Healthcare Safety

Exposure to Electrocautery Toxins

Understanding a potential occupational hazard

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ELECTROCAUTERY is routinely used to cut and coagulate tissue during surgery. In this process, tissue is heated to the boiling point of its constituent fluid causing cell membranes to rupture, ejecting a bioaerosol of cellular constituents and chemicals into the air that is referred to as surgical smoke or plume (Biggins and Renfree). At least 80 chemicals have been identified in electrocautery smoke; these include hydrocarbons, nitriles, fatty acids, phenols, carbon monoxide, acrylonitrile, hydrogen cyanide, formaldehyde and benzene (Biggins and Renfree). Several of these compounds are considered to be toxic or even mutagenic or carcinogenic (Gatti, et al; Sagar, et al; Ernst; Tomita, et al). As a result, precautions to help operating room personnel avoid smoke inhalation have been advocated and strict guidelines have been enforced [Ulmer(a); (b)].

With advances in minimally invasive techniques, an increasing number of patients undergo laparoscopic abdominal surgery. During laparoscopic surgery, the electrocautery smoke produced remains within the abdominal cavity until it is evacuated through one of the ports or by a suction device. As a result, the smoke remains in contact with the patient's peritoneal surface for a longer duration and has a greater chance of being absorbed into the systemic circulation through the peritoneum (Hensman, et al). Elevated levels of intraperitoneal and systemic carboxyhemoglobin due to peritoneal absorption of carbon monoxide during routine laparoscopic cholecystectomy have been reported (Esper, et al). Absolute levels of intraperitoneal carbon monoxide were found to increase from an average of 4.7 ppm to an average of 686 ppm, while carboxyhemoglobulin were found to increase from 0.7% to 1.2% (Esper, et al).

Theoretically, the relative exposure of the surgeon and patient during abdominal surgery to electrocautery smoke can be dependent on the surgical approach. During open surgery, electrocautery smoke readily escapes from the patient's intra-abdominal cavity into the ambient air, giving the surgeon and operating room personnel the greatest exposure via inhalation. During laparoscopic surgery, the electrocautery smoke generated remains within the patient's abdominal cavity, giving the patient the greatest exposure through the peritoneum, although continuous leakage from around the trocars and rapid decompression through the port sites when the trocars are removed may result in significant exposure to the surgeon and operating room personnel.

Despite these theoretical possibilities, little data exist on surgeon and patient exposure during laparoscopic and open abdominal surgery. While several studies (Hollmann, et al; DesCoteaux, et al) have identified various chemical constituents of electrocautery smoke, few have quantified them and measured the actual exposure of the surgeon and the patient to these constituents.

The objective of this study was to quantify the exposure of the surgeon and the patient to known chemical toxins in electrocautery smoke, and to determine whether any qualitative or quantitative differences existed in the exposure during either surgical technique.

Patients & Methods

The ileal pouch anal anastomosis (IPAA) was chosen as the representative operation because of all colorectal procedures it involves the most dissection and can be performed by either a standarized laparoscopic or open technique. Patients requiring an IPAA with a diverting ileostomy who were older than 18 years of age and had a body mass index (BMI) of less than 30 m/kg^2 were eligible for this study. Patients with a history of multiple abdominal or pelvic operations were excluded. Ten patients were prospectively enrolled to the laparoscopic or open group of the study depending on the practice and preference of

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Abstract: *Electrocautery is widely used in surgery for dissecting tissue and cauterizing blood vessels. This process produces a visible plume of smoke that contains several toxins and chemicals which are potentially hazardous to humans. Limited quantitative data exist on the degree of exposure of healthcare practitioners and patients to these toxins and chemicals during laparoscopic and open colorectal surgery.*

In this study, the authors quantify surgeon and patient exposure to chemical toxins known to be found in surgical smoke during laparoscopic and open colorectal surgery. No significant exposure to any of the measured chemical toxins was detected to either population in either surgical approach. Based on these findings, it was determined that current strategies of reducing the exposure to surgical smoke among healthcare practitioners and patients seem effective. Further study is needed to quantify the exposure of other known toxins and chemicals in electrocautery smoke.

the operating surgeon. The study was approved by the Institutional Review Board and informed consent was obtained from all participants.

The surgeon's exposure to benzene, toluene, xylene, acetone and styrene was measured, while the patient's preoperative and postoperative blood was tested for benzene, ethyl benzene, toluene, xylene, carboxyhemoglobin and cyanide. These chemicals were selected for this investigation based on the following:

1) A prior investigation had identified benzene, ethyl benzene, styrene, carbon disulfide and toluene as significant constituents of electrocautery smoke produced during routine open colorectal procedures (Sagar, et al). A similar composition of electrocautery smoke has been reported during reduction mammoplasty (Hollmann, et al).

2) Esper, et al reported significant increases in patient serum carboxyhemoglobin levels during routine laparoscopic cholecystectomy.

3) These chemicals are known to be potentially toxic or mutagenic in humans.

4) Reliable and accurate methods for their collection, detection and measurement are commercially available.

Ex Vivo Control Experiment

To validate and verify the sensitivity of the analytic methods, a piece of thigh muscle from a fresh human cadaver was cauterized for 3 minutes using a similar electrocautery machine in the same settings used in the operating room. The resultant smoke was collected from near the tip of the electrocautery by an active sampling method. The resultant sample was analyzed using the same methods used to analyze the ambient air samples collected during the in vitro study procedures.

Key Terms

•**Diverting ileostomy:** a temporary opening in the ileum (a part of the small bowel) attached to the anterior abdominal wall. An ileostomy provides a way for bowel contents to leave the body when a part of the bowel has been removed.

•**Peritoneum:** a thin membrane that lines the abdominal and pelvic cavities, and covers most abdominal viscera.

•**Trocar:** a thin cylindrical device inserted in to the body cavity to allow the use of laparoscopic instruments during surgery.

Ambient Air Measurements

During a preliminary experiment, active and passive air sampling methods were compared; no significant differences were detected (data not shown); therefore, the authors elected to use a passive sampling method because of logistical convenience.

Chem Disk personal chemical monitoring system is a small lightweight device measuring approximately 3 cm in diameter that passively samples air within the breathing zone (defined as a 12-inch sphere surrounding the nose) of the person wearing it. It is commercially available and is designed to measure the exposure of various chemical contaminants in the air, and to demonstrate workplace compliance with permissible exposure limits (PELs) and short-term exposure limits (STELs) as defined by OSHA.

One disk was clipped to the surgeon's mask and another was attached to an IV pole five feet from the surgeon and six feet from the ground. The monitoring system clipped to the surgeon's mask was considered representative of the surgeon's exposure to cautery smoke.

The disk contains activated charcoal compound that passively collects ambient chemicals by adsorption. The chemical samples are removed from the charcoal and placed in a gas chromatograph and are then sent through a flame-ionization detector; results are then recorded by weight. The chemical weight calculated by this method is then combined with the volume of air collected during the sampling period. The end result is a mass of chemical per volume of air over a period of time. The results are expressed in either ppm or milligrams of chemical in a cubic meter of air (mg/m^3).

Disks were analyzed by Assay Technology (AIHA lab No. 11124). The normal rate of air exchange in an operating room was approximately 23 air exchanges per hour.

Patient Blood Level Measurements

Preoperative venous samples were drawn within six hours of surgery and postoperative samples were taken at the end of the surgical procedure, before the patient was awakened from anesthesia. Benzene, ethylbenzene, toluene and xylene levels were measured by headspace gas chromatography, carboxyhemoglobin by cooximetry and cyanide by high-performance liquid chromatography. All samples were analyzed by Medtox, St. Paul, MN.

Table 1

Patient & Operative Characteristics

	Laparoscopic IPAA	Open IPAA
Age (mean) years	34	51
Gender (male:female)	4:1	4:1
BMI (kg/m^2)	23	26
Operative time (minutes)	335	222

Operative Procedure

The operative procedures, whether laparoscopic or open, were performed using standard techniques for an IPAA. During laparoscopic procedures, a smoke filter was routinely used to help maintain good visualization. During open procedures, cautery smoke was routinely suctioned by the first assistant in order to maintain visualization and to reduce surgeon exposure. These practices were not changed for the purpose of the study.

Table 2

Qualitative & Quantitative Composition of Electrocautery Smoke*

	Quantity Found (µg)	Exposure (mg/m^3)	Exposure (ppm)	Detection Limit (ppm)	PEL ppm[12]
Acetone†	2.44	0.39	0.16	0.1	1,000
Benzene†	9.32	1.5	0.46	0.02	50
Ethyl acetate	5.01	0.8	0.22	0.06	400
Ethyl alcohol	98.6	16	8.2	0.1	1,000
Ethyl benzene	0.656	0.1	0.024	0.02	100
Heptane	1.15	0.18	0.044	0.02	500
Isopropyl alcohol	2.83	0.45	0.18	0.06	400
Methyl ethyl ketone	2.79	0.44	0.15	0.04	200
Methyl isobutyl ketone	1.15	0.18	0.044	0.03	100
Perchloroethylene	2.09	0.33	0.048	0.05	300
Styrene†	3.85	0.61	0.14	0.02	600
Toluene†	ND	ND	ND	0.08	500
Xylene†	ND	ND	ND	0.08	100

**measured during ex vivo control experiment.*
†also measured during in-vitro study procedures (open and laparoscopic, n = 5 respectively).

Results

Table 1 provides the mean age, gender distribution and BMI of the patients in the two groups. Table 2 demonstrates the composition and the quantity of the various chemical constituents of electrocautery smoke generated during the ex vivo control experiment in order to validate the sensitivity of the analytical methods. The chemicals marked with a dagger represent those whose actual exposures were analyzed during surgery.

Analysis of the samples collected during the actual surgical procedures identified toluene from the sampling disk attached to the surgeon and the IV pole in two cases (and were considered to be contaminants); none of the other chemicals tested (benzene, acetone, styrene, toluene) were detected from either source. The preoperative and postoperative levels for cyanide, carbon monoxide, benzene, ethyl benzene, toluene and xylene were below the standard detectable levels in the laparoscopic and open patients (data not shown).

Discussion

The main limitation of this study was whether the nondetected concentrations of various chemicals in the air and blood samples represented actual absence of exposure or a deficiency in the monitoring strategy. To reduce the risk of a false negative result, the authors conducted an ex vivo control experiment. This experiment verified the chemical composition of electrocautery smoke to be similar to what has been previously reported (Sagar, et al; Hollmann, et al), and also validated the sensitivity of the analytic methods used in this investigation.

From a practical standpoint, the exposure of surgeons and patients during laparoscopic and open surgery to the chemicals measured were below the recommended safety levels and the detection limits of the analytic methods used. This fact indicates that the mechanisms in place to remove the smoke in the surgical field (through suction devices) and in the operating environment (room air exchanges at a prescribed rate) are effective and minimize the exposure of healthcare providers and patients to these chemicals.

The rate of air exchanges and the use of protective face gear are routine in all operating rooms as they are based on standard guidelines recommended by American Institute of Architects, OSHA and other regulatory agencies [AIA; Ulmer(a); (b)]. The practice of suctioning smoke from the surgical field during laparoscopic and open surgery is not standardized; however, it is a routine practice performed to improve the visibility in the surgical field.

The results also suggest that the degree of exposure of the surgeon and patient to electrocautery smoke is not influenced by the operative approach (laparoscopic or open). In particular, during laparoscopic surgery the potential risk of absorption of the chemical constituents of electrocautery smoke through the peritoneum seems to be negligible, at least for the chemicals that were measured. This is likely due to the standard practice of using smoke evacuation devices—a practice the authors recommend for all laparoscopic cases that involve significant electrocautery use.

Hollmann, et al reported the presence of 2-furancarboxaldehyde (furfural) in surgical smoke measured at 2 cm from the point of origin during a reduction mammoplasty. That level is 12 times higher than the occupational exposure limit. Several animal studies have shown significant hepatic toxicity in the form of necrosis, cirrhosis and carcinomas after chronic ingestion and inhalation of furfural (Hollmann, et al). As a result of dilution in the environment, gas density distribution and cutaneous absorption, the measured concentration does not practically represent the actual concentration to which the surgeon was exposed.

A previous investigation had identified significant levels of benzene, ethyl benzene, styrene, carbon disulphide and toluene in electrocautery smoke that was collected near the tip of the electrocautery (Sagar, et al). However, the exposure of the surgeon and the patient to these chemicals is negligible when measured under circumstances that represent the actual exposure of the surgeon and the patient during an operation as demonstrated in the current investigation.

Conclusion

The objective of this investigation and other similar reports is not to cause complacency or paranoia, but to advocate the continuous judicious appraisal of the various technologies on which healthcare practitioners depend. The evaluation of surgical smoke may seem trivial; however, it is important to remember that although the authors were unable to detect measurable levels of any of the toxic or mutagenic components of electrocautery smoke, they do exist and, therefore, the cumulative exposure of even minute unmeasurable amounts over a surgeon's lifetime may not be insignificant.

Follow-up qualitative and quantitative studies of the other electrocautery smoke constituents using more sophisticated sampling and analytical techniques, along with quantification of the actual magnitude of exposures, are important next steps. Similarly technological adjustments that allow the more efficient and effective evacuation of electrocautery smoke from the surgical field and the operative environment are necessary. ■

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