing up, we can conclude that although the quantitative analysis showed relatively low levels of the selected compounds in the smoke and determined in the urine, it should be borne in mind that:

1. Concentrations of the compounds tested in the urine make only a small percentage of the total absorbed dose (e.g. benzene).
2. The presence of a mixture of numerous toxic compounds, even in trace amounts, in the urine, due to the possibility of interaction can significantly increase their overall toxicity potential.
3. Despite the short time of exposure (the duration of the operation does not exceed 2 h) and relatively low concentrations, one cannot rule out the potential threat of carcinogenic compounds (e.g. benzene).

In addition, to reduce or eliminate the potential risk of exposure to the compounds produced during tissue pyrolysis, which can be harmful to the fetus, one should consider using gasless laparoscopic techniques in pregnant women. A significant proportion of these operations, > 50% has already been performed in women who suffer from gallstones and are of childbearing age. In this case, the elevation of the abdominal wall can be applied [28–31], or bipolar devices can be used for laparoscopic purposes causing lesser production of the toxic smoke [31].

CONCLUSION

1. During laparoscopic surgery, in the abdominal cavity smoke is produced, which was shown to contain many potentially dangerous chemicals.
2. The smoke source is probably thermocoagulation of the tissues and their pyrolysis that take place during the procedure.
3. The patient's exposure to the produced chemicals is usually a one-time and short-term one, and the concentrations of benzene and toluene found in the urine are relatively low.
4. The presence of chemical compounds in the urine is a result of their absorption by peritoneum and their circulation in the body.
5. The results indicate the possibility of establishing biological monitoring to determine the concentrations of benzene and toluene in the urine as major biomarkers of the patients' exposure during laparoscopic procedures.

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CASE REPORT | Open Access

HPV positive tonsillar cancer in two laser surgeons: case reports

Margo Rioux[1], Andrea Garland[2*], Duncan Webster[2] and Edward Reardon[2]

Abstract

A 53 year-old male gynecologist presented with human papillomavirus (HPV) 16 positive tonsillar squamous cell carcinoma. He had no identifiable risk factors with the exception of long term occupational exposure to laser plumes, having performed laser ablations and loop electrosurgical excision procedures (LEEP) on greater than 3000 dysplastic cervical and vulvar lesions over 20 years of practice. The second patient is a 62 year old male gynecologist with a 30 year history of laser ablation and LEEP who subsequently developed HPV 16 positive base of tongue cancer. He also had very few other risk factors for oropharyngeal cancer or HPV infection. HPV is a probable causative agent for oropharyngeal squamous cell carcinoma and has been reported as being transmittable through laser plume. This paper suggests that HPV transmitted through laser plume can result in subsequent squamous cell carcinoma.

Keywords: Laser plume, Human Papillomavirus, Squamous cell carcinoma, Tonsillar cancer, Oropharyngeal cancer

Background

Carbon dioxide (CO2) lasers are commonly used to excise lesions on the larynx, cervix, lower genital tract, and perianal regions. Although this is an effective treatment modality, there are concerns regarding potential adverse events associated with its use. Tissue destruction from the laser's energy produces a gaseous plume containing cell contents and other aerosols. Many potential risks have been associated with laser plume exposure including the risk of human (HPV) transmission; *in vitro* experiments have reported HPV transmission through laser plumes. Furthermore, there are two case reports describing health care professionals contracting oropharyngeal HPV following long-term occupational exposure to laser plumes. Certain HPV subtypes are known to be oncogenic, therefore, laser plume exposure may put health care professionals at increased risk of oropharyngeal carcinoma development. This case report describes, to our knowledge, the first cases of HPV-16 positive oropharyngeal squamous cell carcinomas in two surgeons following long-term occupational laser plume exposure.

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Case presentations

Patient A is a 53 year-old male gynaecologist who consulted the Department of Otolaryngology having noticed a lesion on his right tonsil and a lump in the right side of his neck. His symptoms had started a few months prior to his visit and included increased fatigue. The physical exam revealed right tonsil hypertrophy and a small node at the posterior aspect of the right mandible. A CT scan of the region demonstrated a 2.2 cm soft tissue lesion in the right tonsil extending to the right soft palate; it also confirmed the presence of a level 2 lymph node. A biopsy of the right tonsil was performed confirming invasive squamous cell carcinoma of moderate to poor differentiation. The cancer was staged at T2N1M0. Testing at the National Microbiology Laboratory in Winnipeg, Manitoba revealed that the lesion was positive for HPV type 16 by hybrid capture assay (Luminex Hybridization).

Patient A had no identifiable risk factors for oropharyngeal cancer or HPV with the exception of occupational exposure to HPV-positive laser plumes, having performed laser ablation and later loop electrosurgical excision procedures (LEEP) of more than 3000 dysplastic cervical and vulvar lesions over 20 years. Most of these procedures were performed in an environment without proper ventilation or mask. Being in a long-term monogamous relationship with his wife, he denies any other sexual contacts. She was tested following patient A's diagnosis and was found to be HPV negative. Unfortunately, she had no HPV testing prior to patient A's cancer diagnosis. Additionally, the patient is a non-smoker and consumes alcohol only occasionally. He has never been vaccinated against HPV. The association of his diagnosis with workplace exposure warranted his receipt of worker's compensation.

He received Intensity Modulated Radiotherapy over 35 fractions with adjuvant cisplatin for 3 courses. Treatment side-effects caused significant reduction in quality of life due to marked dysphagia and xerostomia, which resulted in 40 lbs weight loss despite percutaneous gastrostomy feeding, radiation-induced Lhermitte's sign, and 40% high frequency hearing loss. He returned to work 11 months following initiation of therapy. In the four years since treatment, he has had no recurrence of squamous cell carcinoma; he was subsequently vaccinated against HPV types 6, 11, 16 and 18. He continues to practice gynecology, but has not returned to laser surgery.

Patient B is a 62 year old gynecologist who recently consulted his local otolaryngologist after having a foreign body sensation in his throat for many weeks. A biopsy of the base of tongue revealed a squamous cell carcinoma; the lesion was positive for HPV 16. The base of tongue lesion was excised by laser and he also had a bilateral modified neck dissection. He had been practicing for 30 years, of which he spent 15 doing weekly laser ablations with a CO2 laser. He reported poor ventilation in this clinic space and subsequently moved to a different area where he performed loop electrosurgical excision procedures for the next 15 years. He is a non-smoker, only drinks occasionally, and was married twice. Once again, this patient may have contracted HPV through occupational laser plume exposure.

Discussion

Squamous cell carcinomas are accountable for 90% of head and neck cancers [1]. Tobacco smoke, alcohol, and HPV exposure are the strongest risk factors associated with head and neck squamous cell carcinomas; however, family history, low socioeconomic status, Epstein-Barr virus, acquired immunodeficiency syndrome (AIDS), and human immunodeficiency virus (HIV) status are also minor risk factors [1]. Review of Patient A's history reveals that he had no known risk factors for head and neck squamous cell carcinoma other than being HPV-positive. Although it is impossible to confirm, the patient denies other sexual contact. He is in a long term monogamous with his wife and swabs collected from patient A's wife following his cancer diagnosis where negative for HPV. In the absence of other risk factors, it is possible that the source of HPV infection could be due to occupational laser plume exposure. Patient B was also a non-smoker with only occasional alcohol consumption. He was, however, married twice and the HPV status of these partners was not established. There is an abundance of evidence in the literature supporting HPV's role in the oncogenesis of head and neck squamous cell carcinomas, as well as strong evidence supporting HPV transmission through laser plume.

The potential for HPV transmission through laser plume has been explored by various authors. Many studies have reported the presence of intact HPV DNA in laser plume of HPV-positive lesions; however, other studies have not been able to recreate these findings [2]. Two case reports describe HPV infection in two health care professionals regularly exposed to laser plumes in an occupational setting. Both reported no other risk factors or other possible exposures to the virus [3,4]. Furthermore, there is a significantly increased incidence of nasopharyngeal warts in laser surgeons when compared to a control group [5]. HPV transmission and subsequent tumour growth has been demonstrated in bovines inoculated with laser plume produced by destruction of HPV-positive tissue [6]. This presents a strong argument in favour of HPV transmission through laser plume.

The relationship between HPV and oropharyngeal squamous cell carcinomas has been studied extensively. A study of the American SEER database from 1984 to 2004 reveals that HPV-positive head and neck cancers have increased 225% during the study period, while HPV-negative head and neck cancers have decreased by 50% [7]. Retrospective studies in Canada [8] and Australia [9] both report an increase of cancer in sites potentially related to HPV infection, such as the base of the tongue and the tonsils, when compared to sites not associated with HPV. A Canadian study has reported that 73% of cancers of the base of the tongue and tonsils were HPV-positive [10]. Oral Squamous cell carcinomas are strongly associated with HPV 16 and HPV 18 [11]. Reviews have concluded that existing evidence points towards a clinically significant [12] and causal relationship [13] between HPV and oropharyngeal squamous cell carcinoma.

Patient A's lesion was a poor to moderately differentiated cancer with a stage of T2N1M0. His cancer responded well to treatment and he has not had any relapse. HPV-positive and HPV-negative oropharyngeal squamous cell carcinomas seem to be two distinct types of cancer as they have different histological appearances [14] and genetic signatures [15]. HPV-positive tumours tend to present at a higher stage, [7] however, they seem to be associated with a higher survival rate [7,16,17], and a better response to treatment [18]. Despite this increased survival rate and response to treatment, it is not recommended to modify the management of HPV-positive oropharyngeal squamous cell carcinoma as there is not enough high quality evidence to support it at this time [19,20].

Conclusions

This article reports on a case of HPV-16 positive oropharyngeal squamous cell carcinoma in two laser surgeons following occupational exposures to laser plumes. There is now a strong body of evidence supporting a causal relationship between oncogenic HPV types and head and neck squamous cell carcinomas. It is also recognized that HPV may be transmitted through laser plume. Therefore, long term occupational exposure to laser plumes may lead to HPV infection and oropharyngeal squamous cell carcinomas. There is significant morbidity associated with these lesions and their treatment. It would thus seem prudent to reduce laser plume exposure amongst healthcare professionals. Existing protective methods such as standard surgical mask and laser mask have been described as ineffective against viral pathogens [21]. The National Institute for Occupational Safety and Health (NIOSH) recommends the use of local exhaust ventilation (LEV) in addition to general room ventilation. Portable smoke evacuators should be used to reduce surgical smoke levels. The device should be fitted with High Efficiency Particulate Air (HEPA) filter or its equivalent, which should be monitored and replaced on a regular basis. The nozzle inlet should be kept within 2 inches of the surgical site and be kept ON at all times when the laser is in use [22]. Furthermore, the Canadian Center for Occupational Health and Safety (CCOHS) recommends the use of respirators (N95 grade or higher) to protect healthcare workers [23]. A 2008 survey of various North American medical facilities indicated that less than half of respondents used effective LEV and even fewer used proper respiratory protective equipment [24]. Therefore, many health care workers are being exposed to oncogenic HPV strains. In the absence of effective screening methods, those infected risk developing oropharyngeal cancer [25]. This highlights the potential role of primary prevention through prophylactic HPV vaccination. Those exposed to laser plume in an occupational setting may benefit from vaccination against oncogenic HPV strains, in order to prevent infection and reduce the risk of subsequent oropharyngeal cancer.

Consent

Written informed consent was obtained from the patients for publication of the Case report. Copies of written consents are available for review by the Editor-in-chief of this journal.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MR has reviewed the patient's chart as well as the literature and drafted the manuscript. AG has conceived this case report, participated in its coordination and has helped draft the manuscript. DW has helped review the manuscript and provided substantial intellectual content to the original manuscript. ER has helped draft the manuscript. All authors have read and approved the final manuscript.

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Bovie Smoke

A Perilous Plume

PATRICK W. McCORMICK, MD

When analyzed, smoke from electrosurgical units, commonly known as Bovie smoke, is shown to be quite similar to that of other potentially pathogenic smoke, behaving as a carcinogen, a mutagen and an infectious vector. In addition, particulate matter in smoke is known to have health risks related to inducing inflammatory and allergic responses in susceptible people.

The fact that electrosurgical smoke is common and has been present in operating rooms for many years has led to a complacency regarding this smoke and its potential toxicity. A comparison of laser plume and electrosurgical smoke shows little difference in terms of the health risk, and in some respects the electrosurgical smoke poses a greater risk, particularly if these risks are quantified on a time-weighted basis that takes into account accumulation over long periods of exposure. For example, a study that directly compared electrosurgical smoke with laser plume and tobacco smoke showed that electrosurgical smoke is more toxic than laser plume or tobacco smoke (5). One gram of tissue was lasered with a carbon dioxide laser, and an identical gram of tissue was vaporized with electrosurgical current. A comparison of the emitted chemical byproducts to those present in average tobacco smoke demonstrated that the laser smoke generated from a gram of tissue was equivalent to smoking three unfiltered cigarettes, while the electrosurgical smoke was equivalent to smoking six unfiltered cigarettes.

This article details some of the known risks of exposure to Bovie smoke. As importantly, it presents best practices for avoiding Bovie smoke exposure to the greatest extent possible.

Electrosurgical units transmit a current from a dissecting or cutting surgical instrument to a dispersion electrode. The resistance to the flow of this current at the tissue interface generates heat, which causes coagulation of proteins that leads to hemostasis and vaporization of tissue by superheating intracellular water content. The result is disintegration of cell integrity and aerosolization of cellular debris. The destruction of biological tissue with heat results in the generation of smoke that is composed of volatile organic compounds, inorganic compounds, and both inert and biologically active particulate matter such as viruses. The smoke generated by an electrosurgical unit is comparable to that generated by a laser, and the mechanism is fundamentally the same (3). Aerosols of biological tissue and smoke due to heat generated by friction also are generated by high-speed air drills.

The mutagenicity of electrocautery smoke has been evaluated by collecting smoke produced during reduction mammoplasty (6). The smoke was collected at locations between two-and-a-half and three feet above the operative field, typical of the exposure experienced by the operating team. The smoke was collected in filters and extracted for analysis. The extracts were tested with strains of Salmonella typhimurium in a standardized Ames test, which is a well-recognized technique for evaluating the mutagenicity of a substance. The results demonstrated that all of the smoke samples contained mutagens. The finding of mutagens is an important qualitative result because there is no established safe level of mutagens, and the likelihood of establishing safe levels is quite remote. Therefore, the implication is that the amount of smoke to which operating personnel are exposed should be as minimal as possible.

Volatile Organic Compounds

With regard to carcinogenicity, attention is typically focused on the volatile organic compounds and polycyclic aromatic compounds contained in the smoke. A health hazard evaluation report by the National Institute for Occupational Safety and Health, NIOSH, discussed the content of volatile organic compounds in surgical smoke (7). Volatile organic compounds are described as a class of molecules that have a sufficiently high vapor pressure to allow the compound to exist in a gaseous state at room temperature. Of the array of chemicals known to exist in biological tissue smoke, formaldehyde, acetaldehyde, and toluene were identified.

Formaldehyde concentrations were quite variable. They ranged as high as 0.021 parts per million, ppm, compared to a sample taken outside the operating room door of 0.005 to 0.007 ppm. Formaldehyde is known to be an irritant at exposures of 1.0 ppm or greater in the general population, but symptoms of irritation occur earlier in persons with preexisting conditions such as allergies or respiratory disease. In addition, NIOSH identifies formaldehyde as a potential human carcinogen, and the Occupational Safety and Health Administration, OSHA, has identified a 0.75 ppm eight-hour time-weighted average as the upper limits of allowable worker exposure. The time-weighted average accounts for the elevation in the concentration of formaldehyde during exposure to surgical smoke over a period of time in a typical working day.

> **Bovie smoke behaves as a carcinogen, a mutagen and an infectious vector and can induce inflammatory and allergic responses in some people.**

The report identified acetaldehyde concentrations that ranged from 0.001 ppm to 0.012 ppm, compared to a background of 0.002 ppm. Acetaldehyde is considered by the Environmental Protection Agency as a probable human carcinogen, and NIOSH recommends keeping exposure to acetaldehyde at the lowest feasible concentration. However, the OSHA guidelines for an eight-hour time-weighted exposure are much higher than those identified in this report at 200 ppm.

Toluene was identified in concentrations of 0.002 ppm to 0.015 ppm. Toluene is a known respiratory and eye irritant, and excessive inhalation exposure can lead to neurotoxicity. The symptoms of toluene exposure are not identified below 100 ppm in published studies.

The Particulars of Particulate Matter

Particulate matter is found in electrosurgical smoke, and the nonliving particulate matter is typically quantified as particles per cubic foot, ppcf. It has been noted that baseline measurements in an operating room are typically near 60,000 ppcf (4). With the use of electrosurgical tools that generate smoke, the typical rise in particulate matter plateaus at approximately one million ppcf in five minutes. It takes approximately 20 minutes following cessation of generation of electrocautery smoke for the operating room ventilation system to return particulate concentrations to baseline level. Comparison of laser plume and electrosurgical smoke using a spectrophotometer has demonstrated that both types of smoke have a very similar particle content and size distribution.

The smaller particulate matter is thought to be the most harmful in that it typically penetrates surgical masks and travels through the respiratory tree to the alveolar level. The particles typically are less than five microns in size, and more than 77 percent of particulate matter within surgical smoke is less than 1.1 μm in size. An experimental protocol using Sprague-Dawley rats exposed to electrocautery exhaust demonstrated lung parenchyma changes, including alveolar congestion, blood vessel hypertrophy of varying degrees, focal emphysematous changes, and muscular hypertrophy of blood vessels (10). A previous study demonstrated similar changes with carbon dioxidelaser plume (2).

The particulate matter also includes living organisms, and both viable bacteria and viruses in electrosurgical smoke has been reported. Papillomavirus was identified in vapor from bovine warts treated with both laser-derived material and electrosurgical cautery (8). Of the two, more virus load was present in the laser-derived material. Despite this provocative finding, the size of these particles is such that they are easily filtered out by a surgical mask and that there appears to be a low likelihood of transmission of the papillomavirus through its presence in electrosurgical smoke. Surgical smoke has been identified to carry viable bacteria that have been cultured from surgical smoke, including Bacillus subtilis and Staphylococcus aureus. In addition, mycobacteria

Continues ▸

Evacuation of the Bovie smoke near the source has the greatest likelihood of preventing exposure and any health consequences associated with it.

Continued

have been isolated from smoke, including Mycobacterium tuberculosis (9).

However, the presence of carcinogenic and mutagenic chemicals as well as inert and biologically active particulate matter represents a health hazard that varies with the susceptibility of the exposed individual. The presence of hypersensitivities, allergies, immunocompromised states, and/or a combination of surgical toxic exposures with other toxic environmental exposures such as smoking may change the risk profile on a case-by-case basis. Given the complexity of the variables involved, individual risk stratification cannot be established in a rigorous scientific fashion. The hazards of electrosurgical smoke are for the most part potential hazards without a large epidemiological database demonstrating their harmfulness to humans. In the presence of a scientifically verifiable hazard and the absence of definitive epidemiologic proof of health consequences, the most prudent course of action is to minimize exposure, which has virtually no downside risk.

Evacuators and Masks

There is almost uniform agreement among authors in this field that evacuation of the smoke near the source has the greatest likelihood of preventing exposure and any health consequences associated with it. The NIOSH recommendations suggest a smoke evacuator system that can pull approximately 50 cubic feet per minute with a capture velocity of 100 to 150 feet per minute at the inlet nozzle (1). Filters are necessary to capture the contents of the smoke and must be replaced regularly. Used filters are considered biohazardous wastes that require proper disposal. The regulations further suggest that a smoke evacuator nozzle be kept within two inches of the surgical site to maximize effective capturing of airborne contaminants. The use of routine suction designed for elimination of liquids from the surgical field is not adequate to evacuate electrosurgical smoke and eliminate the health hazards associated with it.

The other common practice is the use of a surgical mask. It is true that surgical masks cannot eliminate the very fine particles that are associated with respiratory inhalation, and even high-efficiency masks will become saturated at a certain point, thus allowing the air to flow around the mask rather than through it. Nonetheless, the masks are efficient in eliminating larger particle sizes, including viruses. NS

Patrick W. McCormick, MD, FACS, MBA, associate editor of *AANS Neurosurgeon*, is a partner in Neurosurgical Network Inc., Toledo, Ohio. The author reported no conflicts for disclosure.

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REVIEW

Surgical smoke and infection control

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KEYWORDS
Laser; Plume; Smoke; Infection control; Surgery; Electrocaute

Summary Gaseous byproducts produced during electrocautery, laser surgery or the use of ultrasonic scalpels are usually referred to as 'surgical smoke'. This smoke, produced with or without a heating process, contains bio-aerosols with viable and non-viable cellular material that subsequently poses a risk of infection (human immunodeficiency virus, hepatitis B virus, human papillomavirus) and causes irritation to the lungs leading to acute and chronic inflammatory changes. Furthermore, cytotoxic, genotoxic and mutagenic effects have been demonstrated. The American Occupational Safety and Health Administration have estimated that 500 000 workers are exposed to laser and electrosurgical smoke each year. The use of standard surgical masks alone does not provide adequate protection from surgical smoke. While higher quality filter masks and/or double masking may increase the filtration capability, a smoke evacuation device or filter placed near (2-5 cm) the electrocautery blade or on endoscope valves offers additional (and necessary) safety for operating personnel and patients.

Introduction

The term 'smoke' is used to describe any gaseous byproduct containing bio-aerosols, including viable and non-viable cellular material. In the medical literature, the terms 'smoke', 'plume' and, sometimes, 'aerosol' are used to describe the product of laser tissue ablation and electrocautery. The product of ultrasonic scalpels is frequently referred to as 'plume', 'aerosol' and 'vapour'.

The generation of surgical smoke by electrocautery and laser systems has the same mechanism. During the procedure (cut, coagulate, vaporize or ablate tissue), the target cells are heated to the

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point of boiling, causing the membranes to rupture and disperse fine particles into the air or pneumoperitoneum. The qualities of surgical smoke produced by these two methods are very similar. During the use of ultrasonic scalpels, aerosols are produced without a heating (burning) process. This process is generally referred to as 'low-temperature vaporization'. On the whole, this low-temperature vapour has a higher chance of carrying viable and infectious particles than higher temperature aerosols.

The mean aerodynamic size of particles generated varies greatly depending on the energy method used. Electrocautery creates particles with the smallest mean aerodynamic size (<0.1 μm), laser tissue ablation creates larger particles (~ 0.3 μm), and the largest particles are generated by use of an ultrasonic scalpel (0.35-6.5 μm). These particles travel greater distances from their point of production (up to 100 cm). The nature of small particles presents a hazard to patients and personnel. Particles of 0.5-5.0 μm are frequently referred to as 'lung-damaging dust' since they can penetrate to the deepest regions of the lung. Surgical smoke can induce acute and chronic inflammatory changes, including alveolar congestion, interstitial pneumonia, bronchiolitis and emphysematous changes in the respiratory tract (Table I).

Furthermore, the type of procedure, the surgeon's technique, the pathology of the target tissue (e.g. whether particular bacteria or viruses are present), the type of energy imparted, the power levels used, and the extent of the surgery (cutting, coagulation or ablating) are other factors influencing the quantity and quality of the surgical smoke.

Surgical smoke has also been demonstrated to be cytotoxic, genotoxic and mutagenic.[1]

Table I Risks of surgical smoke

Acute and chronic inflammatory changes in respiratory tract (emphysema, asthma, chronic bronchitis)
Hypoxia/dizziness
Eye irritation
Nausea/vomiting
Headache
Sneezing
Weakness
Lightheadedness
Carcinoma
Dermatitis
Cardiovascular dysfunction
Throat irritation
Lacrimation
Colic
Anxiety
Anaemia
Leukaemia
Nasopharyngeal lesions
Human immunodeficiency virus
Hepatitis

Potential health risks associated with surgical smoke

Electrosurgery

Electrosurgery is one of the most commonly used energy systems in laparoscopic surgery. Two major categories of potential complications related to electrosurgery are mechanical trauma and electrothermal injury. Electrothermal injuries and the burning of proteins and lipids produces a noxious odour noticeable in the operating room (OR). In addition to possible long-term effects, these chemicals may cause headaches, irritation and soreness of the eyes, nose and throat.[2] The American Occupational Safety and Health Administration (OSHA, www.osha.gov) has set permissible exposure limits (PELs) for workers. The health effects associated with these chemicals represent exposure in excess of these PELs. The purpose of PELs is to prevent these health effects from occurring and to provide a safe working environment for people potentially exposed to these chemicals.

While hydrocarbons, phenols, nitriles and fatty acids are the most prominent chemicals found in electrocautery smoke, acrylonitrile and carbon monoxide (CO) are of most concern.[1]

Acrylonitrile has toxic effects due to the formation of cyanide. Short-term exposure can cause eye irritation, nausea, vomiting, headache, sneezing, weakness and lightheadedness. Long-term exposure causes cancer in laboratory animals and has been associated with higher incidences of cancer in humans. Repeated or prolonged exposure of the skin to acrylonitrile may produce irritation and dermatitis.

CO is of particular concern in laparoscopic procedures and is readily absorbed from the peritoneum into the bloodstream, creating a route for systemic intoxication. The combination of CO and haemoglobin forms carboxyhaemoglobin (HbCO) and methaemoglobin (MetHb). Excessive accumulations of HbCO and MetHb cause hypoxic stress in healthy individuals as a result of the reduced oxygen-carrying capacity of the blood. In patients with cardiovascular disease, such stress can further impair cardiovascular function.[1,3]

Hydrogen cyanide is a colourless, toxic gas that may cause headache, weakness, throat irritation, vomiting, dyspnoea, lacrimation, colic and nervousness after absorption through skin and lungs.

Benzene causes irritation in eyes, nose and respiratory tract, headache, dizziness and nausea. Long-term exposure even at relatively low concentrations may result in various blood disorders, ranging from anaemia to leukaemia. Many blood disorders associated with benzene exposure may occur without symptoms.

The mutagenic effect created by thermal destruction of 1 g of tissue is equivalent to that of three or six cigarettes for laser and electrocautery smoke, respectively.[1] A recent study demonstrated that electrosurgical smoke, produced in a helium environment, reduced the clonogenicity of MCF-7 human breast carcinoma cells in a dose-dependent manner and concluded that electrosurgical smoke is cytotoxic.[4]

In one study, pellets of B16-F0 mouse melanoma cells were cauterized and the plume was collected in culture medium. Intact melanoma cells were identified in the culture media.[5] The authors concluded that viable cancer cells can be disseminated in the abdominal cavity and can lead to port-site metastasis in laparoscopic surgery. However, others concluded that malignant cells only aerosolize during laparascopy in the presence of carcinomatosis and that it is unlikely that tumour aerosolization contributes significantly to port-site metastasis.[6,7]

In recent years, electrocautery has been commonly used for the treatment of genital warts, caused by human papillomavirus (HPV), and cervical neoplasia in patients infected with human immunodeficiency virus (HIV). Although electrocautery is potentially less hazardous than laser smoke as a route of disease transmission, intact virions have been shown to be present in electrocautery smoke, and their infectivity has been demonstrated.[1] Therefore, genital warts must not be treated by electrosurgery. Simple excision is the therapy of choice.

Laser

There has been an increasing awareness of the potential health risk of laser-generated plumes. Many laser systems, on impact with targeted tissue, produce a plume of smoke containing debris and vapour, which is released into the surrounding area. Chemicals that have been found in the plume generated by laser tissue ablation are benzene, formaldehyde, acrolein, CO and hydrogen cyanide. These chemicals have been found in the smoke plume from both carbon dioxide (CO_2) and Nd:YAG lasers.[1]

Furthermore, viable particles (i.e. cellular elements and erythrocytes) have been found in plumes, suggesting their infectious potential. Over recent years, medical professionals have become aware of the dangerous exposure to viruses. Numerous studies have been conducted to examine virus viability in electrocautery and laser smoke.[8,9] In a tissue culture study using a CO_2 laser, proviral HIV DNA was recovered from the suction tubing used to remove the plume.[10] In another study, bovine papillomavirus DNA was detected in the laser aerosol.[11] In a survey, the incidence of nasopharyngeal lesions among CO_2 laser surgeons was found to be higher than in a control group, indicating that CO_2 laser surgeons are at increased risk of acquiring nasopharyngeal warts through inhalation of laser plumes.[12] A case report linked the laryngeal papillomatosis in an Nd:YAG laser surgeon to virus particles in the laser plume from one of his patients.[13] Since HPV and HIV can be detected in laser plumes, it is probable that other viruses, such as hepatitis viruses, may also be liberated in plumes during laser use.[14]

Ultrasonic scalpel

Large quantities of cellular debris ($>1\times10^7$ particles/mL) are found in plumes generated by ultrasonic scalpels. The particles created by the ultrasonic scalpel are composed of tissue, blood and blood byproducts. Unfortunately, those aerosols have not been well studied and no agreement exists about their exact composition. Whether the risk posed by aerosols generated by the use of ultrasonic scalpels is comparable with that of laser and electrocautery is not known. It might be greater due to the larger size of particles generated and because its low temperature vapour may contain more viable particles.[1] Research is needed to determine the potential dangers of aerosols generated by ultrasonic scalpels to assess their ability to spread pathogens and cells and to form toxins.

Recommendations by national organizations

OSHA estimates that 500 000 workers are exposed to laser and electrosurgical smoke each year, including surgeons, nurses, anaesthesiologists and surgical technologists. Surgical masks are good at capturing larger sized particles, generally 5 μm and larger, but they do not provide adequate protection in filtering smoke. Various studies demonstrated that specially designed masks (respirators) are still insufficient barriers. Furthermore, leakage of the mask's seal to the face is another source of possible penetration. No studies have measured the effectiveness of these respirators. The degree to which they protect individuals from surgical smoke is not known and varies depending on the filtering efficiency of the different respirators. As blood-borne pathogens have been identified in surgical smoke, occupational health regulations should be applied. Employers should provide appropriate personal protective equipment such as, but not limited to, gloves, gowns, laboratory coats, face shields or masks, and eye protection. Personal protective equipment will only be considered to be 'appropriate' if does not permit blood or other potentially infectious materials to pass through to or reach the employee's work clothes, street clothes, undergarments, skin, eyes, mouth or other mucous membranes under normal conditions of use and for the duration of time for which the protective equipment will be used.

OSHA does not specifically require the use of smoke evacuation and filtering systems. However, it does regulate staff exposure to a wide range of substances that are found within surgical smoke plumes, and has established PELs for these substances.

Other organizations recommend smoke evacuation systems where high concentrations of smoke and aerosols are generated. Systems with a capture velocity of 30-40 m/min are recommended, and the needle inlet should be kept 5 cm from where the plume is generated. Proper filters have to be installed and disposed of properly when room suction systems are used because room suction systems are less effective.[15-18]

Recommendations for infection control

During open surgery, there are various ways for OR personnel to avoid surgical smoke, e.g. by moving or turning away from large plumes and thereby avoiding inhalation. They can engage higher quality filter masks or double masking. A simple smoke evacuation system suction device can be placed near the electrocautery blade (2-3 cm) when smoke is produced; if placed too far away, only 50% of the smoke will be evacuated.[1,19] The three components of an efficient evacuation system should be: a capture device that does not interfere with the surgeon's activities; a vacuum source which has strong enough suction to remove the smoke properly; and a filtration system that is capable of filtering the smoke and making the environment safer.[20]

During endoscopic surgery, a chimney effect may cause a jet stream through the trocards towards the operating personnel. Moreover, smoke during endoscopic procedures is accumulated and then released all at once in a relatively high-velocity jet in a particular direction. Consequently, the surgeon or OR personnel can be exposed to a high concentration of cells, burns and infectious particles. To avoid this, personnel should ensure that the jet is not pointed towards them. By partially opening the Luer-lok valve on a cannula throughout the operation, especially when electrocautery is used, it might be possible to prevent smoke build-up and rapid release.

Recently, filters have become available that can be attached to the Luer-lock valve on the cannula and can be set to allow continuous ventilation and filtration of the pneumoperitoneum at a rate that does not exceed the inflow rate of the insufflator. These add-on filters have been shown to reduce operative time by practically eliminating the need to interrupt the procedure and release the accumulated smoke that obstructs the surgeon's view. These filters remove most of the harmful chemicals and nearly all biological material that might be present, and eliminate most of the smoke's odour.[1]

Conclusion

Surgical smoke and aerosols are irritating to the lungs and have approximately the mutagenicity of cigarette smoke. Risks from exposure are cumulative and are greater for those closer to the point of smoke production. OR personnel should decide which, if any, methods they want to utilize to minimize their exposure. Smoke evacuators and high-efficiency filtration masks/respirators can help to prevent the transmission of infectious agents.

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