Evaluation of Surgical Plume Particle Exposures in a Hospital and Private Medical Office Suite

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Contents

Supplemental Report to "CHARACTERIZATION OF SURGICAL PLUME AEROSOLS AND ASSESSMENT OF OCCUPATIONAL EXPOSURES AMONG OPERATING ROOM PERSONNEL"

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights

This report is a supplement to the study, "Characterization of Surgical Plume Aerosols and Assessment of Occupational Exposures among Operating Room Personnel."* This work is an evaluation of exposures to surgical plume produced by energy-based surgical instruments.

What We Did

- We compared characteristics of surgical plume particles produced by four surgical instruments in controlled trials with human tissue. We looked at particle size distribution, number and mass concentrations, particle surface area, and particle-bound polycyclic aromatic hydrocarbon concentrations.
- We measured concentrations of surgical plume particles during surgical procedures in operating rooms in a hospital and a treatment procedure in a private medical office.
- We compared concentrations of surgical plume particles with and without the use of local exhaust ventilation during controlled trials and surgical procedures in operating rooms.

We evaluated characteristics of and exposures to surgical plume particles during controlled trials of plume production. We also evaluated exposures during medical procedures in hospital operating rooms and at a private medical office. We compared concentrations of surgical plume particles with and without the use of local exhaust ventilation. We found that the average plume particle size ranged between 0.03–0.20 micrometers, small enough to penetrate to the deepest parts of the lung. We also found that local exhaust ventilation significantly reduced exposures and recommend its routine use.

What We Found

- Average plume particle size ranged from 0.03–0.20 micrometers, depending on the surgical instrument, tissue type, and location of measurement.
- The electrosurgical unit created the highest ratio of particle-bound polycyclic aromatic hydrocarbons per particle surface area unit. This ratio is a measure of potential toxicity.
- The plasma jet produced the highest particle number concentrations measured at locations in the operating room.
- Local exhaust ventilation used at the point of plume generation resulted in statistically significant decreases in particle concentrations in the operating room.
- When a plasma jet was used in a private medical office with only residential-style general ventilation, particle number concentrations were higher than those observed in the hospital operating rooms.

What the Employer Can Do

- Ensure operating rooms achieve recommended minimum total and outdoor air changes per hour.
- Develop policies that require the use of local exhaust ventilation controls when using equipment that produces surgical plume.
- Train hospital and medical office staff on the potential hazards of surgical plume and control methods that can be used to minimize exposures.
- Vent exhaust room air directly outdoors if local exhaust ventilation is unavailable during plume producing procedures in the private medical office to avoid recirculation of surgical plume throughout the medical office suite. Operate the room ventilation exhaust at the highest level possible.

What Employees Can Do

- Use local exhaust ventilation when using surgical plume producing equipment.

*https://jscholarship.library.jhu.edu/bitstream/handle/1774.2/40192/KING-DISSERTATION-2014.pdf?sequence=1&isAllowed=y

Abbreviations

µm	Micrometer
ACH	Air changes per hour
cfm	Cubic feet per minute
cm	Centimeters
cm^3	Cubic centimeters
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
CMD	Count Median Diameter
CPC	Condensation particle counter
DC	Diffusion-charging
ELPI	Electrical low pressure impactor
ESU	Electrosurgical unit
GM	Geometric mean
GSD	Geometric standard deviation
HEPA	High efficiency particulate air
HPV	Human papilloma virus
HVAC	Heating, ventilation, and air-conditioning
LEV	Local exhaust ventilation
NIOSH	National Institute for Occupational Safety and Health
OR	Operating room
OSHA	Occupational Safety and Health Administration
PAS	Photoelectric aerosol sensor
PBZ	Personal breathing zone
pPAH	Particle-bound polycyclic aromatic hydrocarbons
SA	Surface area
WPS	Wide-range particle spectrometer

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Introduction

This report is a supplement to the study "Characterization of surgical plume aerosols and assessment of occupational exposures among operating room personnel" [King 2014]. This work is an evaluation of exposures in hospital operating rooms (ORs) and a private medical office to surgical plume produced by energy-based surgical instruments. At the hospital ORs, a surgeon used a variety of energy-based surgical instruments to cut and cauterize tissue; at the private medical office, the surgeon applied one of the instruments to a patient's facial dermal tissue as a treatment. These instruments produce particles and combustion products, termed 'surgical plume,' when applied to human tissue.

The Occupational Safety and Health Administration (OSHA) has reported that an estimated 500,000 workers, including surgeons, nurses, anesthesiologists, and surgical technologists, are exposed to surgical plume every year [OSHA 2008]. Exposures to surgical plume have prompted concerns by health care workers about acute (e.g., eye and respiratory irritation) and chronic health effects. A recent National Institute for Occupational Safety and Health (NIOSH) survey of healthcare workers found that 44% of electrosurgery respondents and 49% of laser surgery respondents reported never having been trained on the hazards of surgical plume. Of all respondents, less than a third reported their employers had procedures for addressing laser or electrosurgical plume hazards [Steege et al. 2016]. Additional information on surgical plume hazards can be found in Appendix A.

Methods

The main objective of this work was to describe characteristics of surgical plume particles produced by commonly used energy-based surgical instruments applied to human tissue. During a series of controlled trials, we measured surgical plume particle characteristics in hospital ORs during the application of four instruments to samples of human skin and fat tissue. The intent of these trials was to replicate surgical plume produced during actual surgical operations. Particle measurements at the point of plume production were made during a first series of trials; measurements at the level of the personal breathing zone (PBZ) of a surgeon at the surgical table were made during a second series of trials. These controlled trials were performed because of the difficulty to collect these measurements during actual surgeries. Measurements at other locations in the hospital ORs were taken during all tissue sample trials to measure particle concentrations and potential exposures of health care workers close to and distant from the source of surgical plume production. During these trials, the effectiveness of local exhaust ventilation (LEV) engineered into one of the instruments (electrosurgical unit [ESU]) was also evaluated to assess the reduction in concentrations of surgical plume particles when the LEV was used.

We characterized particles in surgical plume during the trials using direct-reading instruments. The characterizations were conducted in an empty hospital OR in cooperation with a board-certified plastic surgeon employed at the hospital. The surgeon used four surgical instruments and samples of human tissue (removed from patients during previous surgeries) to produce surgical plume for characterization. These tissues were collected

according to a protocol approved by two Institutional Review Boards. Informed consent for the tissue donation was obtained from patients undergoing routine procedures in which excess skin and fat tissue removed would otherwise be disposed of as medical waste.

The four surgical instruments we used were:

- An ESU, consisting of a generator and electrode handpiece, which applies an electric current at the tip of the knife into the tissue. This instrument can be used in either 'cut' or 'coag' modes. The ESU had a built-in LEV port opening near its tip so that LEV could be turned on to capture particles at the point of generation. A 7/8-inch inner diameter tube led from the ESU to a surgical plume evacuator, a Buffalo Filter ViroVac®; manufacturer's specifications indicate an airflow rate of 25 cubic feet per minute (cfm) for this tubing size.
- A harmonic scalpel which vibrates at 55,000 hertz and shears tissue based on the principle of cavitation (formation of multitudes of minute bubbles, fragmenting the cellular and tissue structures).
- A neutral plasma coagulator, also called plasma jet, which utilizes a stream of argon gas passing over an electrode in the handpiece of the unit, creating a stream of argon plasma to cut, cauterize, or sterilize tissue. The effects on tissue by the stream of argon plasma depend on the quantity and speed of argon gas and how much energy is applied to the gas at the tip of the handpiece [Plasma Surgical Limited 2009].
- A carbon dioxide (CO_2) laser, which vaporizes the tissue's water component and aerosolizes the dry component as plume.

For the series of controlled trials, the sampling protocols and instrumentation used to characterize surgical plume particles are described in the following two sections. Following these sections, we describe the methods used to characterize surgical plume particles during four surgical procedures performed by the surgeon in hospital ORs and a cosmetic procedure performed in a private medical office setting.

Controlled Trials: Surgical Plume Near the Point of Generation and at the Periphery of the Operating Room

For the first series of trials, we characterized particles near their point of generation. The surgeon placed a large sample of human tissue consisting of skin and fat on absorbent pads in the center of the surgical table in a location, which approximated the site of surgical work on a patient (Figure 1). Using one of the four surgical instruments, the surgeon turned the instrument on and applied it to the skin. At a distance of approximately 5 centimeters (cm) from the point of surgical instrument contact with the skin tissue, the inlet of an 18-inch long conductive flexible silicone tube was positioned to collect particles. The particle-laden airstream was diverted simultaneously to particle-measuring instruments on a mobile cart next to the surgical table where the plume was generated. The selected surgical instrument was applied to the skin tissue for 1 minute followed by a period of 1–2 minutes of no application to allow for particle clearance. One full trial for the surgical instrument was completed when this cycle was repeated for a total of five consecutive on/off repetitions during which continuous, real-time monitoring was conducted.

Figure 1. Tissue on the surgical bed, with the black inlet tube connected to the diluter. Photo by NIOSH.

We used five direct reading instruments to characterize different parameters during these trials including: particle size distribution, particle number concentration, respirable mass concentration, active particle surface area (SA) concentration, and total concentration of particle-bound polycyclic aromatic hydrocarbons (pPAHs). A similar array of particle monitoring equipment has been utilized in other studies of ultrafine particle exposures [Evans and Fent 2015; Evans et al. 2010; NIOSH 2010, 2013]. Because of the high concentrations of particles expected at the point of plume generation, we placed a diluter (filter with bypass) in-line after the capture of particles, but prior to measurement by the direct reading instruments. This diluter prevented the particle concentrations from exceeding the upper limits of the direct reading instruments and provided a dilution factor of 28. The dilution factor was experimentally determined with the same particle sampling setup in a controlled test atmosphere. The diluter was not needed during particle production by the harmonic scalpel.

The five direct reading instruments we used were:

- a Dekati Ltd. electrical low pressure impactor (ELPI) to provide particle number concentrations and real-time size distribution measurements of particles
- a TSI model 3007 condensation particle counter (CPC) to measure particle number concentrations
- a TSI model 8533 DustTrak to provide real-time particle mass estimates
- an EcoChem Analytics DC 2000CE diffusion-charging (DC) based instrument to provide real-time SA measurements
- an EcoChem Analytics PAS 2000CE photoelectric aerosol sensor (PAS) to detect pPAHs on ultrafine particulate matter generated through incomplete combustion

We placed two additional instruments in the periphery of the hospital OR to characterize particle concentrations. A CPC was located four feet above the floor in front of one of the exhaust vents in the far corner of the hospital OR opposite the entrance to the room. A TSI model 8525 P-Trak particle counter was located at the circulating nurse's station immediately to the right of the entrance to the hospital OR. A P-Trak is similar in operation to the CPC although the concentration of particles sized 0.020–1.0 micrometers (μm) that are reliably detected by the P-Trak is up to 500,000 particles per cubic centimeter (particles/cm^3) as compared to 100,000 particles/cm^3 in the size range of 0.010–1.0 μm for the CPC. The measurements in the periphery of the room provided information regarding the spread, concentration, and distribution of surgical plume particles to which circulating hospital OR personnel could be exposed. See Figure 2 for a diagram of the room and placement of the sampling equipment during these trials.

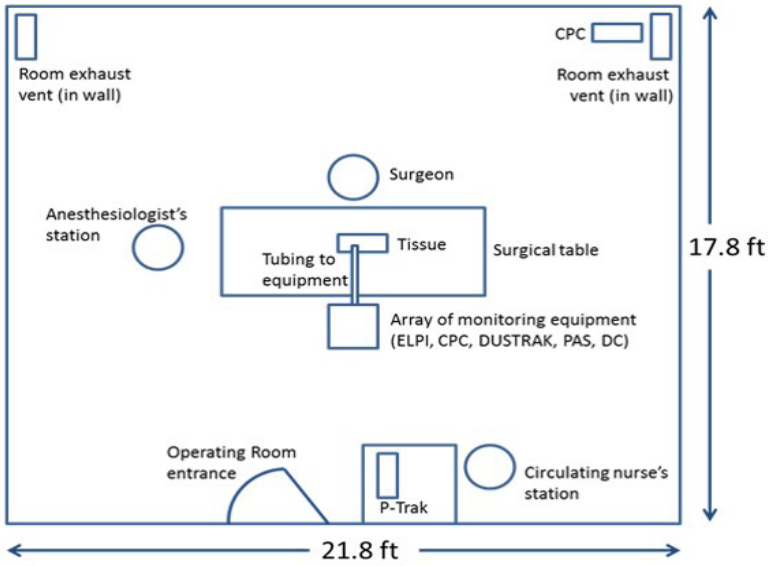

Figure 2. Diagram of the hospital OR and placement of the sampling equipment near the point of generation sampling.

Prior to conducting the controlled trials of plume production, the two CPCs and the P-Trak were placed side-by-side to determine background particle number concentrations in the hospital OR. Background particle concentrations recorded by all three instruments were low (below 100 particles/cm^3), allowing increases in particle concentrations during the trials to be specifically attributed to surgical plume. No other particle-generating activities were performed at the times the trials were conducted.

Controlled Trials: Surgical Plume at Personal Breathing Zone Level and at the Periphery of the Operating Room

For the second series of trials, we characterized particles in the PBZ-level of the surgeon at the surgical table. The surgeon placed a sample of human tissue containing skin and fat on absorbent pads in the center of the surgical table. The location of the tissue sample on the table approximated the site of surgical work on a patient. Using one of four surgical plume-

producing instruments listed previously, the surgeon applied the instrument to the tissue using the same surgical technique used during a typical surgical procedure. Application of the instrument to both skin and fat from the tissue was performed separately to evaluate differences in plume characteristics based on tissue type. Because these instruments are often applied in a short, intermittent, and sporadic manner during a typical surgery, a similar design was incorporated in the design of these plume production trials. For each specific instrument applied to either the skin or fat tissue, 20 consecutive sampling periods were conducted by the monitoring equipment whose inlets were located in what would be the PBZ space of an individual working at the surgical table (Figure 3). Each sampling period lasted 30 seconds. For the first 5 seconds of each sampling period, the surgeon applied the instrument to the tissue to create a plume of particles. After completing 20 sampling periods using one instrument on one type of tissue, plume production was ceased and the particle concentrations were allowed to return to background level (approximately at or below 100 particles/cm^3) before a new round of 20 sampling periods using a different instrument on a fresh area of the tissue was conducted.

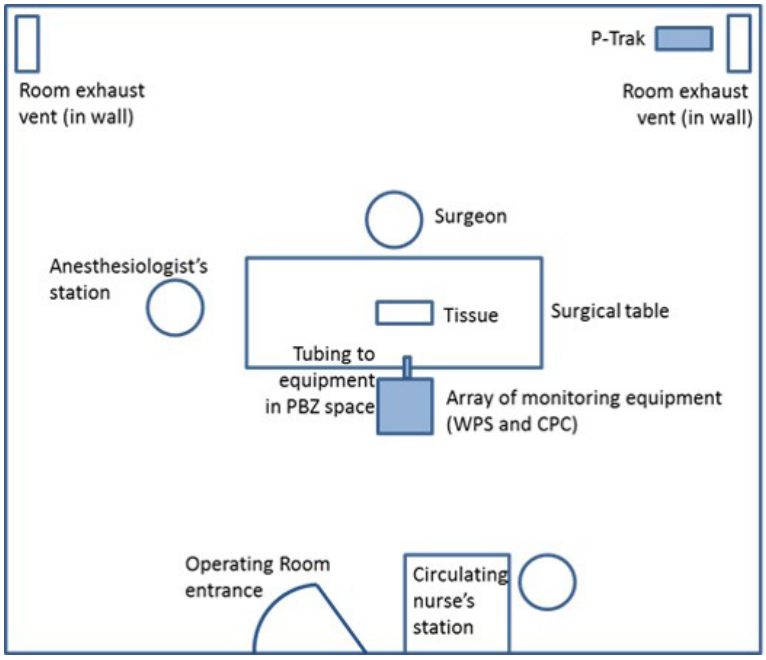

Figure 3. Diagram of the hospital OR and placement of the sampling equipment at PBZ-level during sampling.

Two monitoring instruments were located on a mobile cart stationed next to the surgical table:

- an MSP Corporation model 1000XP-A wide-range particle spectrometer (WPS) to characterize size distributions of surgical plume particles in the PBZ-level
- a TSI model 3007 handheld CPC to characterize particle number concentrations of surgical plume particles in the PBZ-level

Short lengths of non-conductive tubing (approximate length: 30 cm) were added to the instruments' inlets. The tubes' particle-collecting inlets were 41 cm above and offset by 41 cm from the point of plume production on the table and were 120 cm in height above the floor of the hospital OR.

A P-Trak was located 4 feet above the floor in front of one of the exhaust vents in the far corner of the hospital OR opposite the entrance to the room to measure particle concentration in the periphery of the room.

Surgical Plume during Actual Surgical Procedures in Operating Rooms

Exposures to surgical plume under actual work conditions were assessed in hospital ORs where access was granted during selected surgical procedures. The surgical procedures (i.e., brachioplasty, thighplasty, breast augmentation, necrotic tissue removal) that were evaluated varied in the amount of surgical plume produced and included high plume-producing operations. All patients involved in the surgical procedures provided informed consent to have a NIOSH investigator and monitoring equipment present in the hospital OR. Personal protective equipment worn by health care workers at the surgical table included surgical masks and sterile gloves and gowns. The primary focus was to establish the magnitude of exposure to and characteristics of surgical plume particles, specifically size distribution and particle count concentrations, in locations in the hospital OR both near to and distant from the site of the surgical plume production. All sampling equipment was placed to ensure that sampling had no impact on the surgical procedure itself nor interfered with the surgical care by the hospital OR personnel. Measurement of surgical aerosols in the hospital OR did not require change in any surgical technique usually used.

Because of the space restrictions near the surgical table, the main sampling equipment was placed near the anesthesiologist's station at the head of the surgical table, named location A (Figure 4). Short sections of tubing for particle collection to the WPS and CPC instruments at this location were used so that collection in or very near the PBZ of the anesthesiologist was accomplished. Direct-reading particle monitoring was conducted throughout the selected procedures. Particle counters were also stationed in two other locations in the hospital OR (i.e., locations B and C) to assess particle concentration. To provide data on background particle size and count concentration, sampling was conducted prior to the start of the surgical procedures when no plume was produced.

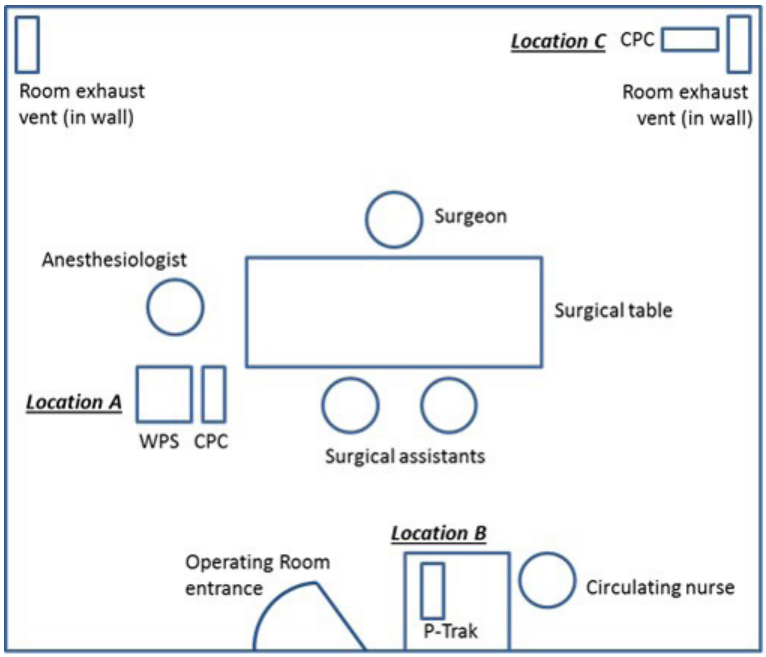

Figure 4. Diagram of the hospital OR and placement of the sampling equipment used during surgical procedures.

An LEV system, the Buffalo Filter Plume Safe® model 1202, was available in the hospital OR and used by the surgeon as needed (Figure 5). A surgical assistant held the evacuation system's 7/8-inch diameter tubing approximately 2–3 inches from the point of surgical plume production to evacuate plume from the surgical area. While the equipment has variable airflow control, the manufacturer's specifications indicate a maximum airflow setting of 48 actual cfm. Measurements were made at settings typically used by the surgeon in the hospital OR and ranged from 17–35 cfm.

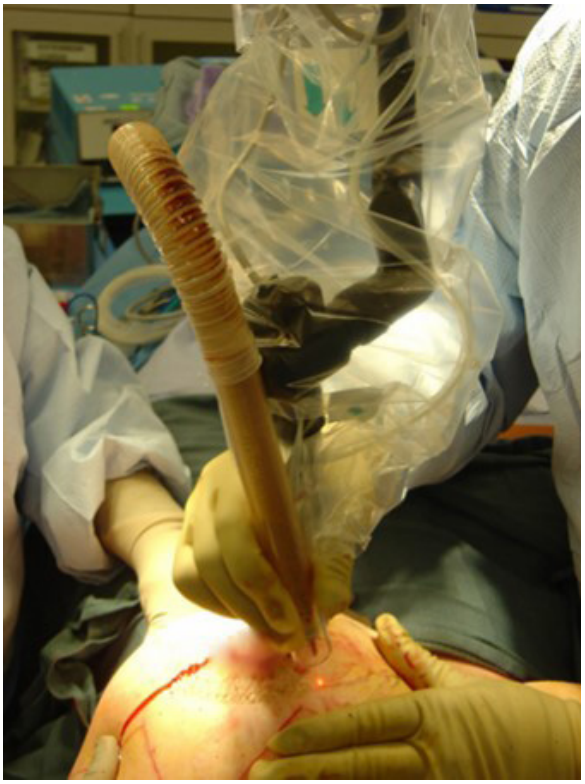

Figure 5. Photograph of surgical plume particles captured using LEV during a surgical procedure with a CO_2 laser. Photo by NIOSH.

We characterized and compared particle number concentrations in regions of the hospital OR during the surgical procedures. Data from the CPCs and P-Trak were log-transformed for statistical analysis to approximate a normal distribution. Descriptive statistics such as geometric mean (GM) number concentration, geometric standard deviation (GSD), and the range of number concentrations were calculated from those data points collected between the initiation of plume production in a surgical procedure through the last point of plume production in that procedure plus 10 minutes.

Surgical Plume during a Cosmetic Procedure in a Private Medical Office

We measured concentrations of plume particles during a procedure in a private medical office in a typical suburban office park. We took limited measurements during a single non-invasive, non-surgical procedure in a treatment room. During this procedure, the surgeon used the plasma jet on low level on the facial skin tissue of a client for cosmetic purposes rather than to cut or cauterize tissue. Particle number concentrations were measured in the treatment room as well as outside of the room during the treatment. General ventilation in the room was provided by a residential heating, ventilation, and air-conditioning (HVAC) unit that provided lower efficiency in removing small particles compared to the high efficiency particulate air (HEPA) filtration provided in the hospital ORs.

Operating Room Ventilation Assessment

The air supply vents in the hospital ORs used for the controlled trials and the actual surgical procedures were located above the surgical table. The supply air vents provided a downward laminar flow of HEPA-filtered air from above the surgical table to the room's two exhaust vents, each located near the floor in the room's two corners farthest from the hospital OR entrance, in accordance with OR design standards [ANSI/ASHRAE/ASHE 2013]. We made ventilation measurements in the hospital ORs using a TSI AccuBalance Plus® model 8373 air capture hood and a TSI VelociCalc Plus® model 8386A. We measured the air volume flowing through the ventilation supply registers and exhaust vents and used that information to calculate the number of air changes per hour (ACH) in the hospital ORs. Measurements were also made to determine if the rooms were maintained under positive pressure as designed. All ventilation characteristics remained the same during the controlled trials as they were during the actual surgical procedures.

Results and Discussion

Controlled Trials: Surgical Plume Particles at the Point of Generation and at the Periphery of the Operating Room

Five consecutive 1-minute rounds of plume generation were performed with each surgical instrument. In addition to overall particle number concentration, the ELPI provided size distribution data for particles produced by each of the surgical instruments. Summary statistics for count median diameter (CMD), GM particle number concentration, and GM respirable mass concentration (including respective GSD), are summarized for each configuration of the surgical instruments in Table 1. The two instruments that produced the lowest respirable mass concentrations (the harmonic scalpel and the plasma jet) also produced particles with the smallest particle CMD (harmonic scalpel: 0.034 μm; plasma jet: 0.041–0.046 μm). This is reflective of the fact that mass concentration is highly dependent on the size of the particles. Although the harmonic scalpel also produced the lowest particle number concentrations, the plasma jet produced particle number concentrations up to twenty times that of the harmonic scalpel. The GM particle number concentrations produced by the CO_2 laser, plasma jet, and ESU were ten to 100 times greater than those produced by the harmonic scalpel.

Table 1. Plume particle characteristics at the point of generation in the controlled trials by instrument

Instrument	Count median diameter (μm) [GSD]	GM particle number concentration* (particles/cm^3) [GSD]	GM respirable mass concentration† (milligrams/m^3) [GSD]
Harmonic Scalpel	0.034 [1.48]	711,000 [5.68]	0.161 [3.60]
CO_2 laser	0.070 [5.86]	76,900,000 [2.73]	158 [3.18]
ESU (cut mode), *with LEV*	0.085 [12.37]	974,000 [4.42]	1.68 [12.60]
ESU (cut mode), *without LEV*	0.095 [7.99]	7,780,000 [3.87]	22.4 [5.56]
ESU (coag mode), *with LEV*	0.061 [9.60]	3,150,000 [5.96]	0.795 [12.21]
ESU (coag mode), *without LEV*	0.069 [8.25]	13,000,000 [5.44]	5.53 [9.69]
Plasma Jet (cut mode)	0.041 [5.18]	15,200,000 [3.27]	0.118 [6.85]
Plasma Jet (coag mode)	0.046 [6.84]	6,160,000 [5.18]	0.063 [8.26]

*Measured by the ELPI

†Measured by the DustTrak

Simultaneous measurements of active SA (measured by the DC 2000CE) and total pPAH concentrations (measured by the PAS 2000CE) were made at the point of generation during the five 60-second periods of surgical plume generation for each surgical instrument configuration. When these concentrations are measured simultaneously and calculated in a pPAH/SA ratio, the amount of PAH mass per unit area of the active surface of the particles is quantified and creates a normalized indicator of PAHs on fine particles. Mage [2002] cites the importance of particle chemistry, such as PAH adsorption, on health effects of fine particles. The higher the pPAH/SA ratio, the greater the quantity of PAH molecules per unit SA [Ott and Siegmann 2006]. This ratio, therefore, is relevant to the quantity of pPAHs transported into the deepest regions of the respiratory tract [Polidori et al. 2008].

Ott and Siegmann [2006] suggest two ways to calculate the pPAH/SA ratio: (1) regression analyses with the slope of the least-squares regression line yielding the pPAH/SA ratio and (2) calculation of individual ratios using the means from each averaging period. Table 2 shows the results from both analyses for each of the tested surgical instrument configurations. The slopes of the regression equations, underlined in the table, show the ratio as determined by that method.

Table 2. Comparison of pPAH/SA calculated from regression equations and ratios of GM concentrations by surgical instrument

Instrument	Regression equation, PAS vs. DC [Coefficient of Determination]	Ratio of pPAH GM/SA
Harmonic scalpel	y = 0.0531x + 9.1602	0.09
CO_2 laser	y = 0.195x – 145.67	0.12
ESU (cut mode), *with LEV*	y = 1.983x + 2,379	0.93
ESU (cut mode), *without LEV*	y = 0.6531x + 10,912	0.62
ESU (coag mode), *with LEV*	y = 0.9304x + 5,344.3	0.46
ESU (coag mode), *without LEV*	y = 0.4199x + 6,304.6	0.32
Plasma jet (cut mode)	y = 0.0719x + 646.41	0.10
Plasma jet (coag mode)	y = 0.0408x + 257.89	0.05

The calculation of the pPAH/SA regression analyses and GM ratios yielded similar results. The range of the slopes of the regression equations for the harmonic scalpel and plasma jet (0.04–0.07) reflected the range of calculated ratios for those two instruments (0.05–0.10). The results suggest that these two instruments produced particles with lower concentrations of pPAHs per unit SA. The CO_2 laser produced particles with a slightly larger regression line slope (0.20) and ratio (0.12). A clear difference was observed, however, between the results of the ESU and those of the other surgical instruments. Without the use of LEV for the ESU, the regression line slopes (0.42, 0.65) and calculated GM ratios (0.32, 0.62) indicated considerably greater quantities of pPAHs per SA unit compared to the other instruments. Interestingly, the use of the LEV control increased the slopes (0.93, 1.98) and GM ratios (0.46, 0.93) even further, the highest among all surgical instrument configurations.

The differences observed in the pPAH/SA ratios and presumably in the potential toxicity of the particles, is likely related to the underlying mechanism by which each instrument cuts the tissue. The harmonic scalpel, the instrument with a low PAS/DC ratio, relies on the principle of cavitation (production of microscopic bubbles within the cellular structure of the tissue) via ultrasonic vibration of the surgical tip as it is applied to the tissue. Because this method is less likely to cause pyrolysis of the tissue compared to the others, lower pPAH concentrations are likely generated, resulting in lower pPAH per unit SA of the aerosolized particles.
In contrast, the ESU applies an electrical current at the point of contact of the surgical instrument with the tissue. This action appears to increase the production of pPAHs and their adsorption onto the surfaces of the particles. The higher pPAH/SA ratio in the cut mode of the ESU compared to the coag mode may reflect the fact that the cut mode uses a low voltage in a constant electrical waveform to produce maximum current concentration focusing intense heat at the site. The coag mode uses a high voltage intermittent electrical waveform producing less heat [Covidien 2008]. The higher heat in the cut mode may therefore increase the production of PAHs adsorbed onto the particles.

Particle number concentrations differed considerably between the two areas in the periphery of the hospital OR where real-time measurements were made during controlled trials. Figure 6 shows the time series measurements made at the circulating nurse's desk near the entrance to the hospital OR during the plume production trials by surgical instrument configuration. The plasma jet in cut and coag modes created the highest concentration of particles at this location. Figure 7 shows the time series of measurements made in the periphery of the hospital OR near one of the room's exhaust vents during the same periods of plume production as in Figure 6 by surgical instrument configuration. Similar to the measurements made at the circulation nurse's desk, concentrations are highest for particles produced by the cut and coag modes of the plasma jet. Unlike at the circulating nurse's desk where there were numerous peaks and a large variability in particle concentrations over time, concentrations at the side of the room near the exhaust show a gradual increase in particle concentration until an apparent static equilibrium is reached. The observed differences in concentration patterns are likely due to the airflow patterns in the hospital OR. In this hospital OR, laminar airflow was introduced above the surgical table and air flowed downward to the surgical table towards the peripheries of the room.

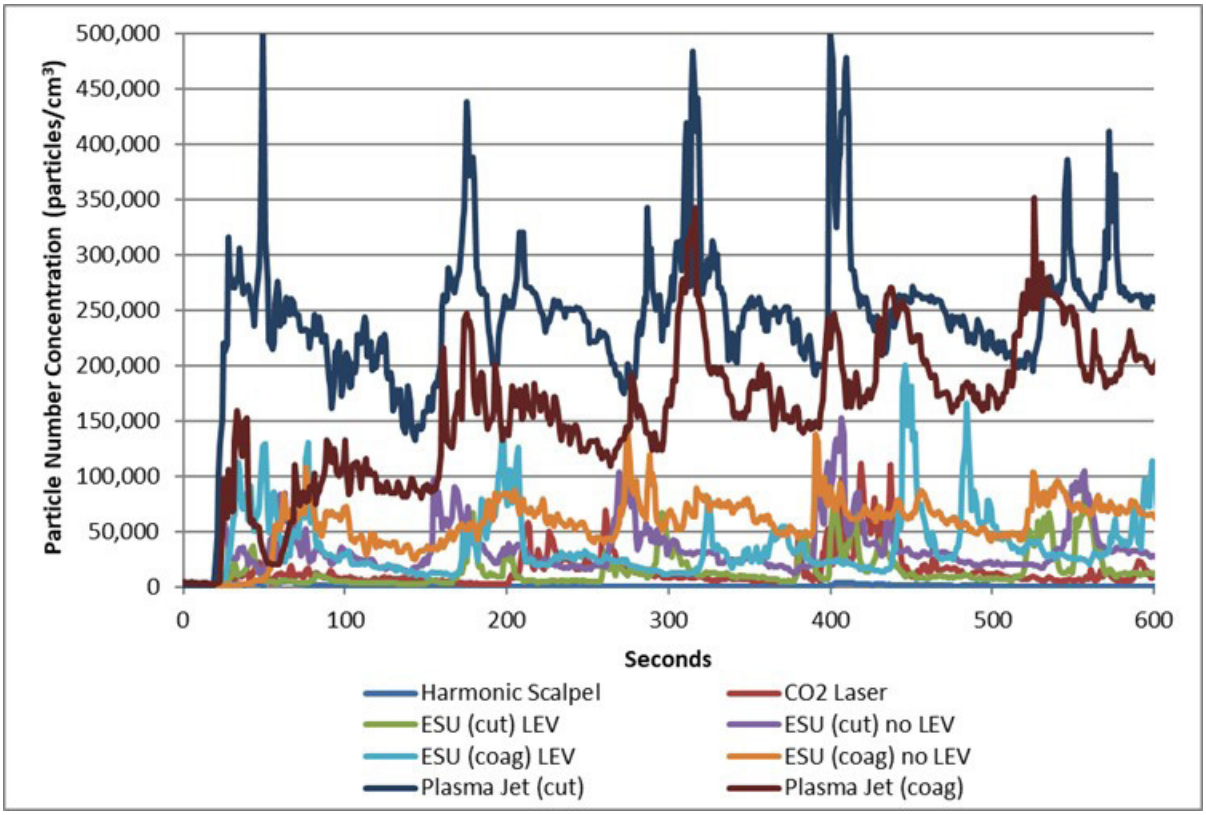

Figure 6. Particle number concentrations measured by a P-Trak at the circulating nurse's desk for each surgical instrument over the course of the plume production trials.

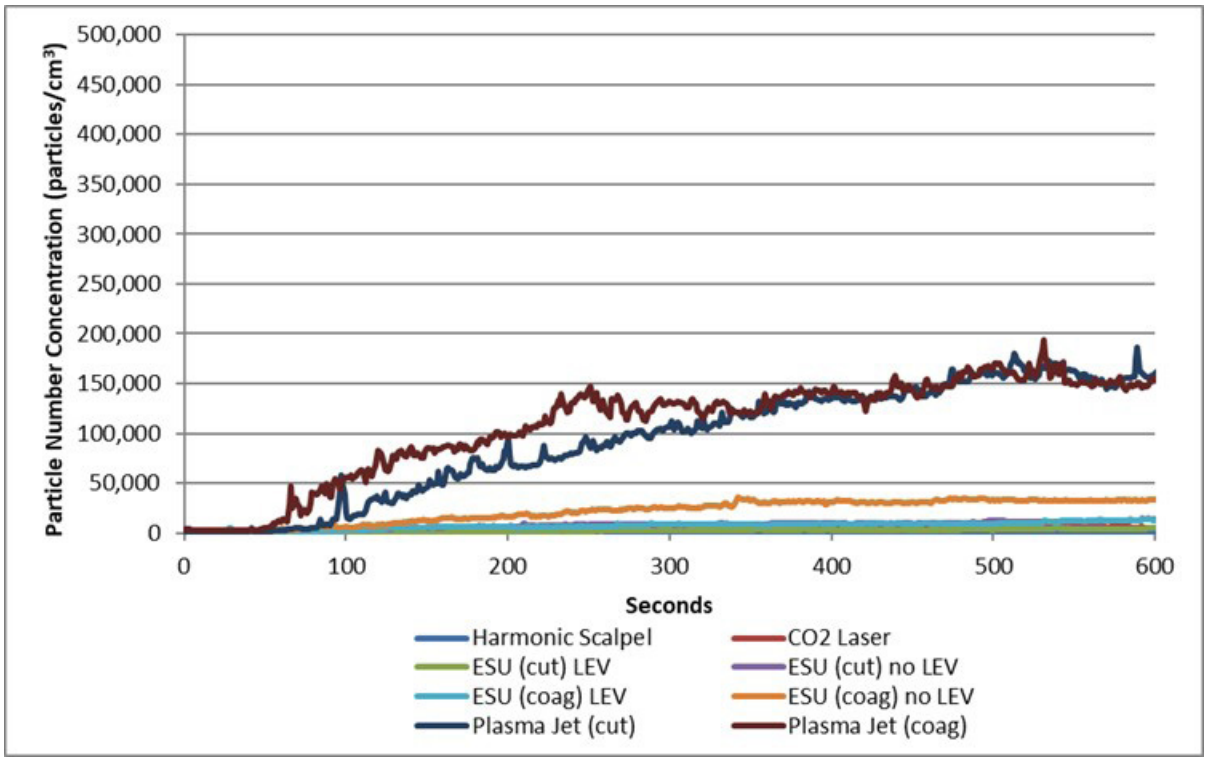

Figure 7. Particle number concentrations measured by a CPC near the hospital OR exhaust for each surgical instrument over the course of the plume production trials.

Despite the CO_2 laser producing the highest number concentrations of particles at the point of generation, particles produced by the plasma jet (both cut and coag mode) had the highest concentrations in the periphery of the hospital OR. Peak number concentrations reached 500,000 particles/cm^3 at the circulating nurse's desk while peak concentrations less than 200,000 particles/cm^3 were measured near the room exhaust vent. Smaller particle size diameter and mass concentrations for particles produced by the plasma jet may account for their ability to remain aerosolized longer and become dispersed throughout the room.

Figures 8–11 show the particle concentrations produced during use of the ESU (in cut and coag modes) with the built-in LEV control on and off. The LEV port was located approximately 1.5 inches from the tip of the ESU and was used in the 'low' setting. Lower particle number concentrations were seen in both areas of the periphery of the room when the LEV was used as compared to when the LEV was not used. In addition, particle concentrations were higher at the circulating nurse's desk than the opposite side of the room near the exhaust vent. Activation of the LEV at the point of particle generation by the ESU led to a statistically significant reduction in particle number concentrations ($p < 0.001$) at the circulating nurse's desk of 65% in the cut mode and 37% in the coag mode compared to non-LEV use in these modes. For the location near the exhaust at the opposite side of the room, LEV use led to significant ($p < 0.001$) reductions in GM particle number concentrations of 69% for the cut mode and 60% for the coag mode.

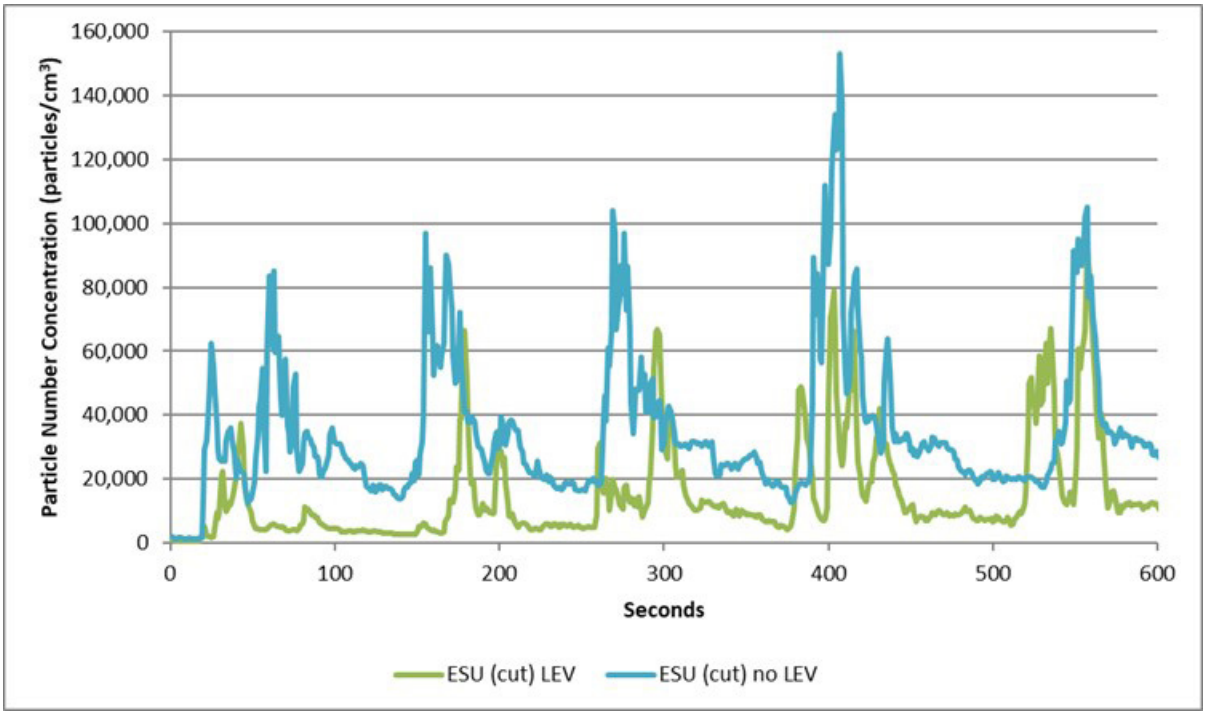

Figure 8. Comparison of particle number concentrations at circulating nurse's desk with and without LEV use during electrocautery in cut mode as measured by a P-Trak.

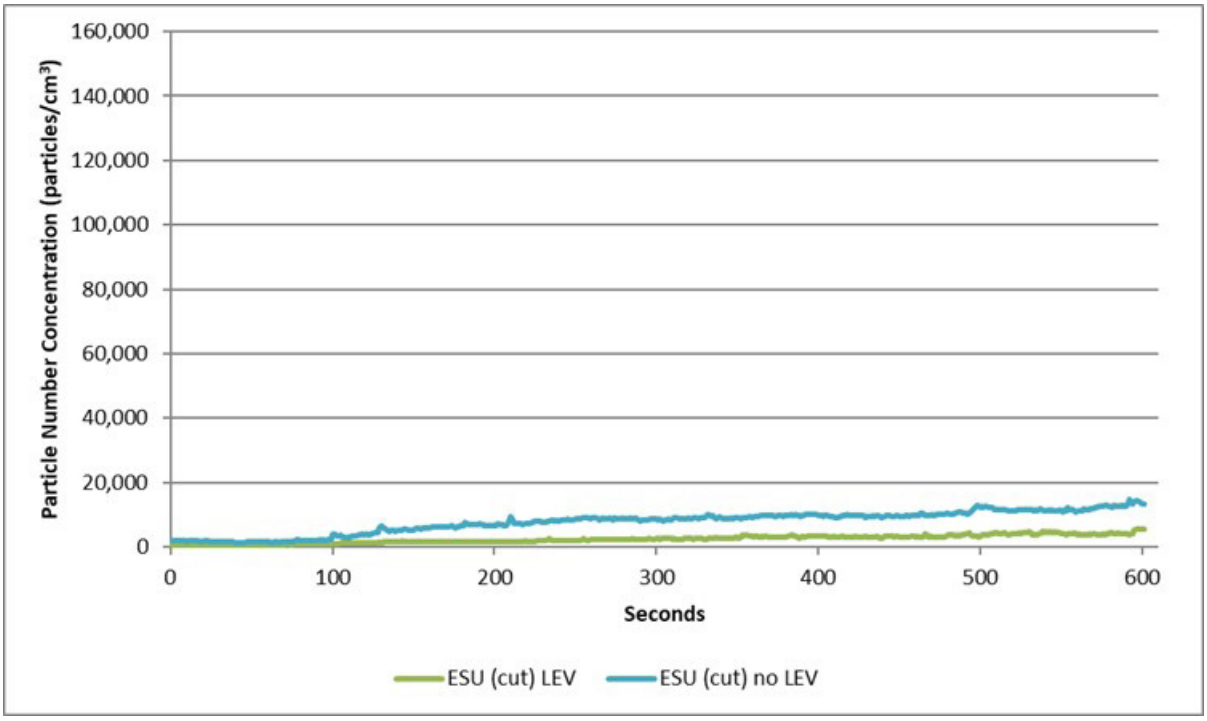

Figure 9. Comparison of particle number concentrations near exhaust vent with and without LEV use during electrocautery in cut mode as measured by a CPC.

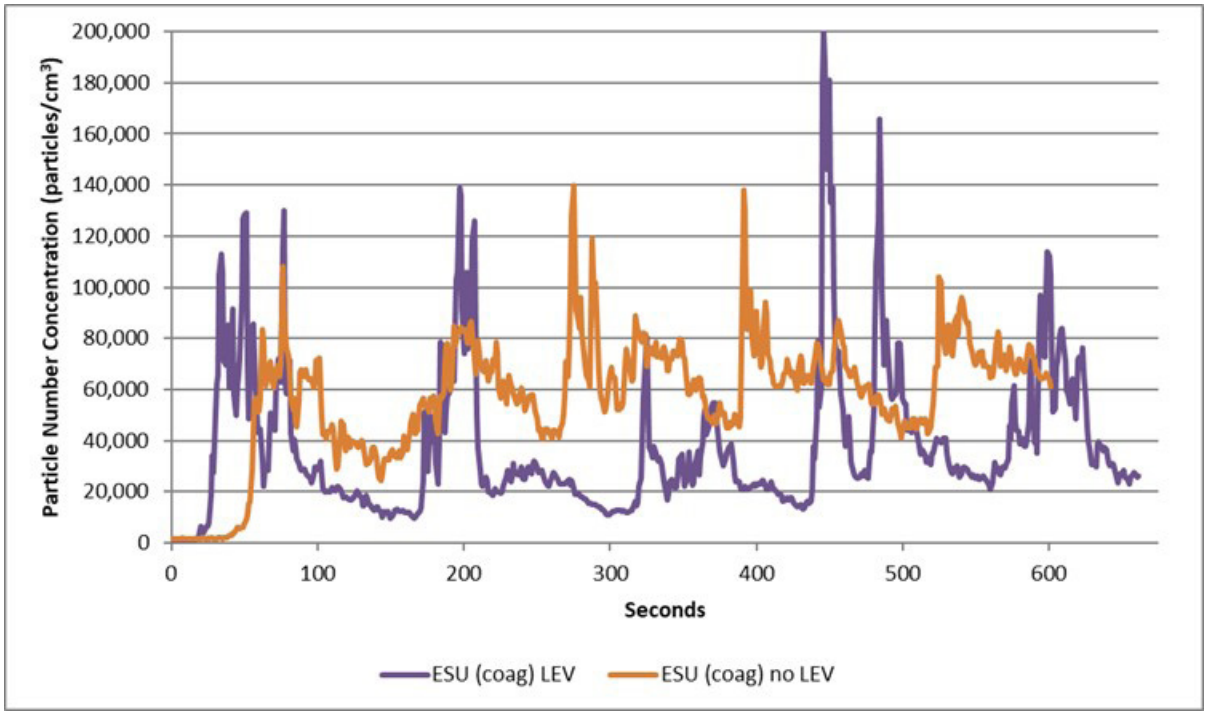

Figure 10. Comparison of particle number concentrations at circulating nurse's desk with and without LEV use during electrocautery in coag mode as measured by a P-Trak.

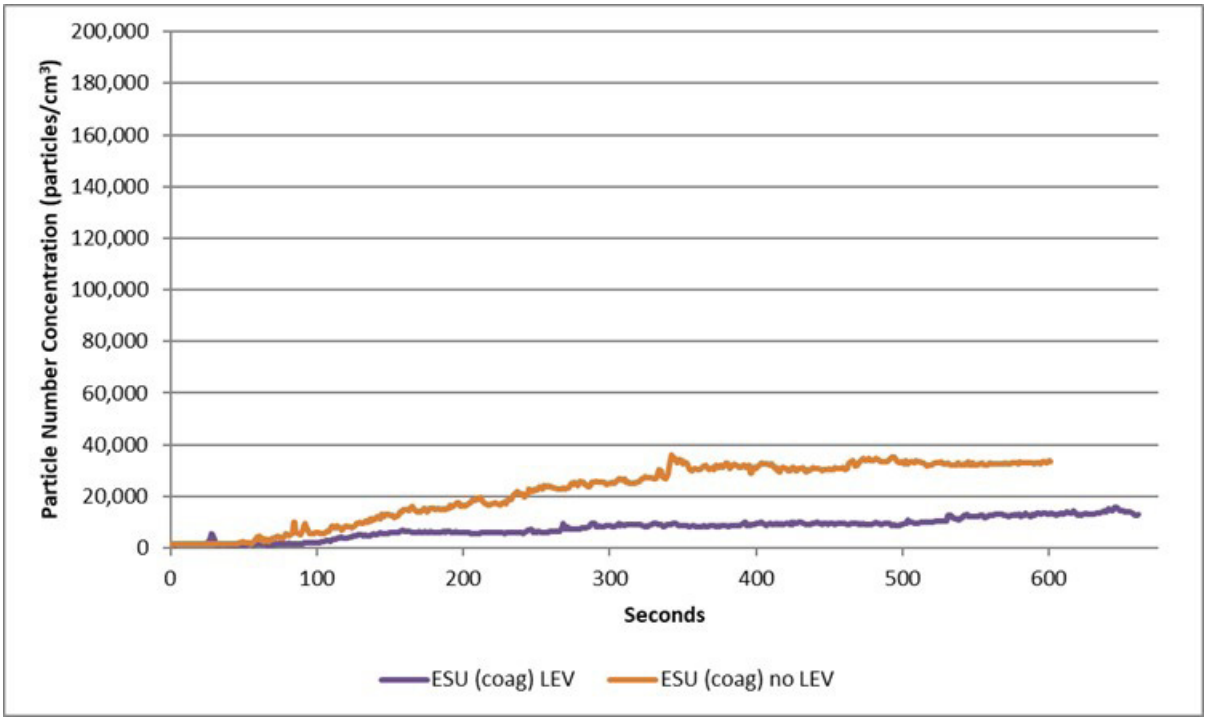

Figure 11. Comparison of particle number concentrations near exhaust vent with and without LEV use during electrocautery in coag mode as measured by a CPC.

For the hospital OR used in these series of trials, the exhaust airflow exceeded the supply airflow by approximately 100 cfm, suggesting a slight negative pressure in the room. We calculated an air change rate of approximately 20 ACH on the basis of room dimensions.

Controlled Trials: Surgical Plume Particles at Personal Breathing Zone level and at the Periphery of the Operating Room

Table 3 shows particle size distribution statistics for each instrument and tissue type. CMDs ranged from 0.03–0.19 µm for the skin tissue and from 0.04–0.12 µm for the fat tissue. Table 4 provides descriptive statistics for the GM particle number concentrations measured in the PBZ at the surgical table and at the periphery of the room. The instrument that generated the highest particle number concentrations when applied to skin and fat tissues was the plasma jet in both the cut and coag modes. Concentrations of surgical plume particles produced by the plasma jet and measured at PBZ level of a surgeon were about 200–300 times greater than those produced by the harmonic scalpel, depending on tissue and instrument mode. Electrocautery produced PBZ concentrations that were almost 50 times greater than the harmonic scalpel, while the CO_2 laser produced concentrations up to 20 times greater, depending on tissue type.

Table 3. Surgical plume particle size distributions by instrument and tissue type as measured at the surgeon's PBZ level using a WPS

Instrument	Skin	Fat
	Count median diameter (µm) [GSD]	Count median diameter (µm) [GSD]
Plasma jet (coag)	0.088 [2.1]	0.090 [2.2]
Plasma jet (cut)	0.082 [1.9]	0.115 [2.6]
ESU (coag)	0.129 [2.4]	0.116 [2.1]
ESU (cut)	0.190 [2.2]	0.088 [3.1]
CO_2 laser	0.086 [2.9]	0.091 [3.0]
Harmonic scalpel	0.028 [2.0]	0.038 [3.8]

Table 4. Geometric mean particle number concentrations and GSDs of surgical plume by surgical instrument and tissue type at the PBZ level of the surgeon and at the room periphery (PBZ level) as measured using a CPC and P-Trak

Instrument	Skin	Skin	Fat	Fat
	Surgical PBZ GM concentration (particles/cm^3) [GSD]	Room periphery GM concentration (particles/cm^3) [GSD]	Surgical PBZ GM concentration (particles/cm^3) [GSD]	Room periphery GM concentration (particles/cm^3) [GSD]
Plasma jet (coag)	72,572 [1.24]	64,797 [1.12]	108,632 [1.33]	38,178 [1.18]
Plasma jet (cut)	67,995 [1.30]	66,517 [1.09]	95,159 [1.25]	37,238 [1.20]
ESU (coag)	10,149 [1.53]	17,726 [1.15]	3,602 [1.38]	2,083 [1.19]
ESU (cut)	4,884 [1.75]	8,805 [1.17]	282 [1.36]	146 [1.24]
CO_2 laser	4,362 [1.40]	13,704 [1.21]	5,375 [1.11]	3,060 [1.12]
Harmonic scalpel	220 [1.92]	541 [1.88]	457 [2.98]	51 [1.49]

During trials on the skin tissue, concentrations at the periphery of the room were found to be generally equal to or greater than at the surgical table whereas the opposite was found during the trials on the fat tissue. These differences may be explained by the general ventilation characteristics in the hospital OR where skin trials were performed compared to the hospital OR where the fat trials were performed. On the basis of our airflow measurements and room dimensions, the hospital OR where the trials were conducted on the skin tissue had about 24 ACH. The exhaust airflow exceeded supply by approximately 200 cfm indicating that the room was under negative pressure with respect to the adjacent corridor. We determined an air change rate of 21 ACH in the room where trials were conducted on the fat tissue. Because the air supply exceeded the exhaust by approximately 200 cfm, the room was under positive pressure with respect to the adjacent corridor.

Surgical Plume Particles during Actual Surgical Procedures in an Operating Room

Table 5 lists the type and length of surgical procedure evaluated, room ACH, types of plume-producing equipment used, and whether LEV was used during surgical plume production. Two surgical procedures, the brachioplasty and the thighplasty, are treated as separate procedures in the tables. Although nearly identical work was performed on the two extremities (i.e., arm 1 and arm 2, or leg 1 and leg 2), they were done consecutively with a break of surgical work and plume production between them. The surgeon used LEV during the surgical work on the first extremity while not on the second extremity to evaluate the impact LEV use had on particle concentrations around the hospital OR.

Table 5. Surgical procedures monitored for determination of surgical plume concentration

Procedure	Length of procedure (minutes)	Calculated room ACH	Use of LEV	Plume producing equipment used
Brachioplasty 1 (arm 1)	50	23.6	yes	ESU and plasma jet
Brachioplasty 2 (arm 2)	48	23.6	no	ESU and plasma jet
Thighplasty 1 (leg 1)	82	21.3	yes	ESU and plasma jet
Thighplasty 2 (leg 2)	89	21.3	no	ESU and plasma jet
Breast augmentation	74	21.3	no	ESU and plasma jet
Necrotic tissue removal	17	23.6	no	ESU

Brachioplasties

Figure 12 shows real-time measurements of particle number concentrations at locations A and B during the brachioplasty with and without LEV. The period of ESU and plasma jet use with LEV on arm 1 corresponds to 8:57 a.m. to 9:20 a.m.; the period of ESU and plasma jet use without LEV on arm 2 corresponds to 9:48 a.m. to 10:09 a.m. The reduction in peak particle number concentrations in both locations due to LEV use is readily observed.

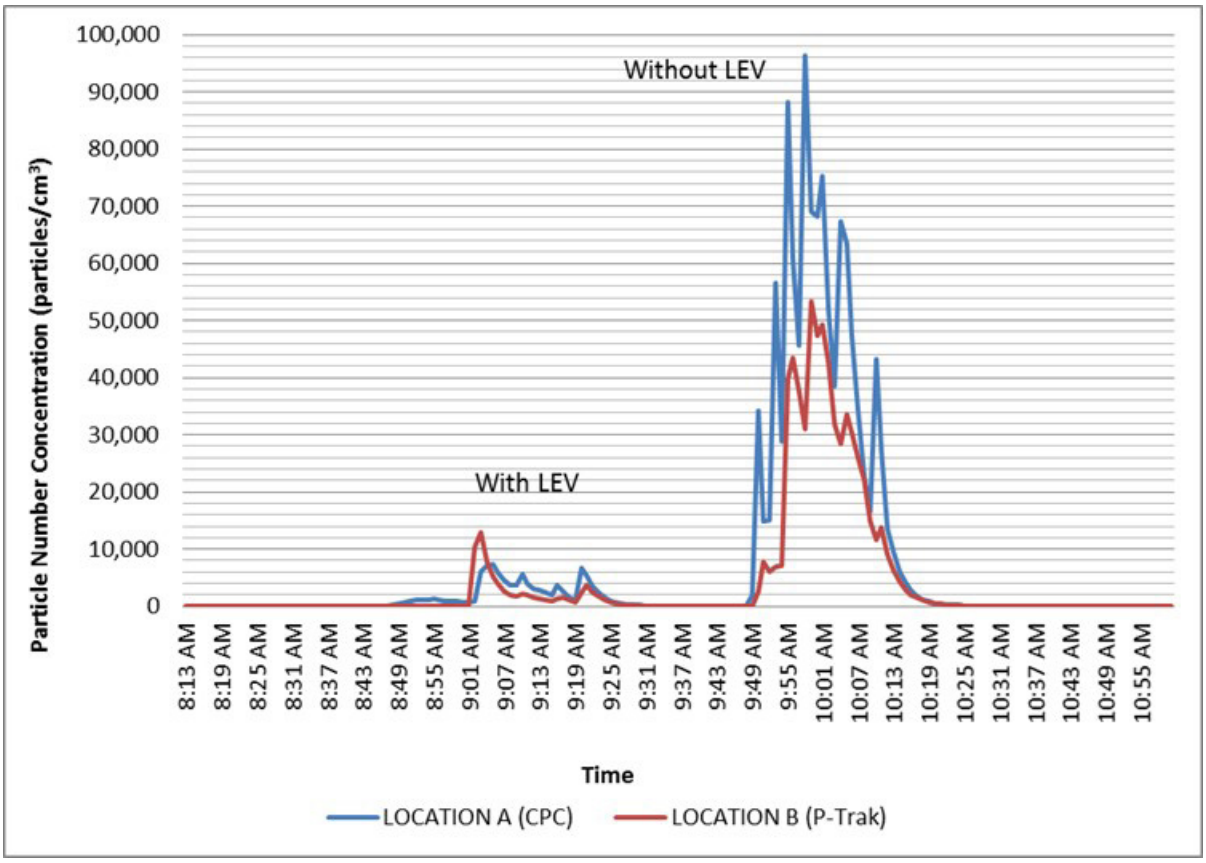

Figure 12. Airborne particle number concentrations (particles/cm^3) during brachioplasties with and without LEV use as measured by a CPC and P-Trak.

Mean particle number concentrations in both areas of the hospital OR were much higher during brachioplasty done without LEV than with LEV (Table 6). For example, at location A, the GM was 16,140 particles/cm^3 without LEV and 1,817 particles/cm^3 with LEV. Peak number concentration at this location reached 96,433 particles/cm^3 without LEV compared to 7,435 particles/cm^3 when LEV was used. Similar results were seen at location B. The use of LEV reduced the GM particle number concentrations by 89% at both locations. Furthermore, the LEV reduced peak particle number concentrations by 93% at location A and 76% at location B.

Table 6. Descriptive statistics for particle number concentrations in particles/cm^3 by surgery type and location in hospital OR as measured using CPCs (locations A and C) and a P-Trak (location B)

Procedure	Location A geometric mean concentration (particles/cm^3) [GSD] (range)	Location B geometric mean concentration (particles/cm^3) [GSD] (range)	Location C geometric mean concentration (particles/cm^3) [GSD] (range)
Brachioplasty 1 (LEV used)	1,817 [2.85] (149–7,435)	917 [4.75] (17–12,982)	N/A
Brachioplasty 2 (no LEV used)	16,140 [6.10] (23–96,443)	8,499 [5.86] (54–53,435)	N/A
Thighplasty 1 (LEV used)	3,277 [3.92] (32–15,918)	1,114 [3.54] (23–4,556)	3,460 [4.20] (46–20,933)
Thighplasty 2 (no LEV used)	23,913 [4.92] (26–134,324)	13,267 [7.57] (2–71,748)	21,669 [5.35] (35–136,400)
Breast augmentation (no LEV used)	230 [3.78] (11–3,941)	245 [3.89] (8–6,813)	232 [3.78] (10–2,802)
Necrotic tissue removal (no LEV used)	1,875 [3.22] (246–10,560)	890 [2.17] (183–2,934)	N/A

N/A = not applicable; no data collection instrument was available

When the average particle size distribution was calculated and plotted for measurements taken during the brachioplasty with LEV use (data not shown), a low concentration of particles across the size distribution was observed with no discernible major peaks. The CMD of the particle size distribution was 0.035 µm, with a GSD of 2.53 (Table 7). In contrast, the average particle size distribution for measurements taken during the brachioplasty when no LEV was used showed a sharp peak produced with a CMD of 0.105 µm and a narrower GSD of 1.8. This data showed that the LEV was able to capture large numbers of particles, particularly those on the larger end of the size range.

Table 7. Particle size distribution (CMDs and GSDs) by surgery type at location A as measured using a WPS

Procedure	Averaged over procedure (or) point-in-time during plume generation	Count median diameter (µm) [GSD]
Brachioplasty 1 (LEV)	Averaged over procedure	0.035 [2.53]
Brachioplasty 2 (no LEV)	Averaged over procedure	0.105 [1.8]
Thighplasty 1 (LEV)	Averaged over procedure	0.042 [2.50]
Thighplasty 2 (no LEV)	Averaged over procedure	0.091 [2.33]
Breast augmentation (no LEV)	Point-in-time after plasma jet use for cutting/cauterizing purposes	0.098 [2.00]
Breast augmentation (no LEV)	Point-in-time after ESU use	0.099 [2.36]
Breast augmentation (no LEV)	Point-in-time after plasma jet use for antibacterial purposes	0.035 [2.02]
Necrotic tissue removal (no LEV)	Point-in-time after ESU use	0.092 [2.02]

Thighplasties

Figure 13 shows real-time measurements of particle number concentrations at locations A, B, and C with and without use of LEV during brachioplasty. The period of ESU and plasma jet use with LEV on arm 1 corresponds to 8:48 a.m. to 9:27 a.m.; the period of ESU and plasma jet use without LEV on arm 2 corresponds to 10:07 a.m. to 10:55 a.m. The substantial reduction in peak particle number concentrations at all locations due to LEV use is readily observed.

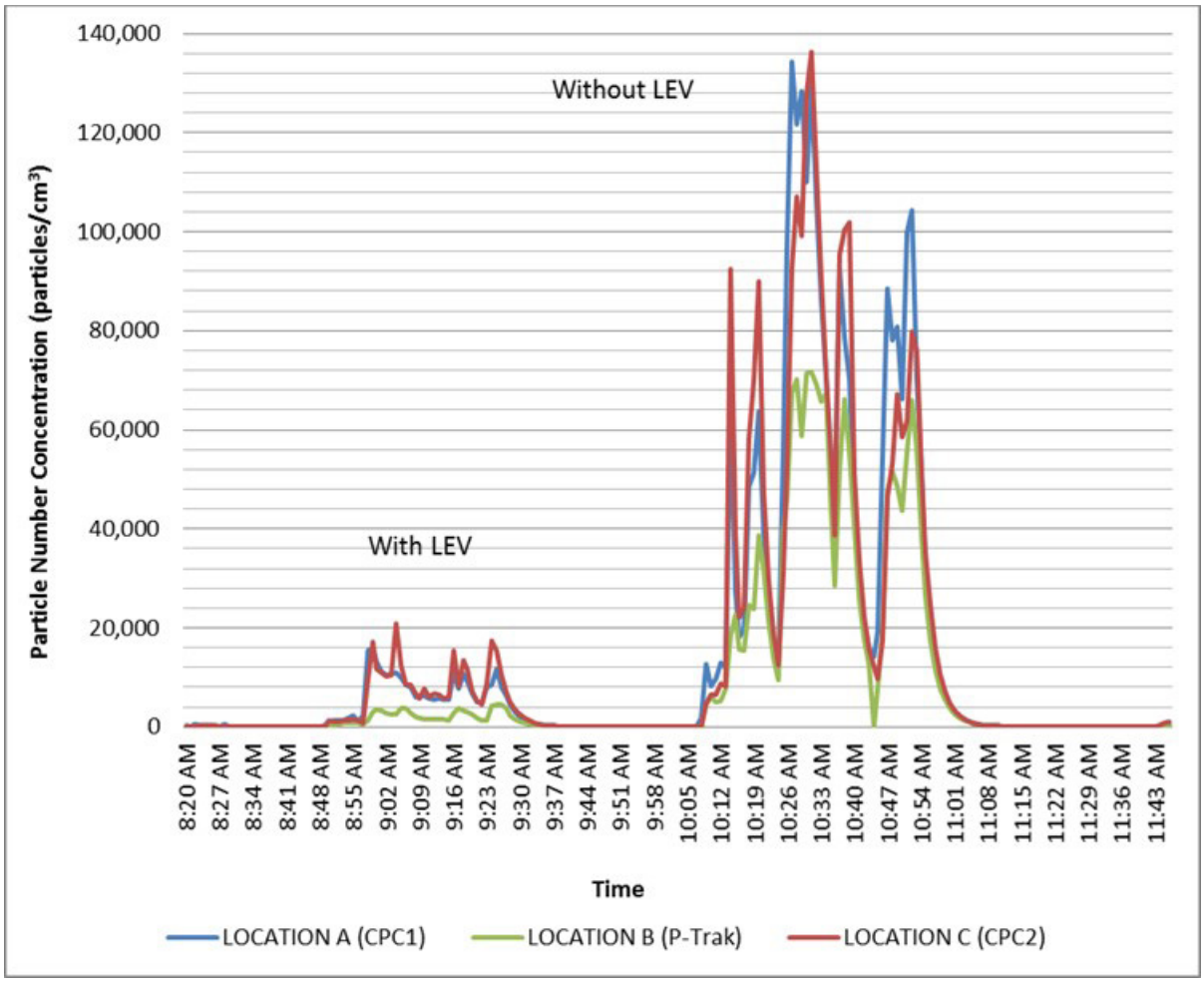

Figure 13. Airborne particle concentrations (particles/cm^3) during thighplasties with and without LEV use as measured by the CPCs and P-Trak.

LEV use reduced the GM particle number concentrations by 86% at location A (23,913 vs. 3,277 particles/cm^3), 92% at location B (13,260 vs. 1,114 particles/cm^3), and 84% at location C (21,669 vs. 3,460 particles/cm^3) (Table 6). Furthermore, the LEV reduced peak particle number concentrations by 88% at location A (134,324 vs. 15,918 particles/cm^3), 94% at location B (71,748 vs. 4,556 particles/cm^3), and 85% at location C (136,400 vs. 20,933 particles/cm^3).

The average particle size distribution for measurements taken during the thighplasty without LEV use showed a single major peak with a CMD of 0.091 µm (GSD: 2.33) (Table 7). The average particle size distribution for measurements taken during the thighplasty with LEV showed low concentrations of particles across the particle size distribution with no major peaks and a CMD of 0.042 µm (GSD: 2.5).

Breast Augmentation

Figure 14 shows real-time measurements of particle number concentrations at locations A, B, and C during the breast augmentation procedure. At various points during the procedure, intermittent use of the ESU and plasma jet instruments occurred. Power settings for the ESU were 40W (cut) and 40W (coag). For the plasma jet, a power level setting of 70 was used for cutting and

coagulating tissue. However, the setting was lowered when the surgeon used the plasma jet to treat the dermal tissue for antibacterial purposes. For this purpose, the plasma jet was swept across the surface of the dermal breast tissue for a more sustained period compared to when it was used to cut or coagulate tissue. The surgeon used these instruments for only seconds at a time rather than repeatedly and for a sustained period as used during the brachioplasties and thighplasties. The period during which the plume producing instruments were used intermittently corresponds to 2:17 p.m. to 3:02 p.m. The highest peaks in particle number concentration at any of the locations corresponded to the two instances (2:57 p.m. and 3:02 p.m.) when the surgeon used the plasma jet for its antibacterial properties rather than to cut tissue.

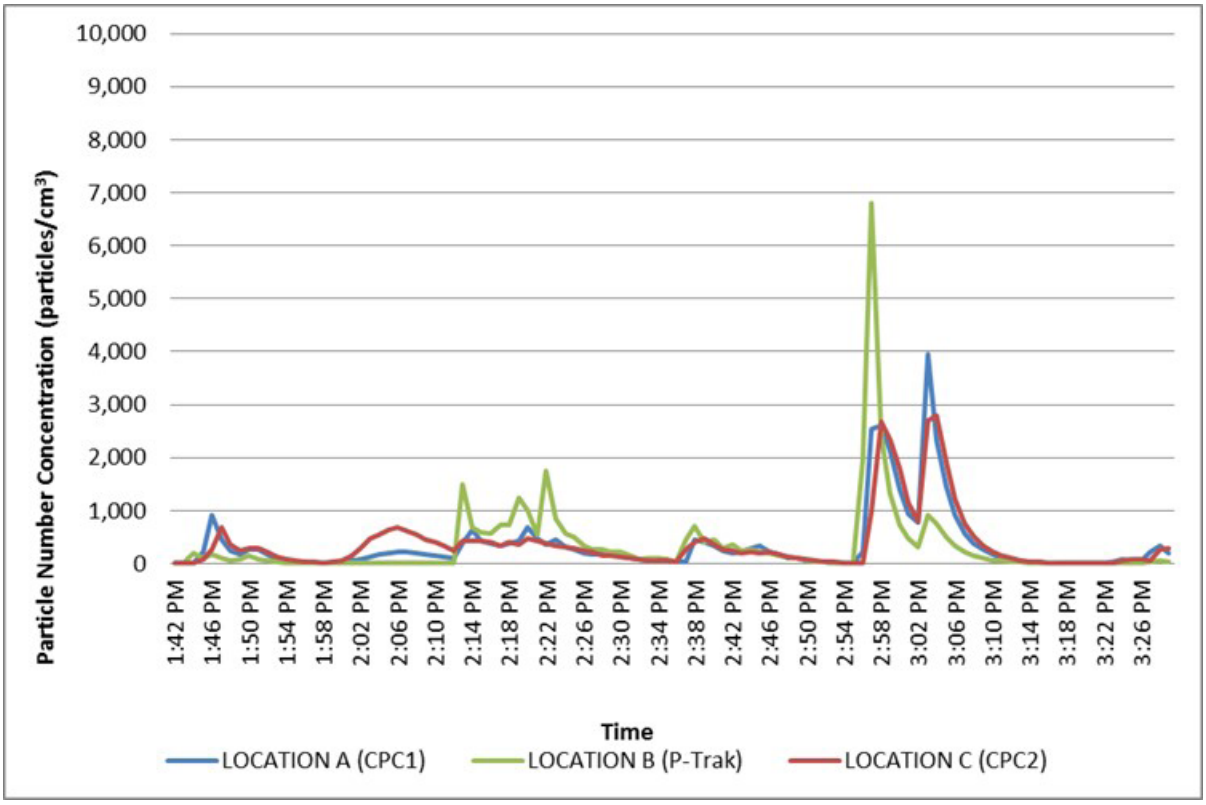

Figure 14. Airborne particle concentration (particles/cm^3) during breast augmentation, without LEV use as measured by the CPCs and P-Trak.

The GM particle number concentration during the breast augmentation was 230 particles/cm^3 (peak: 3,941 particles/cm^3) at location A near the surgical table compared to 245 particles/cm^3 (6,813 particles/cm^3) at location B near the door, and 232 particles/cm^3 (peak: 2,802 particles/cm^3) at location C near the exhaust vent (Table 6).

Particle size distributions were calculated and plotted for measurements made during specific times of plume production during the surgery to identify peaks of particle concentrations of specific particle sizes and to determine CMD and GSD of the distribution. These included measurements at 2:20 p.m. after two instances of short bursts of plasma jet use at a higher setting for cutting and coagulating and at 2:43 p.m. after several instances of shorts bursts of ESU use (Figure 14). Each particle size distribution for these measurements revealed a single

major peak. CMDs were 0.098 µm (GSD: 2.00) for cuts made by plasma jet and 0.099 µm (GSD: 2.36) for cuts made by ESU (Table 7). A measurement taken at 2:58 p.m. after a more sustained use of the plasma jet at a lower setting for antibacterial purposes (Figure 14) showed a shift to a smaller diameter particle size. For this measurement, the CMD was 0.035 µm (GSD: 2.02) (Table 7).

Necrotic Tissue Removal

Figure 15 shows real-time measurements of particle number concentrations at locations A and B during the removal of necrotic tissue around a patient's nipple using only the ESU. During the procedure, the ESU was used twice, approximately 4 minutes apart, and for periods of approximately 20 seconds each. The period during which the ESU was used corresponds to 12:33 p.m. to 12:37 p.m., with a 20-second pulse of ESU use at both the start and finish of that period. Peaks in particle number concentration can be seen at those two times predominantly at location A. Activities outside this 4-minute time range when the ESU was used may have caused increases in particle number concentrations unrelated to surgical plume particles. For example, at 12:22 p.m. additional draping material was unfolded and positioned above the patient's head near location A and at 12:50 p.m. this additional draping material was removed.

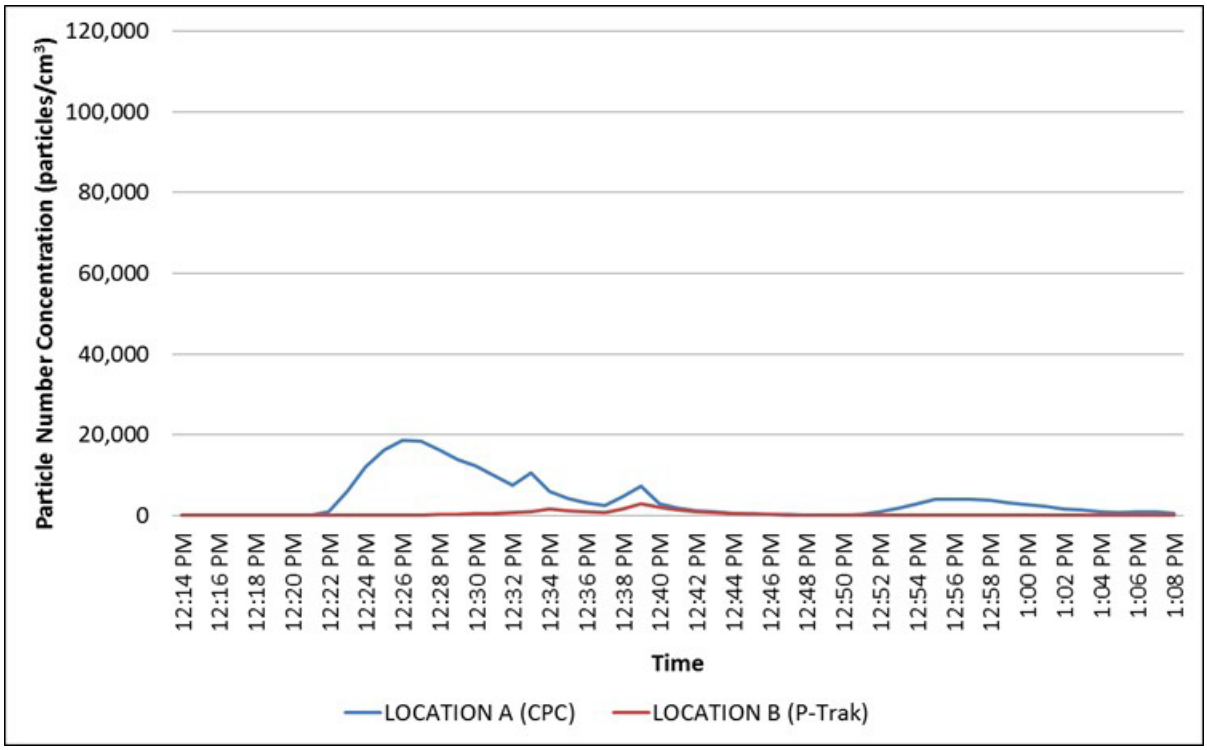

Figure 15. Airborne particle concentrations (y-axis: particles/cm³) during necrotic tissue removal including plume production (12:33–12:37 p.m.), as measured by a CPC and P-Trak.

The GM number concentration at location A near the surgical table was 1,875 particles/cm^3 (peak: 10,560 particles/cm^3) compared to 890 particles/cm^3 (peak: 2,934 particles/cm^3) at location B near the door (Table 6).

The size distribution of particles measured at 12:38 p.m., immediately after one of the 20-second bursts of ESU use, produced a CMD of 0.092 µm (GSD: 2.02), similar to that seen in the other surgical procedures after surgical plume production (Table 7).

Surgical Plume during a Cosmetic Procedure in a Private Medical Office

When the surgeon used the plasma jet on low level on the facial skin tissue of a client for cosmetic purposes rather than to cut or cauterize tissue, it produced a consistent plume of particles. Peak particle number concentrations reached nearly 400,000 particles/cm^3 (Figure 16), higher than the peak of 136,400 particles/cm^3 measured during any of the surgical procedures in the hospital OR. Additionally, the concentrations of airborne particles appeared to be sustained at these concentrations for a longer period compared to the hospital OR, likely due to differences in HVAC systems and air change rate. Airflow measurements were not made in the medical office.

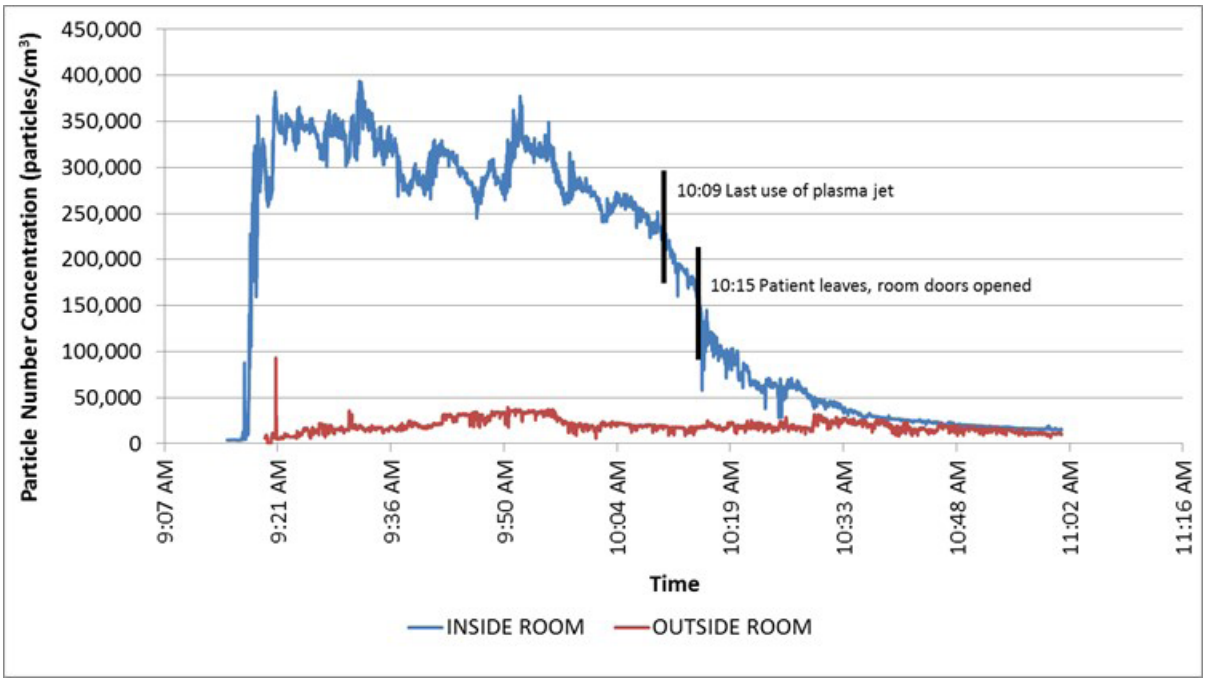

Figure 16. Real-time particle number concentrations during a treatment procedure in a private medical office as measured by CPCs.

Study Limitations

Limitations of this evaluation include the fact that only a small number of varied procedures were evaluated in one hospital location, the surgeries were performed by a single board-certified surgeon, and the results may not be reflective of all possible surgical plume exposures. However, this evaluation adds to and reinforces similar results from the limited scientific literature in this area.

Conclusions

A range of particle size distribution and concentration values was found during plume producing surgeries with different surgical instruments. Overall, the GM particle diameters ranged from 0.03–0.20 µm. The presence of particles in this size range indicates that these particles can penetrate to the deepest regions of the lungs. The plasma jet produced the greatest particle number concentrations measured around the hospital OR. The ESU produced the greatest concentration of pPAHs per unit SA among the four instruments evaluated. This suggests that the plumes produced by different surgical instruments may present different inhalation hazards to health care workers. The airflow patterns in the hospital ORs likely affected the surgical plume concentration patterns observed in different areas of the hospital OR. Particle concentrations near the entrance to the room at the circulating nurse's desk were generally higher than at the opposite side of the room near the room exhaust vent. Air change rates of 21–24 ACH were measured in the hospital ORs where these procedures took place. Ventilation rates such as these provided rapid reductions in even the highest surgical plume concentrations measured near the surgical table to near background levels within about 10–15 minutes after the last use of the instruments.

The use of built-in LEV on the ESU significantly reduced particle number concentrations compared to when no LEV was used, revealing the effectiveness of this control under the tested conditions. Measurement of particle number concentrations during actual surgical procedures in which a hand-held LEV device was used showed the effectiveness of the LEV at reducing concentrations of particles to near background levels. The use of LEV greatly reduced the potential employee exposures to surgical plume in the hospital OR. While acceptable levels of surgical plume particles have not been determined from a health standpoint, this evaluation demonstrates that the use of LEV at the point of plume production can significantly reduce the number of particles in the employees' breathing zone in all areas of the hospital OR.

Recommendations

On the basis of our findings, we recommend the actions listed below.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Use LEV (either hand-held or when incorporated into the surgical instrument) when using surgical plume producing equipment. The LEV should include HEPA filters and should be used as close to the point of plume production as practical and in accordance with the manufacturer's recommendations to achieve maximum efficiency.
2. Ensure hospital ORs (and procedure rooms functioning the same as hospital ORs) maintain the recommended minimum total (20 ACH) and outdoor (4 ACH) and are under positive pressure according to current ASHRAE guidelines for health care facilities [ANSI/ASHRAE/ASHE 2013].
3. If LEV is unavailable during plume producing dermal treatments in the private medical office, vent exhaust air from the room directly outdoors if possible, operating the room ventilation exhaust at the highest level possible. Avoid recirculation of surgical plume throughout the medical office suites. General room exhaust cannot reduce concentrations of and exposures to surgical plume in the medical office as effectively as LEV therefore LEV is the preferred control measure [ANSI/LIA 2011].

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Require the use of available LEV controls by surgical staff when using surgical plume producing equipment.
2. Train hospital staff on the potential hazards of surgical plume and control methods to minimize exposures.

Appendix A: Surgical Plume Hazards

OSHA has reported that an estimated 500,000 workers including surgeons, nurses, anesthesiologists, and surgical technologists, are exposed to laser or electrosurgical plume every year [OSHA 2008]. However, OSHA has not published any regulatory or enforcement standards for exposures to surgical plume. NIOSH has recommended engineering controls, particularly LEV, and work practices to minimize health care workers' exposures to the plume. In particular, plume evacuators with a capture velocity of 100–150 feet per minute, HEPA filters, and a suction nozzle inlet held 2 inches from the point of plume production were recommended [NIOSH 1996]. In the 2012 edition of "Perioperative Standards and Recommended Practices", the Association of periOperative Registered Nurses (AORN) also recommended that exposure to electrosurgical plume and laser plume be minimized and removed using a plume evacuation system and/or a central wall suction system [AORN 2012].

Employees have reported eye, respiratory, and mucous membrane irritation that they associated with exposure to surgical plumes. Lobraico reported that 4.4% of respondents questioned complained of throat irritation (cough or soreness/hoarseness) after exposure to laser plume. Overall, complaints of eye, nose, or throat irritation; headache; nausea; or noxious odors were reported by 10.5% of the survey respondents [Lobraico et al. 1989]. NIOSH evaluations of surgical plume have revealed higher percentages of such complaints among employees. In 2001, King et al. conducted NIOSH HHEs of electrocautery plume exposures at three hospitals. In one evaluation, a questionnaire was distributed to 50 OR personnel asking about symptoms experienced during exposure to surgical plume. Thirty-three questionnaires were returned (66% response rate) from surgical nurses, anesthetists, and surgical technicians. Of those who responded, 51.5% reported at least one symptom they associated with surgical plume exposure. The symptoms included eye irritation (24.2%), burning of nose or throat (18.2%), headache (21.2%), coughing (24.2%), and nasal congestion or runny nose (3.0%) [NIOSH 2006b]. In another hospital, 106 employees completed the questionnaire (participation rate of approximately 92%); at this hospital, 35.8% of the respondents reported at least one of these symptoms [NIOSH 2006a]. In a third hospital, 48 employees completed the questionnaire (participation rate of approximately 80%); 43.7% of the respondents reported at least one symptom associated with surgical plume exposure [NIOSH 2006c].

While the concern about exposures to surgical plume has been reported for many years, large-scale, well-designed epidemiological studies that define the extent of health effects associated with plume exposures are limited. In a recent study, Gates reported a multivariable analysis looking at the association between nurses' length of hospital OR employment (as a proxy for exposure to surgical plume) and lung cancer risk; the authors reported that a history of working in the hospital OR was not associated with an increased lung cancer rate [Gates et al. 2007]. Smaller studies have focused on the risks associated with infectious bioaerosols (particularly human papilloma virus [HPV]) potentially in surgical plume rather than health effects and/or risks associated with particle exposures [Gloster and Roenigk 1995; Hallmo and Naess 1991; Lobraico et al. 1988, 1989].

Information on human health effects from exposure to surgical plume particles is very limited, as the health effects studies found in the literature are based on animal models. It is also notable that the exposures and doses in the animal studies are larger than those experienced by humans in an occupational setting.

Outcomes among rodents exposed to surgical plume have included pulmonary inflammatory response, with gross and microscopic congestion [Baggish and Elbakry 1987]. The terminal bronchioles were reportedly thickened and hypertrophic, with distension of the alveolar ducts, and demonstrated emphysema. The authors demonstrated a proportional increase in the severity of pulmonary pathology with the duration of laser plume exposure.

Freitag et al. exposed sheep to plume produced by the application of a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser to blocks of sheep bronchial tissue. The sheep were exposed to a single 10-minute plume exposure, three 10-minute exposures, or no plume exposures (control group). Two hours after exposure, the sheep with the single exposure showed a 28% decrease from baseline in tracheal mucus velocity (a marker for mucociliary function of the lung); in contrast, the sheep with multiple exposures had a 56% decrease from baseline. No significant changes in white blood cell count (connoting general inflammation) were seen. However, bronchiolar lavage did reveal pulmonary inflammatory response [Freitag et al. 1987].

Wenig et al. investigated the effects of Nd:YAG laser and electrocautery plume on rats. Twelve rats were exposed to pigskin plume produced by either Nd:YAG laser or ESU according to the three phases of exposure time as described in the 1987 Baggish study. Exposure to the laser plume resulted in alveolar congestion, hypertrophy of blood vessels, and emphysematous changes in all exposed rats, although without increased severity proportional to the exposure time. Similar effects were seen in the rats exposed to electrosurgical plume [Wenig et al. 1993].

Particle exposures are only one component of the potential health hazard associated with the surgical plume. The potential biological component of the plume, which may include viable bacteria and viruses, are an important consideration as well. Hallmo et al. [1991] reported on a case of laryngeal papillomatosis with HPV DNA contracted by a laser surgeon. Calero and Brusis [2003] also concluded that a case of laryngeal papillomatosis was occupationally related after a virologic analysis showed a high probability of a correlation between the case and occupational exposure to HPV DNA. More recently, Rioux et al. [2013] reported on two cases of HPV-16 positive oro-pharyngeal squamous cell carcinomas diagnosed in surgeons after having long-term occupational exposures to laser plumes. Viral HPV DNA has been found in surgical plume produced by CO_2 laser [Garden et al. 1988; Kashima et al. 1991; Sawchuk et al. 1989]. Additionally, bovine papilloma virus collected in plume produced by CO_2 laser has been shown to transmit fibropapillomas in inoculated cattle [Garden et al. 2002].

In addition to the potential biological components in surgical plume, concerns about chemical compounds produced through the combustion process have been expressed. In a recent study, Fitzgerald et al. [2012] compared potentially carcinogenic or irritant volatile hydrocarbon concentrations produced by ultrasonic scalpels and electrocautery knives in human laparoscopic surgeries, and compared them both with concentrations of those compounds found in cigarette plume and urban city air. Results suggested that both electrocautery and ultrasonic dissection were significantly lower in concentrations of these compounds compared to cigarette plume. Ultrasonic dissection produced non-significantly lower concentrations of these compounds compared to electrocautery, with concentrations produced by the ultrasonic scalpel similar to those of city air. Despite lower levels, the authors comment that cumulative exposures may still pose a risk [Fitzgerald et al. 2012].

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