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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

D.S. Hill ^{a,*}, J.K. O'Neill ^a, R.J. Powell ^b, D.W. Oliver ^a

^a Department of Plastic Surgery, Royal Devon and Exeter Foundation Trust, Barrack Road, Exeter EX2 5DW, UK

^b Noy Scott House, Royal Devon and Exeter Foundation Trust, Barrack Road, Exeter EX2 5DW, UK

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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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* Corresponding author. Tel.: +44 7809 761746.

E-mail addresses: danielhill@doctors.org.uk, hillardo@yahoo.com (D.S. Hill), jenniferoneill@hotmail.com (J.K. O'Neill), davidoliver@doctors.org.uk (D.W. Oliver).

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 distances²), 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 morbidity⁶ (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
 Acrolin Hydrogen cyanide
 Acrylonitrile Indole (amine)
 Alkyl benzene Isobutene
 Benzaldehyde Methane
 Benzene 3-Methyl butenal (aldehyde)
 Benzonitrile 6-Methyl indole (amine)
 Butadiene 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 generator¹¹ 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 our 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.

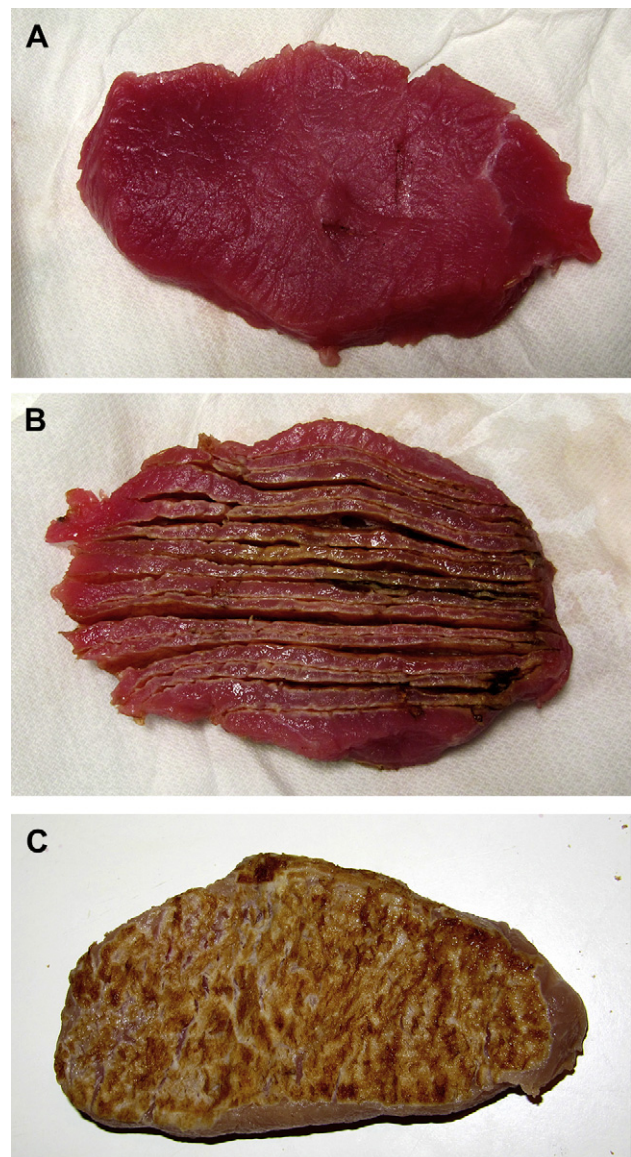


Figure 3 A – standard porcine tissue sample, B – porcine tissue sample following continuous application diathermy probe (cutting setting), C – porcine tissue sample following continuous application of coagulation diathermy (coagulation setting).

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

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 cigarettes⁷ 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.

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 clearance²⁰ 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 to 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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