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Characterization of surgical staff `s exposure to surgical smoke at St. Olavs Hospital

Trondheim, August 2012

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Acknowledgements

This work was performed at the Department of Occupational Medicine at St. Olavs Hospital and at the Department of Public Health and General Practice, at the Faculty of Medicine at the Norwegian University of Science and Technology (NTNU), Trondheim. The work was carried out in collaboration with the Operating Room of the Future (FOR), at St. Olavs Hospital, from August 2011 to August 2012.

First, I would like to thank my supervisor Solveig Føreland, for her support and help, and for always finding time for my questions. Also, a great thank you to Rikke Bram Jørgensen for teaching and helping me with the Fast Mobility Particle Sizer whenever needed.

I would like to express my gratefulness to the Operating Room of the Future at St. Olavs Hospital: to Hans Olav Myhre for the help with the research protocol for this study, and Jan Gunnar Skogaas, for teaching me the principles of electrosurgery. Especially I would like to thank Anne Karin Wik and Therese Marken for helping me with the coordination of the surgical procedures, without you, this work had been impossible to accomplish.

To Bjørn Hilt, thank you for giving me the opportunity to work with my thesis, and to all of the people working at the Department of Occupational Medicine, for being interested, supportive and friendly.

A special thank you goes to the surgical staff at the Department of surgery and the Department of Orthopedic surgery for helping me with my measurements. You always made me feel welcome, and took care of me when I was performing my experiments. It was a pleasure to work with you.

In addition, I would like to thank Hanne Line Daae and Syvert Thorud at the National Institute for Occupational Health for assisting me with the chemical analysis used in this thesis.

Finally, I would like to thank my family and friends for always encouraging me. Not at least, my dear husband Jo, for always being there. Thank you for your endless support and for always believing in me.

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Abstract

Introduction: Surgical smoke is produced when electrosurgery is applied to the patient`s tissue during surgical procedures. The smoke is known to contain numerous of volatile chemical compounds, and carcinogens have been identified. The smoke also contains ultrafine particles, which may propose a health hazard to the surgical staff in the operating room. **Methods:** The aim of the study was to characterize the personal exposure of surgical smoke to the surgical personnel in the operating room, with emphasis on ultrafine particles. Five surgical procedures were selected to be included in the exposure assessment based on frequent use of electrosurgery and relatively short length of the procedures. Sampling of personal exposure to particles in surgical smoke in the range of 5.6-560 nm was performed using a Fast Mobility Particle Sizer, on four different job groups in the operating room. Important determinants of exposure were also investigated, using linear mixed effects models. In addition, three random samples of exposure to volatile organic compounds and aldehydes were executed on the main surgeon on three types of surgeries. **Results:** Type of surgery was an important determinant of exposure to surgical smoke, and the use of electrosurgery resulted in exposure to mainly ultrafine particles. The exposure was highest during abdominoplasty and the lowest during hip replacement surgeries. A total of five VOC`s was identified and quantified. One sample contained low levels of formaldehyde. For the other samples, the levels were below the detection limit. **Conclusion:** The use of electrosurgery resulted in short term high peak exposures to mainly ultrafine particles in surgical smoke. The job groups closest to the emissions are usually the highest exposed. Compared to other working environments the exposure levels for ultrafine particles was low. The concentrations of VOC`s and aldehydes was below the Norwegian OEL.

Contents

1. Introduction

Surgical smoke is produced when electrosurgery (ES) is applied to the patient’s tissue during surgical procedures. During surgeries the staff working in the operating room (OR) will be exposed to the smoke, which consists of a complex mixture of volatile compounds like known irritants, carcinogens, and also ultrafine particles (UFP). The latter are proposed to cause pulmonary disease, (Oberdorster, Gelein et al. 1995) cardiovascular effects (Weichenthal 2012) and alteration of the immune system (Donaldson, Brown et al. 2002).

1.1.Electrosurgery

Electrosurgery, also called surgical diathermy, is commonly applied during surgical procedures. Heat is created by a high frequency current that is used to dissect tissue and coagulate small vessels, a technique which plays a significant role in modern surgery (Ulmer 2008; Duchateau, Komen et al. 2011). The term “diathermy” stems from the Greek origin “dia”- through, “thermy”-heat. The use of heat in surgical procedures is no novelty in medical history; already 3000 years b.c. the Egyptians used heat to treat tumors (O'Connor and Bloom 1996). During commercialization of ES in the 20th century, the use of high frequency current was used in the treatment of small tumors, warts, moles, acne pustules and infected tonsils and hemorrhoids. Today electrosurgery plays an essential part in numerous surgical procedures (Memon 1994).

There are two types of ES: unipolar and bipolar ES. Unipolar ES is the most common type and is employed in most surgical procedures and is the most frequently type used for this thesis. With unipolar ES one utilizes two separate electrodes, which are connected to the ES generator, and where current passes through the patient’s body, se figure 1-1. Bipolar ES is used in delicate surgery, and involves two electrodes, which is combined in one unit and resembles a forceps where the current solely flows between the tips of the ES instrument (Memon 1994).

When using unipolar ES the surgeon holds the active electrode, an electrosurgical pencil with various blades, a needle or a button on the tip, se figure 1-2. These applications produce local heating, when current passes from the ES pencil and through the patient's body. The current exits at the opposite electrode, which is an ES plate that normally consists of a small metal or foil plate placed on the patients body (Watson and Loughman 1978), see figure 1-1. The passage of current through the tissue produces a heating effect beneath each electrode, but since the contact area on the opposite electrode is relatively large, the heating is reduced to a minimum and is dissipated rapidly. However, the active electrode is always small, which leads to the concentration of heat in the immediate vicinity of this electrode, thus producing the desired effects; coagulation and cutting of tissue (Memon 1994).

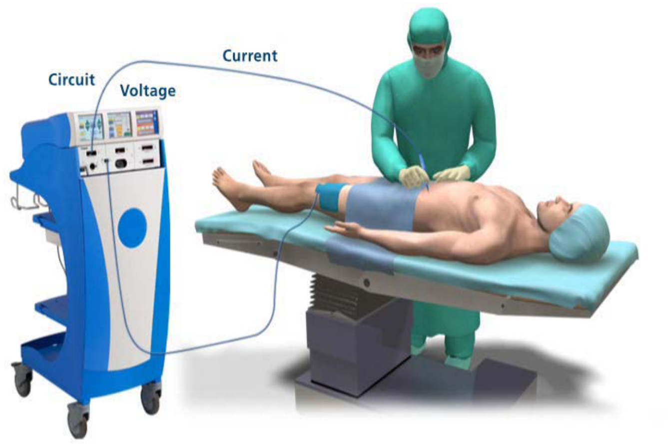

Figure 1-1. Schematic illustration showing and indicating that the electrosurgical unit generates the current to the active electrode which is the ES pencil. The current passes trough the patient to the opposite electrode that consists of a metal or foil plate. The figure is printed with the permission from Jan Gunnar Skogaas at the Operating Room of the Future, St. Olavs Hosptial.

To avoid muscle activity in the patient, and minimize risk of electrocaution hazards, the radio frequency used in ES is higher than 250 kilohertz thus over the mains of 50-60 hertz (Watson and Loughman 1978).

By using radio frequent current, the surgeon can vary between two basic waveforms. The cut waveform involves a continuous wave pattern with low voltage, which forms an arch between the active electrode and the tissue. Temperatures at 100 ºC are achieved and the cells are heated up to the boiling point, and thereby the cell wall ruptures. The coagulation waveform is driven by an interrupted pattern and causes the arc to quench. A rest period delivers the electrical current, and gives a gradual rise in the temperature that holds a temperature under 100 ºC which results in coagulation of the tissue. Also the gradual temperature rise makes the cell`s contents evaporate, denaturizing proteins and carbonizing the tissue. Many surgeons use the coagulation waveform for dissection. Thus carbonized cellular debris is produced and scattered in the air (Spearman, Tsavellas et al. 2007; Ulmer 2008). ES generators also provide blend mode, where current delivery is modified by using cut mode with varying intensity of haemostasis (Watson and Loughman 1978).

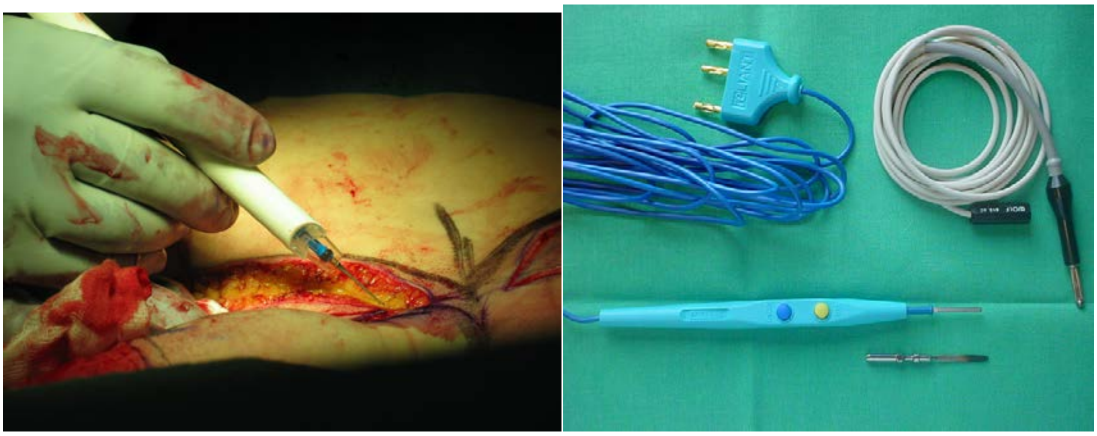

Figure 1-2. Electrosurgical pencils. The figure on the right is printed with the permission from Jan Gunnar Skogaas at the Operating Room of the Future, St. Olavs Hospital. The figure on the left is a photo taken from an operation during the study period.

1.2 Surgical smoke

Surgical smoke is created when ES heats the tissue up to its boiling point, and causes cellular membranes to rupture and, subsequently release its contents into the air. The amount and composition of surgical smoke will vary with surgical procedures. Both amount and contents will be affected by numerous factors including the target tissue, the pathology of the target tissue, the amount of cutting and coagulation performed, the surgeon's technique, and the quantity of energy used (Gatti, Bryant et al. 1992; Barrett and Garber 2003; Al Sahaf, Vega-Carrascal et al. 2007; Wu, Tang et al. 2011). The particulate material represents both the chemical and biological hazard in the smoke because of its contents of chemicals, tissue particles, blood, viruses and bacteria (Ball 1996; Barrett and Garber 2003; Gonzalez-Bayon, Gonzalez-Moreno et al. 2006; Al Sahaf, Vega-Carrascal et al. 2007; Bigony 2007; Hill, O'Neill et al. 2012).

Personnel working in the OR during use of ES are susceptible to exposure to surgical smoke. The exposure to surgical smoke is known to cause various acute health effects in humans. During exposure, acute intoxication with symptoms such as headache, nausea, vomiting and muscle weakness have been reported. Irritations to the eyes is also a known effect (Alp, Bijl et al. 2006) Sore and watery eyes may give the surgeon a blurry vision, preventing optimal sight during the procedure. Viral contamination and regrowth is also documented (Sawchuk, Weber et al. 1989).

In later years there has been a growing interest in the potential adverse health effects from exposure to particles in surgical smoke. This is due to animal studies that have demonstrated chronic effects of surgical smoke on the respiratory organs in rats. Pathological changes due to particle deposition in the alveoli was demonstrated, and the severity of the pulmonary changes such as interstitial pneumonia, bronchiolitis and emphysema increased with the duration of the exposure (Baggish and Elbakry 1987; Freitag, Chapman et al. 1987; Wenig, Stenson et al. 1993).

Introduction

The carcinogenic potential of surgical smoke was assumed, when studies in the late 1970`s showed that condensates from broiling fish and meat was acting mutagenic (Nagao, Honda et al. 1977). Thus it was reasonable to suggest that the condensates collected from surgical smoke could present the same mutagenic potential. In the 1980`s it was found that smoke condensates collected from surgical smoke produced by ES on the mucosa on a canine tongue, had mutagenic activity in Ames test. The mutagenic effect was quantified to be equivalent to six cigarettes (Tomita, Mihashi et al. 1981). The mutagenic potential of surgical smoke was later demonstrated when ES was used on human tissue. Surgical smoke collected during two breast reductions was found to be mutagenic in the Ames test. Although the mutagenic effect was unstable and not evident within two hours after collecting the smoke, the findings did not propose a serious health risk. Still, the attempts to reduce the exposure to the smoke was recommended (Gatti, Bryant et al. 1992; Bigony 2007). Numerous of chemical compounds have been identified in clinical and in vitro surgical smoke studies, and the major organic compounds found are hydrocarbons, nitriles, fatty acids and phenols. Known carcinogenic compounds such as formaldehyde, benzene and polyaromatic hydrocarbons (PAH) have also been detected (Gatti, Bryant et al. 1992; Hensman, Baty et al. 1998; Hollmann, Hort et al. 2004; Al Sahaf, Vega-Carrascal et al. 2007; Moot, Ledingham et al. 2007; Chung, Lee et al. 2010).

Previous studies have found that surgical smoke contains volatile organic compounds (VOC) (Weston, Stephenson et al. 2009; Lin, Fan et al. 2010). VOC`s are categorized after how volatile they are. The World Health Organization has defined VOC as compounds with a lower boiling point at 50-100 ° C and a upper limit with a boiling point at 240 -260 º C. There are VOC outside this range that are more volatile, (very volatile compounds), or less (semi volatile compounds). Organic compounds can also be bound to particles in air, as particulate organic material (Folkehelsa 1996). They consist of different chemical groups, which include aliphatic and aromatic hydrocarbons, terpenes, ketones, alcohols, esters, aldehydes and several halogenated compounds, and are found to be of higher concentration in indoor air than outdoors. Common sources are outgassing of buildings and human activity. The total amount of volatile organic compounds (TVOC) is higher in new buildings than in older ones and the concentrations will decrease over time. Indoor sources are related to human activity such as detergents and solvents (Folkehelsa 1996).

1.4 Exposure to airborne particles

Particles enter the human body by inhalation, via the gastrointestinal tract or they permeate the skin. Inhalation by the respiratory tract is normally the main route of entrance for airborne particles (Gehr, Bachofen et al. 1978). The human respiratory tract is divided into three basic regions which include the extrathoracic region, the tracheobronchial region and the alveolar region (Vincent 2007).

How far down in the respiratory tract particles penetrates when inhaled, depends on their aerodynamic diameter (AED). The aerodynamic diameter is the diameter of a spherical particle having a density of 1 gm /cm^3 that has the same settling velocity in air as the particle of interest (Vincent 2007). Airborne particles are classified how far down in the respiratory tract they penetrate, see figure 1-3. The inhalable fraction of airborne particles is all particles that are inhaled trough the nose and mouth with an aerodynamic diameter ≤ 100 µm.

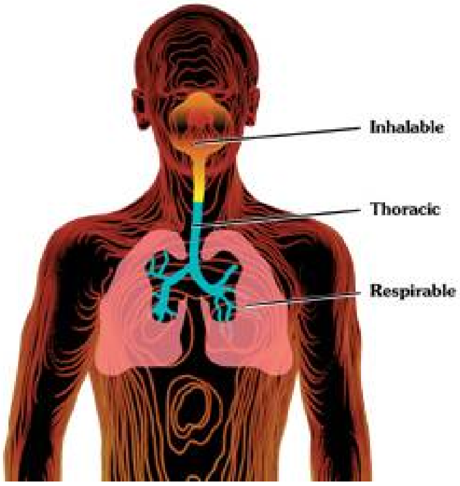

Figure 1-3. The figure shows the inhalable (yellow), thoracic (blue) and respirable (pink), region of the lung. The figure is printed by permission of SKC (SKC 2012).

The thoracic fraction is a sub fraction of the total inhalable fraction and involves particles with an aerodynamic diameter of < 30 µm that can penetrate into the tracheo- alveolar region of the lung. The respirable fraction is the sub fraction of the total inhaled particles with an aerodynamic diameter <10 µm that penetrates into the alveolar region of the lung (Nieboer, Thomassen et al. 2005).

Particle size influences particle motion, and how the particles deposit in the respiratory tract. Larger particles may be trapped in the extrathoracic region and impacted on the surface due to bifurcation in the airways. Particles that penetrate the tracheobronchial region may be deposited by sedimentation because of low airflow and smaller airways. Particles that penetrate the alveolar region may be deposited by diffusion, which is the primary mechanism of deposition of particles less than 0.5 µm (Vincent 2007). Diffusion involves the transport of particles from a region of high concentration of particles to a region of lower concentrations of particles, due to Brownian motion, which includes collision with air molecules (Anderson, Wilson et al. 1990). Diffusion occurs in both extrathoracic region and in the alveolar region where the airflow is low (Hofmann, Sturm et al. 2003; Vincent 2007).

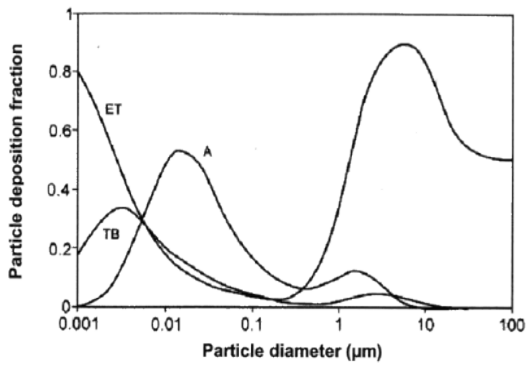

Figure 1-4 The relationship between the particle diameter in µm, and where the particles deposit in the different regions of the respiratory tract. ET=extra thoracic region TB= tracheobronchial region A=alveolar region. From ICRP publication 66: Human Respiratory Tract Model for Radiological protection (ICRP 1994).

However, not all particles that penetrate the lung will deposit in the respiratory tract, as some of them will be exhaled or swallowed (Vincent 2007). See figure 1-4, for the relationship between particle size and where they deposit in different regions of the respiratory tract.

Clearance mechanisms in the airways involve a protective mucus layer transported by cilia, pushing particles towards the larynx in the extrathoracic region, to be swallowed into the gastrointestinal tract ready for excretion. These mechanisms will clear particles larger than about 6µm from the lungs within one or two days. Particles deposited in the pulmonary region, will be cleared by alveolar macrophages. Alveolar macrophages are a part of the innate immune system. They ingest inhaled particles, and hence transport them to the larynx for swallowing. As macrophages respond to particles > 200 nm within a few hours, the remaining fraction is retained in the alveoli epithelium and in interstitial spaces thus, having a much slower clearance from the lung (Kreyling, Semmler-Behnke et al. 2006; Moller, Felten et al. 2008).

1.5 Ultrafine particles in surgical smoke

Surgical smoke is known to contain ultrafine particles (UFP) (Heinsohn and Jewett 1993; Gonzalez-Bayon, Gonzalez-Moreno et al. 2006; Andreasson, Anundi et al. 2009). The term UFP is used for particles <100 nm that have been unintentionally produced, and are generated as incidental by products from different processes such as combustion processes, welding, and laser ablation (Schneider 2007). In surgical smoke, UFP`s are produced when heat from the ES is applied and thus carbonizes the tissue. Humans have been exposed to airborne UFP throughout the evolutionary stages, but the dramatically increase of exposure was a consequence of the industrial revolution, due to anthropogenic sources such as power plants and combustion engines (Oberdorster, Oberdorster et al. 2005). UFP`s are also generated from indoor sources such as cooking, smoking, ironing, electric hair straighteners. Thus we have to consider the exposure to UFP`s as a part of our everyday life (Wallace and Ott 2011).

UPF`s differ from larger particles by their characteristics. An important property of UFP´s is that they have a large surface area to mass ratio, and therefore represent a higher number of particles compared to the total mass of dust in the air (Peters 1997). In addition to a substantially higher number of particles, a larger surface area involves a greater amount of atoms accessible for reactions, or union with, other components (Oberdorster, Elder et al. 2009). These particles tend to agglomerate and aggregate rapidly after generation; an agglomerate consist of a group of UFP`s that are bound by van der Waals interactions, electrostatic forces and surface tension. Aggregates are a heterogeneous particle of different components that are kept together by covalence force, and thus not separate that easily. Figure 1-5 summarizes the properties of ultrafine particles in terms of their characteristics, interactions and respiratory characteristics. These properties increase their chemical and toxic reactivity, and cause a grater inflammatory response compared to larger particles of the same chemistry (Oberdorster, Oberdorster et al. 2005). Previous studies have investigated the exposure to nanoparticles (NP) which are particles <100 nm similar to UFP`s, but are intentionally produced for a purpose and is e. g used sunscreen or in sportswear (Schneider

2007). By using NP`s in experiments, these studies have suggested that because of its surface properties, NP`s may contribute to the generation of reactive oxygen species (ROS) (Donaldson, Brown et al. 2002), which contributes to several negative effects that includes: oxidative stress, tissue inflammation damage to cell membranes, proteins and DNA. These are mechanisms that are linked to cancer. However, no such relationship has been established yet (Knaapen, Borm et al. 2004; Oberdorster, Oberdorster et al. 2005; Singh, Manshian et al. 2009; Donaldson and Poland 2012).

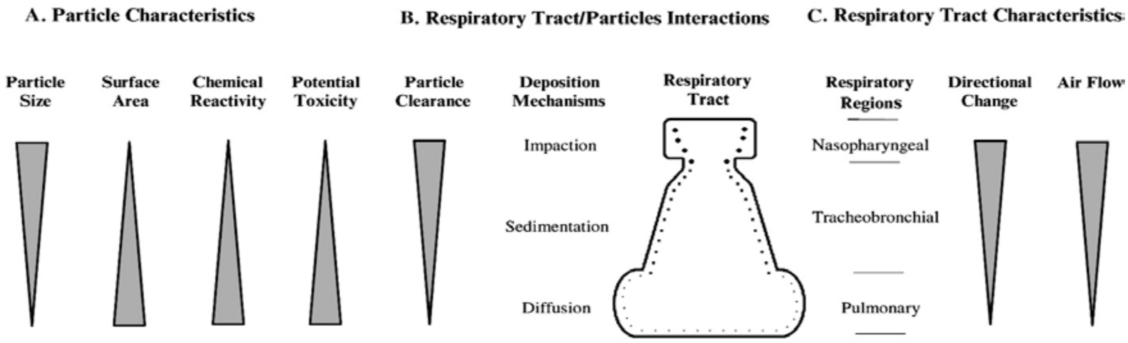

Figure 1-5. The surface area of ultrafine particles increases with their decreasing particle size. A larger surface area gives a higher chemical and toxic reactivity. The clearance of particles, decrease with size. The figure is used by permission of Amanda Hayes (Bakand, Hayes et al. 2012).

UFP´s penetrate the deeper part of the lungs, and combined with greater pulmonary deposition, the alveoli may be prone to toxicity for pulmonary toxicants, represented by these small particles (Daigle, Chalupa et al. 2003; Chalupa, Morrow et al. 2004). The alveoli has a vast internal surface at about 100 m^2 with a air blood barrier estimated at only 2.2 µm thick and with a one layer epithelium representing the most permeable region of the lung (Gehr, Bachofen et al. 1978; Vincent 2007). Because of the single layer of epithelium, it is easy for the UPF`s to move from the alveoli lumen to the blood circulation, and hence be able to reach potentially sensitive targets such as lymph nodes, heart, bone marrow and spleen, by entering the systemic circulation (Oberdorster 2001; Donaldson, Brown et al. 2002; Geiser, Rothen-Rutishauser et al. 2005; Nemmar, Hoet et al. 2006).

Epidemiological studies suggest that exposure to ultrafine particles in ambient air may cause pulmonary diseases, have cardiovascular health effects and do impairment to the immune system (Dockery and Pope 1994; Oberdorster, Gelein et al. 1995). Exposure to UFP`s have also been reported to induce inflammatory mediators in alveolar macrophage-epithelial cell cultures. Exposure led to both induction and increase of these mediators, among them interleukin-6 (Il-6) (Ishii, Hayashi et al. 2005), which is known to stimulate hepatocytes to secrete fibrinogen (Akira and Kishimoto 1992). Elevated plasma levels of fibrinogen, is a known risk factor for ischemic heart disease (Meade, Mellows et al. 1986). In addition, laboratory experiments with particles < 100 nm shows higher deposition of particles in the respiratory tract of subjects with asthma or chronic obstructive pulmonary disease than for healthy subjects. Thus indicating vulnerable groups to be more sensitive to ultrafine particle inhalation (Anderson, Wilson et al. 1990; Eickmann 2011).

1.6 Aim of study

The aim of the study was to characterize the surgical staff`s exposure to surgical smoke, with emphasis on ultrafine particles. Random samples of personal exposure to volatile organic compounds and aldehydes were also performed. In addition the study aims to identify important determinants of exposure to the surgical smoke.

2. Material and Methods

2.1 Workplace description

Operating rooms are specially designed and equipped to provide care of patients with special conditions that require surgery, and is where the surgery takes place. The operating table is where the patient is lying and is usually in the center of the room. The sterile zone provides to protect the patient against infections during surgery, and includes a certain area around the operating table. See figure 2-1 that shows the different zones in the OR and where the ESU and smoke evacuation system can be positioned.

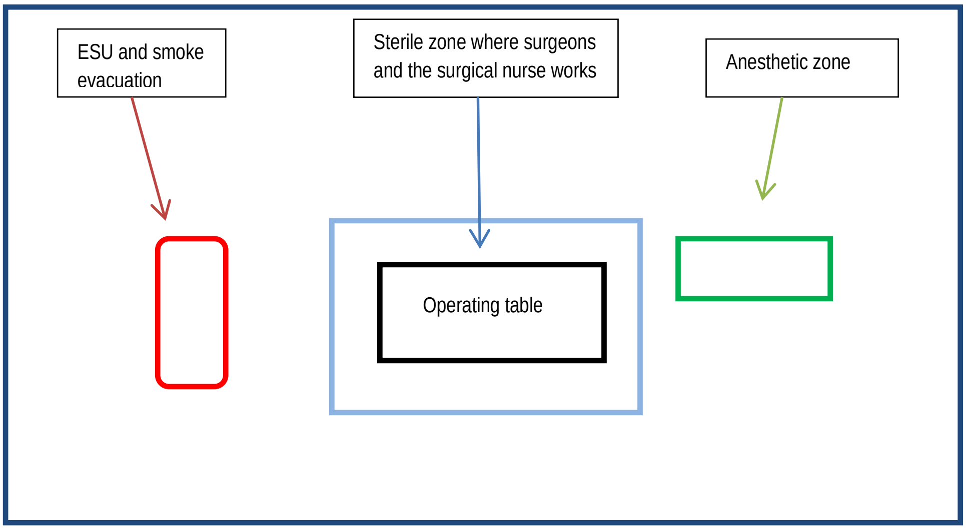

Figure 2-1: the figure shows the sterile zone where the surgeons and the surgical nurse are positioned. The anesthetic zone is on the head side of the bed. The ESU and smoke evacuation system can be at the end or on the side of the operating table.

Operating rooms are equipped with specialized instruments, such as respiratory and cardiac support, patient monitors, diagnostic tools and emergency resuscitative tools that are placed accessible in the room. The anesthetic nurse and their monitoring instruments are usually located at the head of the bed, where the anesthetic nurse and doctor can monitor the patient`s condition throughout the surgery. At the end, or on the sides of the operating table, electrosurgical units as smoke evacuator systems and other important surgical supporting instruments are located.

The main job groups in the operating room are the surgeons, the surgical nurses, and the anesthetic nurse. The surgeons and a surgical nurse are working primarily in the sterile zone, and at least one nurse is standing by in the operating room handing over extra equipment to the surgical nurse in the sterile zone when needed. The anesthetic nurse is positioned at the head end of the operating table, and monitors the patient during surgery. See table 2-1 which includes work descriptions for each job group and type of surgery for each job group where sampling was performed.

Table 2-1. The scheme shows a description of the different tasks performed by each job group.

Job group	Work description	Measurements [A]
Main surgeon	Surgeons cover a broad category of invasive medical treatments and their main task is to perform surgical procedures for the benefit of the patient`s health, which involves cutting in the body of a specific reason, such as tissue repair or removal of diseased tissue. For cutting, coagulation and vaporizing the tissue, they use ES, and are the main operators for this use. They are also the job group closest to the exposure of the surgical smoke. The main surgeon has the superior responsibility during the surgical procedure.	Hip replacement surgery Nephrectomy Abdominoplasty Breast reduction TURP
Assistant surgeon	Many surgical procedures are dependent on two surgeons operating. The assistant surgeon therefore assists the main surgeon during the surgical procedure, and also uses ES frequently.	Hip surgery Nephrectomy Breast reduction
Surgical nurse	The surgical nurses are a part of the surgical team and assist and interact with surgeons and other staff members. They hand surgeons the equipment needed during the procedures, and also assist with the ES pencil if necessary. They can be in or outside the sterile zone.	Breast reduction
Anesthetic Nurse	The anesthetic nurse work with pain therapy and carry out anesthetic treatment of the patients before, during and after the surgical procedures. The anesthetic nurse is not placed in the sterile zone, but positioned at the head end.	Hip surgery Nephrectomy Breast reduction TURP

[A] Type of surgery for each job group where sampling was performed in the current thesis.

2.1.1 Clothing

Operating rooms are sterile environments. The surgical staff needs to wear clothing with the purpose of protecting the patients against any infections. Cotton clothing or disposable clothing, special shoes for surgery; surgical facemasks; and caps are used to prevent the spread of bacteria. The main surgeon, assistant surgeon and the surgical nurse, who works in the sterile zone, need to scrub in before surgery, and wear sterile surgical coats, and two layers with gloves, in addition to the other special clothing.

2.1.2 Ventilation systems

The main task of the ventilation system is to provide clean air to the OR, in order to prevent infections associated with surgery. The hospital has specifications concerning air quality in operating rooms, and the main purpose is to reassure that the input of air is sufficiently free of microbes. Particles are generated in the operating room from people and moving equipment, and acts as carriers for microbes. Thus it is important to have a ventilation system that efficiently can remove these. Other important characteristics of the ventilation system are to create an airflow which carries air from surgical staff away from the surgical wound, and also to provide positive pressure in the OR to prevent contaminated air from the surroundings to enter the OR (Børseth 2012). The air is filtered through a High Efficiency Particulate Air (HEPA) filter which shall supply the OR with air as clean as possible. Clean air means an air free of particles. Particles ≥ 0.3 µm and also micro-organisms are estimated to be removed with 99.97 % efficiency by HEPA filters (Scherrer 2003).

See table 2-2 for the ventilation specifications for each operating room.

2.1.3 Laminar Air Flow

Surgeries with extra high requirements of sterility like orthopedic and implant surgery, are performed in OR`s equipped with Laminar Air Flow (LAF), which propose to maintain an ultra clean environment (Scherrer 2003). The operating rooms with LAF in the current study, have a glass shield around the HEPA filter. This is installed from the ceiling and down. The glass shield creates a barrier around the sterile zone to push the air further down towards the floor, thus keeping the area as free of particles as possible. The air supply in these OR`s are much higher than the general OR`s. See table 2-2 for specifications in the operating room.

2.1.4 Smoke evacuation systems and electrosurgery pencils

To reduce the exposure to surgical smoke when using ES; disposable ES pencils can be equipped with a built-in smoke extraction system. This system involves a “hood” on the upper side of the ES pencil directly connected to a smoke evacuation instrument by a plastic tube. Different smoke evacuation instruments were used. See table 2-2. The ES pencils used in this study were disposable and from ValleyLab. The smoke evacuation instruments are equipped with a HEPA filter that filtrate the smoke evacuated from the ES pencil, figure 2-2 shows the smoke evacuation system with the possibility to extract smoke from two ES pencils simultaneously.

When the surgeon uses the ES pencil, the smoke evacuation system starts automatically starts. The bipolar unit used during surgery does not have a built-in smoke extraction system, and smoke produced from bipolar ES must be extracted manually.

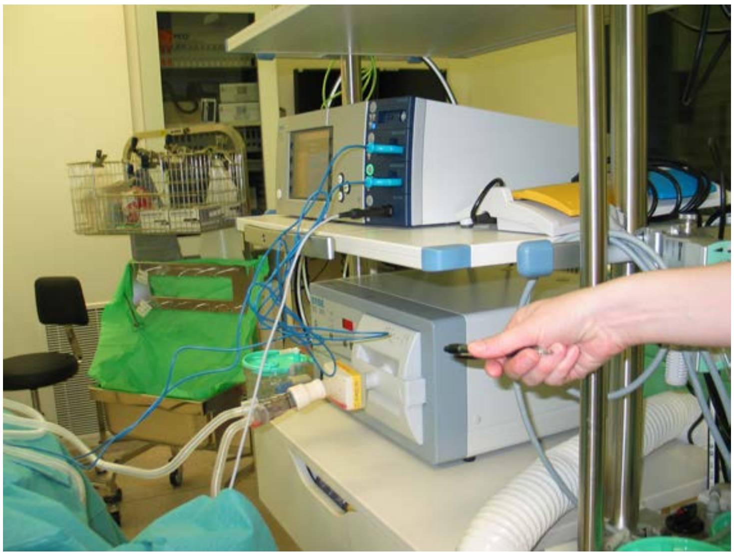

Figure: 2-2. The figure shows the ESU on top and a smoke evacuation system on the bottom. The figure was taken during a bilateral breast reduction in the study period.

Table 2-2. The specifications for each operating room where measurements where performed.

OR[A]	N[B]	Type of surgery	ES unit [C]	Smoke evacuation system [D]	Effect on ES unit	Size of OR	Ventilation
1	4	Hip replacement surgery	ERBEI ICC 300	Smoce Evac 200	Cut 100 W Coag 40 W	43 m^2	22 ac/h
7	9	Hip replacement surgery	ERBEI ICC 300	ERBE IES 300	Cut 100 W Coag 80 W	69 m^2	22 ac/h LAF 30 recycles /h
8	3	Hip replacement surgery	ERBEI ICC 300	LINA	Cut 100 W Coag 80 W	67 m^2	22 ac/h LAF 30 recycles
2	1	Nephrectomy	ValleyLab Force Triad	RapidVac Smoke Evacuator	Cut 30 W Coag 30 W	41 m^2	22 ac/h
6	9	Nephrectomy	ValleyLab Force Triad	Smoce Evac 200	Cut 30 W Coag 30 W	42 m^2	22 ac/h
3	13 3	Breast reduction Abdominoplasty	ERBE VIO 300D	ERBE IES 300	Cut 180 W Coag 180 W	46 m^2	22 ac/h
6	7	TURP	KLS Martin Maximum	None	Cut 150 W Coag 150 W	42 m^2	22 ac/h

[A] Name of operating room [B] The number of measurements performed at the OR [C] The name of ES unit used in the OR [D] Name of smoke evacuation system in the OR

2.2 Particle sampling

The Fast Mobility Particle Sizer (FMPS) TSI 3091 (TSI inc USA) with Fast Mobility Particle Sizer Software version 3.1.0.0 was used for measuring exposure to particles in the range of 5.6-560 nm. The FMPS has a flow rate of 10 l/min and a resolution of one second, to measure the total number concentration and particle number distribution (TSI 2009)

2.2.1 Sampling strategy

Five different surgical procedures were chosen, based on the expected length of the procedures, and the use of unipolar ES. See table 2-3 that describes the procedures chosen. The criteria for choosing types of procedures were based upon expected extensive use of ES and procedures with short expected length. The goal was to perform personal sampling on all personnel working in the OR: the main surgeon, assistant surgeon, surgical and anesthetic nurse. However, due to limitations of the sampling equipment, only operators that were more or less stationary could be sampled on. Three measurements were performed on each job group and each procedure, with the exception of hip surgery. Here several measurements were performed on the main surgeon and the anesthetic nurse in three different operating rooms. The measurements were executed in two different hospitals (Hospital I and II), and included two surgical departments. Hip replacement surgery was the only procedure were exposure measurements were performed in both hospitals. Participation was voluntary.

Table 2-3. Description of the different surgeries were sampling was performed.

Surgical procedure	Description of surgical procedure
Hip replacement surgery	Replacement of hip bone with artificial hip prosthesis.
Nephrectomy	Removal of kidney due to malign cancer. Whole or partial removal.
Breast reduction	Removal of redundant breast tissue. Surface surgery.
Abdominoplasty	Removal of redundant tissue from abdomen. Surface surgery.
Transutheral urologic resection procedure (TURP)	Endoscopic procedure. Resection of redundant prostate tissue. Normally used for prostatic hyperplasia.

Due to the unpredictable nature of the surgical schedule, it was not possible to plan multiple measurements on the same person; therefore sampling was carried out on the persons available at the time.

Five-minute measurement of background particle number concentrations was performed in the OR before and after surgery. The measurement was taken in the area where the personal sampling was performed.

Personal exposure was performed by using a six meter long flexible silicon tube attached to the inlet on the FMPS and on the persons left shoulder, as near to the breathing zone as possible. For surgeons and surgical nurses carrying sterile coats, the tube was placed under the coat up forward the persons back, summiting on the persons left shoulder as shown in figure 2-3. Sampling was executed during the whole length of the surgery: from the surgery started and until the surgeon left the OR.

Figure 2-3. The figure shows the main surgeon with the silicon tubing on the left shoulder.

2.2.2 Instrumentation for particle sampling

Particle size spectra were based upon electrical mobility. The instrument consists of three main parts; a particle charger column, a classification column, and a series of detection electrometers (Jeong 2009).

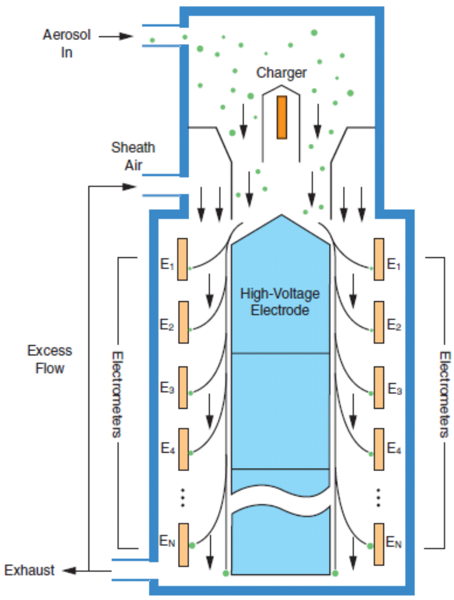

Figure 2-4. FMPS flow schematic. Printed by courtesy of TSI.

The FMPS was equipped with a cyclone with a 1µm cut to remove larger particles that can influence the counts and cause errors. After passing the cyclone, the particles pass through a negative charger to prevent overcharging and then pass on to a positive charger to obtain a predictable charge on the sample, by using a unipolar corona charger (Asbach 2009; Jeong 2009; TSI 2009). The positively charged particles flows with a particle free sheath air (40 L min $^{-1}$) and pass through a high voltage electrode. The high voltage electrode repels the particles towards an array of 22 electrometers. Small particles with high electrical mobility are deviated to the electrode rings near the top of the column; whereas larger particles with low electrical mobility are deviated further downstream the measurement column (Asbach 2009; TSI 2009). Figure 2-4 shows the FMPS flow schematic.

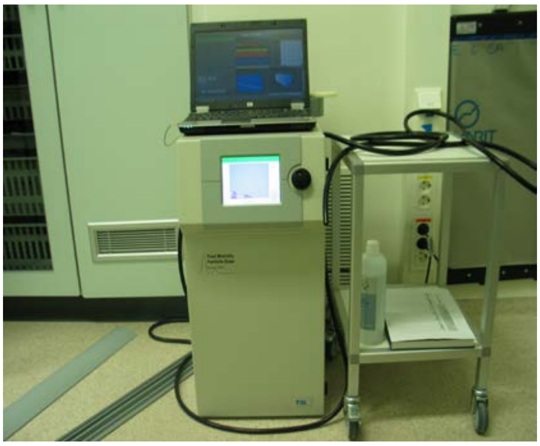

Figure 2-5. The FSMP Spectrometer Model 3091 placed by the wall in the operating room. The picture was taken before an operation during the study.

Particles, which land on the sensing electrodes, transfer their charge. The generated current is amplified by the electrometers, digitized, and read by a microcontroller in the range of 5.6-560 nm, 16 size classes per decade. The data are processed in real time to obtain one particle size distribution per second (TSI 2009). See figure 2-5 which shows the FMPS in the operating room.

2.2.3 Quality control of the instrument

A check for noisy channels was performed before each measurement. A HEPA filter was attached to the inlet on the cyclone and a five-minute run was performed, to make sure the measurement was below the zero line of the instrument.

2.2.4 Data analysis

After each measurement, the data for background measurements, and the personal measurements, was directly exported to Excel for further processing. The size fractions were divided in those <100 nm and the total number particle concentration (#/cm^3) for the whole surgery. Cumulative probability plots of total particles and ultrafine particles showed that the exposure data was best described by log normal distribution and the exposure data were log transformed before statistical analysis. Standard measures of central tendency and distribution [arithmetic mean (AM), geometric mean (GM) and geometric standard deviation (GSD)] were calculated. The range from the lowest AM exposure to the highest AM exposure in the different types of surgery was calculated. In addition the maximum peak exposure was calculated as the highest exposed second during the surgery. Statistical analysis was performed by SPSS version 20. (IBM Corp., Armonk, NY, USA) A two-tailed dependent t-test was performed by using SPSS to examine if there was a significant difference between the background measurements before and after surgery. The test was calculated with a 95 % confidence interval.

2.3 Determinants of particle exposure

Registration

The use of ES was registered by using a registration form during the surgical procedures. Several parameters that could affect the particle concentrations during measurements were also included in the registration form. (Appendix VI and VII) Table 2-2 shows the determinants that were included in the statistical analysis.

2.3.1 Evaluation of determinants of exposure

To evaluate determinants of exposure mixed effects linear models were constructed using Proc Mixed (SAS Institute Inc., Cary, NC, USA) with exposure as the dependent variable. Determinants were treated as fixed effects, and operator as a random effect. The restricted maximum likelihood (REML) algorithm was used to estimate variance components due to the unbalanced nature of the data. Univariate models were first performed after which multivariate models were built stepwise, starting with the variable with the lowest p-value in the univariate model. Variables with p-values > 0.2 in univariate models were excluded from further analysis. Variables with p-values < 0.5 were retained in the multivatiate models, and Akaike's information criterion (AIC) was used to select the optimal combination of exposure determinants in the multivariate model. Separate models were constructed for ultrafine particles and for total particles. Determinants were modeled on a general level, including all measurements. Determinants available for only for hip and breast surgery were found. Therefore separate models were constructed including only the hip or breast measurements.

The software package IBM SPSS statistics version 20 for windows (IBM Corp., Armonk, NY, USA) and SAS version 9.1 (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis.

Table 2-2. The determinants included in the statistical analysis.

Determinants in the statistical analysis	**Description**
Type of surgical procedure	Describes if it is a hip replacement surgery, nephrectomy, breast reduction, abdominoplasty or a TURP
Operating room	The operating room in which the measurements were performed
ES instrument	Describes the type of ES generator used
Surgeons	Describes if there was one or two surgeons performing the surgical procedure.
Ventilation system	Describes the type of ventilation. Laminar Air Flow or not.
Smoke evacuator	Describes the type of smoke evacuation used
Bairhugger on/off *	Describes if the patient had a bairhugger on or off during the surgery
One or two breasts reduced	Describes how many breasts reduced during breast reduction
Length of surgical procedure	Describes in minutes the duration of the surgical procedure
Length of ES use	Describes in minutes the use of ES during the surgery
Surgeries with the use of ES prior to the measurement	Describes the number of surgeries with the use of ES prior to the measurement for the study
Traffic	Registered number of persons walking in and out of the operating room during a surgical procedure
Steps on silicon tube	How many steps on the silicon tube registered during a surgical procedure

*Bairhugger is a forced air warming system, used on upper or lower body during surgery, to prevent perioperative hypothermia (Perl, Brauer et al. 2003).

2.4 Sampling of chemical components

2.4.1 Sampling strategy

Sampling of VOC`s and aldehydes was performed on three selected surgical procedures; breast reduction, nephrectomy and TURP. The measurement was carried out in the breathing zone of the main surgeon, see figure 2-6. Measurements of volatile organic compounds and aldehydes were sampled on the main surgeon during three different surgical procedures. Hip surgery could not be included because of the strict sterile demands connected with bone surgery. The abdominoplasty was excluded because there were no available operations at the time of sampling.

Figure 2-6. Positioning of the Markes ATD tube and Waters Sep-Pak®DNPH-Silica. The figure was taken when performing an experiment in the study period.

2.4.2 Aldehydes

Sampling of Aldehydes where performed using Waters Sep-Pak®DNPH-Silica cartridges for quantifying aldehydes in air. Waters Sep-Pak DNPH-silica cartridges consist of 2, 4-dinitrophenylhydrazine-coated silica packed in Waters Sep-Pak Plus Cartridges, equipped with end caps and plugs. Sampling was carried out using a battery based personal air sampler Model 222-3 (SKC inc) with a flow 50 ml/min.

The Sep-Pak DNPH-Silica cartridges trap aldehydes and ketones in gases by reacting them with the DNPH in the cartridge, to form stable hydrazine derivates. The derivatization reaction takes place during sample collection. The derivates are later eluted and analyzed by High Performance Liquid Chromatography. (HPLC)
Derivation Reaction in the Sep-pak DNPH silica is described in figure 2-7.

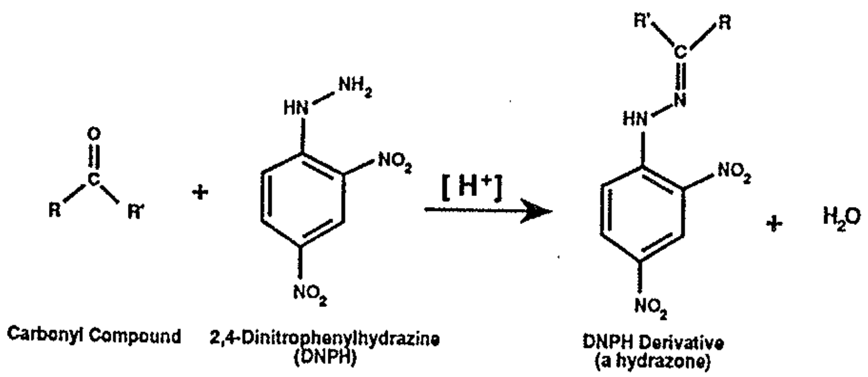

Figure 2-7. The derivation reaction in the Sep-pak DNPH silica

2.4.3 Volatile organic compounds

The VOC measurement where carried out with Markes ADT- tubes with Tenax TA adsorbent. Air passed through the ATD tube by using a battery based personal air sampler Model 222-3 (SKC inc). The air sampler had a collection velocity at 50 ml/min which made the VOC in the air react with the absorbent. The analysis of the Markes ATD-tubes was carried out in a customized thermo desorption injector. The tubes was placed in the adsorption injector and heated up, and thereby flushed with helium and the sample was transported to the injector. Thereafter, the test was transferred to gas chromatography with a capillary column and a Mass Selective Detector. This was a general method for detecting VOC by air sampling, and was best suited for components with a boiling point in the range of 60-250 ° C. Highly volatile compounds will not be detected using Tenax as adsorbent (STAMI 2011).

3. Results

The personal exposure to particles in the range from 5.6 – 560 nm was measured in the breathing zone of surgical staff during surgical procedures were ES was used. The measurements were carried out in real time exposure with one second resolution by using a Fast Mobility Particle Sizer. The results are presented and expressed as the number particle concentration (# / cm^3). The number represents the total number of particles per unit volume of sampled air (10 L / min). Table 3-5 summarises the exposure to the total and ultrafine particles for the different surgical procedures. The sampling of the measurements were accomplished between September 2011 and March 2012. In total, 48 personal exposure measurements were obtained from 29 employees while they were working. Four different job groups working in the OR in two different surgical departments, and two hospitals (Hospital I and II), during selected surgical procedures, were picked out for the measurements. Table 3-1 shows the different procedures, including length and the use of ES.

Table 3- 1. Duration of surgical procedures and the use of ES.

Surgical procedure	Length of surgical procedure (AM)	Length of the use of ES (AM)
Hip surgery	78 min	14 min
Nephrectomy	153 min	65min
Breast reduction	102 min	34min
Abdominoplasty	97 min	44min
TURP	52 min	33 min

3.1 Background measurements

Five-minute background measurements were performed before and after surgery, as close as possible to the area where the main measurement was sampled. Table 3-2 shows the AM particle concentrations for total and ultrafine particles.

Table 3-2. Five-minute background measurements before and after surgery.

Type of surgery	AM total particles (# / cm^3)		AM ultrafine particles (# / cm^3)	
	Before	After	Before	After
Hip replacement	365	909	360	908
Nephrectomy	378	209	366	209
Breast reduction	286	265	278	265
Abdominoplasty	212	206	212	206
TURP	829	332	811	332

For all the background measurements before and after surgery, the majority of the particles were in the ultrafine fraction. All the measurements showed similar background particle concentrations, but hip surgery had a higher particle number concentration after surgery, with a threefold increase compared to the concentration before surgery. TURP had the highest particle number concentration before surgery with an almost threefold decrease in particle concentration compared to the concentration after surgery. There were no significant differences between the measurements before and after surgery.

3.2 Determinant of exposure

Surgical procedure had the lowest AIC and was therefore the strongest determinant of exposure. None of the other determinants of exposure with a p-value <0.2 in the univariate analysis (OR, Type of ES unit and use of ES during the procedures) had a p-value lower than 0.5 in the mulitivariate model. Surgical procedure was the only determinant retained in the final model, see table 3-3 where background levels are given in concentrations and the surgical procedure effect as geometric ratios.

Table 3-3. Exposure estimates from the linear mixed effect model that came out as determinants of exposure. The background levels are given in concentrations and the surgical procedure effect as geometric mean ratios (GMR).

		Total particles (# / cm^3)	Ultrafine particles (# / cm^3)
Background level		628	628
Surgical procedure	Hip	0.30	0.29
	Nephrectomy	1.30	1.23
	Breast reduction	1.24	1.08
	Abdominoplasty	7.52	5.82
	TURP	1 (Reference)	1 (Reference)

Example calculation: Total particle concentration during nephrectomy: Background level x nephrectomy = GMR= 628 x 1.3 = 816.4

3.3 Abdominoplasty

Abdominoplasty, also known as a “tummy tuck”, is a surgical procedure that involves removal of excess fat in the abdominal area, and was the surgical procedure with the highest exposure to particles, see table 3-4 that shows the different exposure levels for the different types of surgery. During surgery, ES was applied to the surface area, and continuously used during the whole procedure before suture. The short pointed needle or blade was used. Only three measurements were obtained, and only on the main surgeon, due to time pressure and the unpredictable nature of the operational schedule.

The mean length of three abdominoplasty procedures was 96 minutes and the mean use of ES was 44 minutes. Abdominoplasty resulted in the highest GM exposure for the main surgeon and the second highest maximum peak exposure, see table 3-5. Figure 3-2 shows a typical exposure to the main surgeon during abdominoplasty. All peaks on the graph could be related to the use of ES. 80% of the particles were in the ultrafine fraction calculated from the AM total particle number concentration, where 90 % were larger than 45.3 nm. Figure 3-1 shows the proportion of particles by surgical procedure, where the ultrafine fraction is dominant in all five surgical procedures, with 80 % or more of the total particle concentration. Figure 3-3 describes the particle concentration as (dN/dlog/(Dp)), which is the number concentration of each channel multiplied with the number of channels per decade (16). The figure shows that the mean peak particle concentrations for the actual procedure, was in the size of Dp 6.4-69.8 nm.

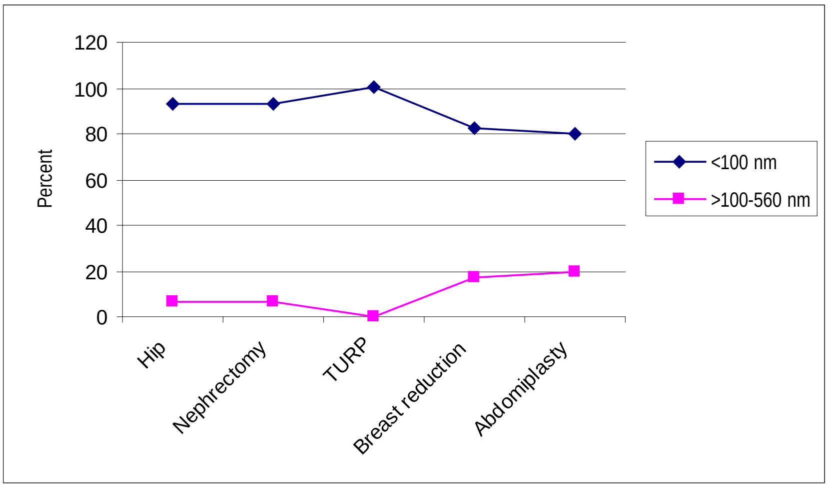

Figure 3-1. The figure shows the total of particles distributed by those ≤100 nm and >100-560 nm, by surgical procedure. The ultrafine fraction is dominant in all five surgical procedures with 80 % or more of the total particle concentration.

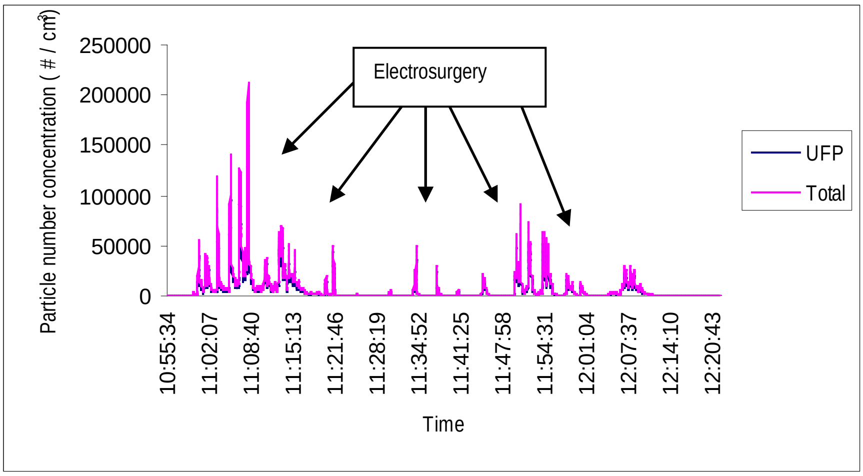

Figure 3-2. Personal exposure to particles in the range of 5.6-560 nm. The sampling was performed on the main surgeon during an abdominoplasty procedure in OR number three. All peaks relate to the use of ES during the procedure.

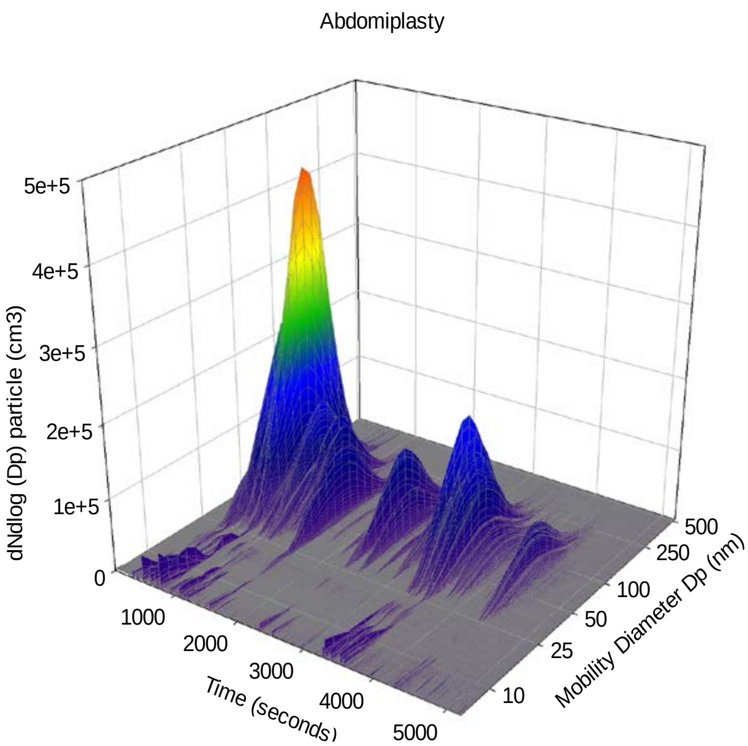

Figure 3-3. The particle size distribution at different times during surgery and when ES was used. Note that this figure presents the same measurement as figure 3-2.

Table 3-4. The exposure to total and ultrafine particles where the results are distributed by type of surgery.

			Total particles (# / cm³)					Ultrafine particles (# / cm³)				
	N[A]	K[B]	AM[C]	GM[D]	GSD[E]	Range [F]	Max [G]	AM[C]	GM[D]	GSD[E]	Range [F]	Max [G]
Abdominoplasty	3	3	5099	4677	1.70	1149-7297	211 760	3928	3629	1.67	1147-5601	147 893
Nephrectomy	9	7	1118	862	2.54	135-1835	113 846	1041	812	2.48	133-1657	113 504
Breast reduction	13	10	1695	813	3.43	135-9917	312 548	1400	700	3.19	127-8508	272 397
TURP	7	5	842	624	3.06	80-1376	2759	842	624	3.06	80-1376	2740
Hip	16	9	466	192	5.05	3.58-2286	196 356	434	187	4.95	3.58-1891	123 186

[A] Number of measurements [B] Number of people sampled from [C] AM particle number concentration

[D] GM particle number concentration [E] Geometric standard deviation [F] the lowest and highest measurement

Table 3-5.Tthe exposure to particles between job groups and surgical procedures.

			Total particles (# / cm³)				Ultrafine particles (# / cm³)			
Job group	Surgery	N[A]	AM[B]	GM[C]	GSD[D]	Max[E]	AM[B]	GM[C]	GSD[D]	Max[E]
Main surgeon	Abdominoplasty	3	5099	4677	1.70	211 760	3928	3629	1.67	147893
	Nephrectomy	3	1428	1388	1.34	84 046	1319	1289	1.30	74 183
	Breast reduction	3	1730	1520	1.95	237 289	1324	1158	1.99	122 873
	TURP	4	789	585	3.78	2759	789	585	3.78	2740
	Hip surgery	7	592	150	8.45	196 356	521	143	8.04	123 186
Assistant surgeon	Nephrectomy	3	898	602	3.57	113 846	795	549	3.44	113 504
	Breast reduction	3	3689	1316	6.93	312 548	3181	1191	6.00	272 397
	Hip surgery	4	445	350	2.26	3006	444	349	2.26	2912
Anesthetic nurse	Nephrectomy	3	1028	768	2.93	12 662	1010	756	2.92	12 662
	Breast reduction	4	344	286	2.06	12 858	320	268	2.01	10 556
	TURP	3	895	679	2.82	2063	895	679	2.82	2063
	Hip surgery	5	307	166	4.13	3877	305	164	4.17	2652
Surgical nurse	Breast reduction	3	1468	1081	3.01	182 958	1138	893	2.60	121 471

[A] Number of measurements performed on each job group   [C] GM particle number concentration   [E] Maximum peak exposure

[B] AM particle number concentration   [D] Geometric standard deviation

3.4 Nephrectomy

Measurements of eight nephrectomy procedures at operating room six, and one nephrectomy at operating room two, were performed. The use of ES was continuous throughout the procedure before resection of the kidney and before suture. Initial to the procedure, the surgeon had a short pointed needle on the diathermy pen, but as the surgeon had to cut and coagulate deeper into the patient, the short tip was replaced with a long pointed tip. The mean length of the procedure was 153 minutes and the mean length of the use of ES were 65 minutes, which gives the longest duration of both respectively, compared to the other types of surgical procedures. 93 % of the total amount of particles was in the ultrafine fraction and 43 % of the ultrafine particles were less than 10.8 nm. Measurements were performed on the main surgeon, assistant surgeon and the anesthetic nurse.

Nephrectomy had the second highest exposure level of all five procedures. Figure 3-4 shows a typical example of exposure to the main surgeon during a nephrectomy procedure where all peaks on the graph can be related to the use of ES. Figure 3-5 describes the particle number concentration as (Dn/dlog/(Dp)), and where the mean peak number concentrations consist of particles in the fraction Dp 9.04-23.04 nm.

The main surgeon had the highest GM exposure, almost two times higher than the assistant surgeon and the anesthetic nurse. The exposure between the anesthetic nurse and assistant surgeon was similar. The highest maximum peak exposure was measured on the assistant surgeon, almost twice the measure than the rest of the job groups in the OR.

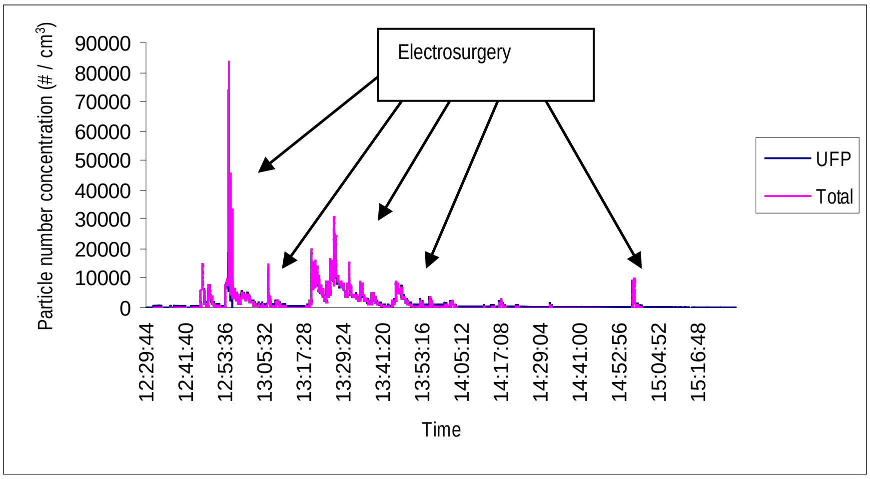

Figure 3-4. The exposure to particles in the range of 5.6-560 nm. The measurement was performed on the main surgeon during a nephrectomy procedure. All the peaks are directly connected to the use of ES during the surgical procedure.

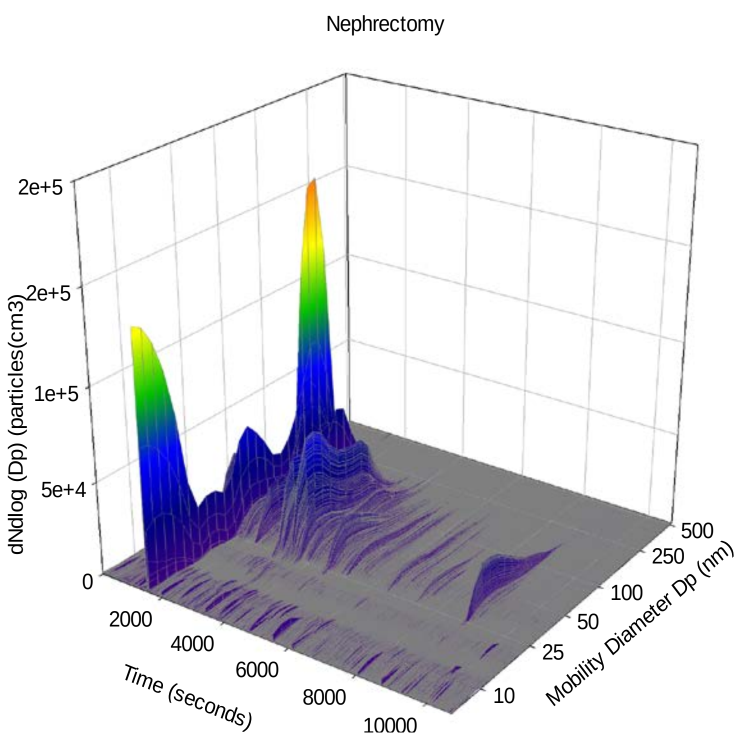

Figure 3-5. The particle size distribution at different times during surgery and when ES was used. Note that this figure presents the same measurement as figure 3-1. Note that this figure presents the same measurement as graph 3-4.

3.5 Breast reduction

A total of 13 measurements were performed on the main surgeon, assistant surgeon, surgical nurse and the anesthetic nurse, in OR number three. Nine of the procedures included bilateral breast reductions, and four included unilateral breast reductions. This was the only surgical procedure that included measurements on the surgical nurse, because during this type of surgery, it was an easy access to the nurse with the sampling tube, and the person stayed put during the procedure.

In bilateral breast reduction, two surgeons reduced one breast each, while continuously using the ES pencil throughout the procedure before suture. In unilateral breast reduction, only one surgeon carried out the procedure. Breast reduction was a surface procedure on which the short pointed needle or a blade on the ES pencil was used.

The mean length of the procedure was 101 minutes, and the mean use of ES was 34 minutes. Breast reduction had the next longest mean duration in minutes after nephrectomy. 83% of the particles was in the ultrafine fraction and 62% of these were >39 nm – 100 nm. Figure 3-6 shows a typical exposure to main surgeon during a breast reduction where all peaks on the graph can be related to the use of ES.

All breast reduction procedures resulted in the second highest GM exposure levels for the main surgeon. The highest maximum peak exposure was measured on the assistant surgeon.

The exposure was quite similar to the main surgeon, the assistant surgeon and the surgical nurse. The anesthetic nurse had the lowest exposure. See table 3-5 for the exposure levels between job groups. Figure 3-7 describes the particle number concentration as (Dn/dlog/(Dp)), and where several peaks had mean particle number concentrations that consisted of particles in the fraction Dp 9.31-93.1 nm.

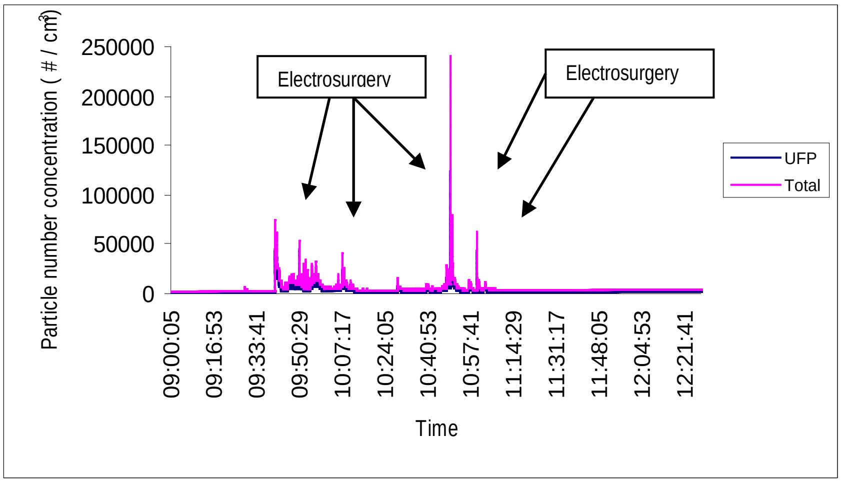

Figure 3-6. Exposure to particles in the range from 5.6-560 nm during reduction of two breasts measured on the main surgeon during the procedure. Peaks on the graph could relate to the use of ES.

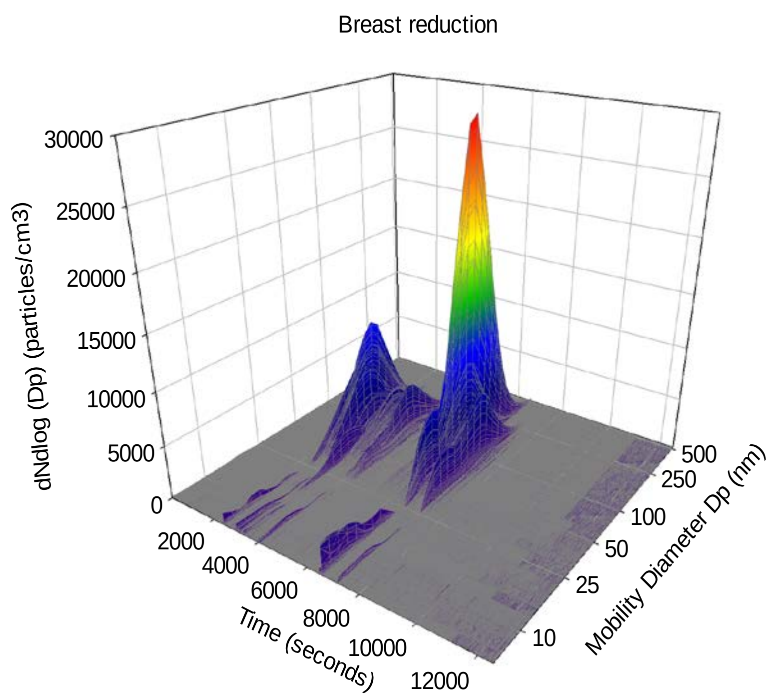

Figure 3-7. The particle size distribution at different times during surgery and when ES was used. Note that this figure presents the same measurement as figure 3-7.

Table 3-8. Exposure estimates from the linear mixed effect model that came out as determinants for the exposure to surgical smoke during breast surgery. The background levels are given in concentrations and the parameter effects as geometric mean ratios (GMR).

	Total particles / cm^3	Ultrafine particles / cm^3
Background level	29	34
Two breasts	7.12*	5.94*
One breast	1(reference)	1(reference)

* $P< 0.05$

Example calculation of the exposure to the total concentration of particles during reduction of two breasts with background level: One breast x 7.12 = 206.48 particles/cm^3

Reducing one or two breasts came out as determinants of exposure to surgical smoke. For breast reduction, a higher exposure to the surgical staff during bilateral breast reduction was found. When reducing two breasts, two surgeons usually reduces one breast each, resulting in simultaneously use of ES, with two ES pencils connected to the same air suction instrument, resulting in a seven fold higher exposure, see table 3-8.

3.6 TURP

The transutheral prostate resection (TURP) is an endoscopic surgical procedure which aim is to remove excess prostate tissue in the prostate gland. The ES consisted of a resectoscope with a loop, lead through the urethra of the patient and towards the prostate gland. ES was continuously used throughout the procedure and only interrupted with a few pauses where the surgeon stopped to rinse out the excess prostate tissue. During the rinsing, the surgeon is exposed to surgical smoke.

Seven measurements were carried out on the surgeon and anesthetic nurse. Only one surgeon performed the procedure. The mean length of surgery was 52 minutes and the mean length of use of ES was 33 minutes. TURP had the next lowest exposure to particles during surgery. See table 3-5. All particles were in the ultrafine fraction and 73 % of the particles were less than 10.8 nm. The exposure between the main surgeon and anesthetic nurse was similar. The use of ES did not result in increased peak exposure to particles, see figure, 3-8. It was observed that the particle concentration could increase during the procedure and after rinsing, but this was not consistent. Figure 3-9 describes the particle number concentration as (Dn/dlog/(Dp)), and where several of the particles was distributed between Dp 9.31-34.75 nm.

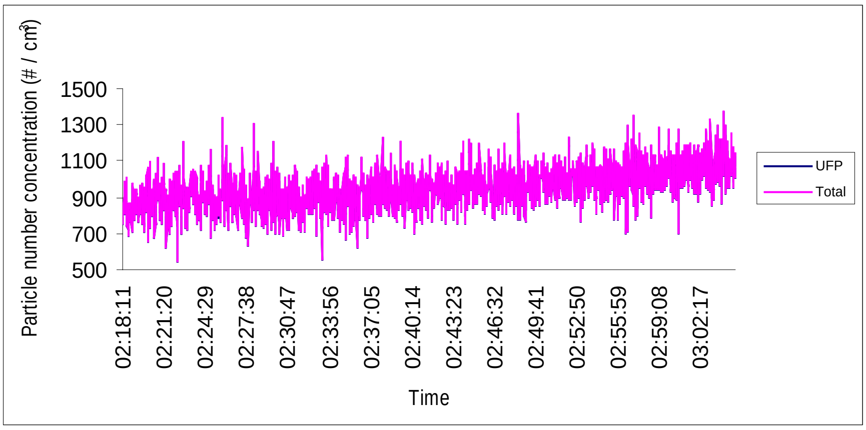

Figure 3-8. The exposure of particles in the range of 5.6-560 nm measured on the main surgeon during TURP. No peaks on the graph could relate to the use of ES.

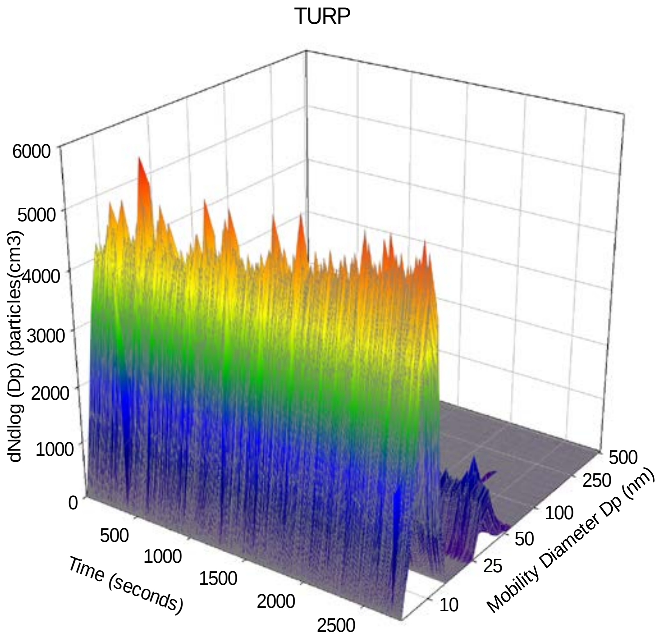

Figure 3-9. The particle size distribution at different times during surgery and when ES was used. Note that this figure presents the same measurement as figure 3-8.

3.7 Hip replacement surgery

Measurements of a total of 16 hip replacement surgery procedures were performed in three different OR`s at two different hospitals. 12 measurements were performed at Hospital I and four measurements were performed at Hospital II. Operating rooms seven and eight at Hospital I had Laminar Air Flow installed, while operating room one at Hospital II had not. See table 2-2. The mean length of hip surgery was 78 minutes, and the mean use of electro surgery was 14 minutes.

Hip replacement surgery was a standardized procedure, where ES with a short pointed needle was used initially in the procedure, cutting and coagulating tissue down to the hipbone. Thus, the main particle exposure was registered and observed in the start of the procedure, see graph 3-10. Hip replacement surgery was the surgery with the lowest exposure to particles including all job groups. It had the highest GSD of all measurements, see table 3-4. 93 % of the particles were in the ultrafine fraction, and 60% of these were smaller than of 8.06 nm. Figure 3-11 describes the particle number concentration as (Dn/dlog/(Dp)), and where the peaks was Dp 9.31-107.5 nm.

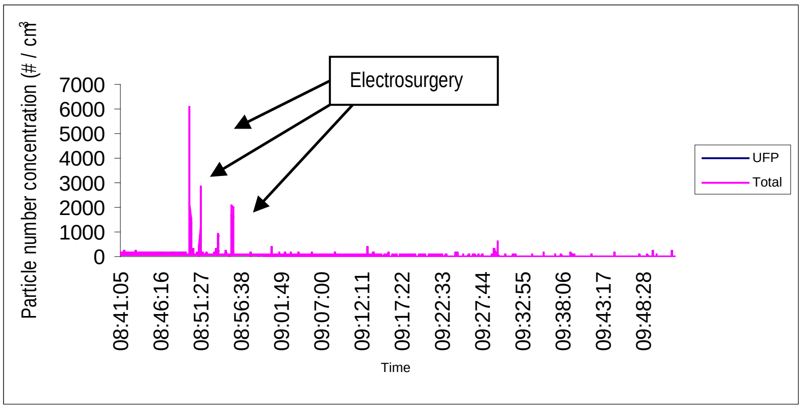

Figure 3-10: The personal exposure to particles in the range from 5.6-560 nm during a hip replacement surgery. The sampling was performed on the main surgeon in OR seven. Peaks related to the use of ES are identified with arrows.

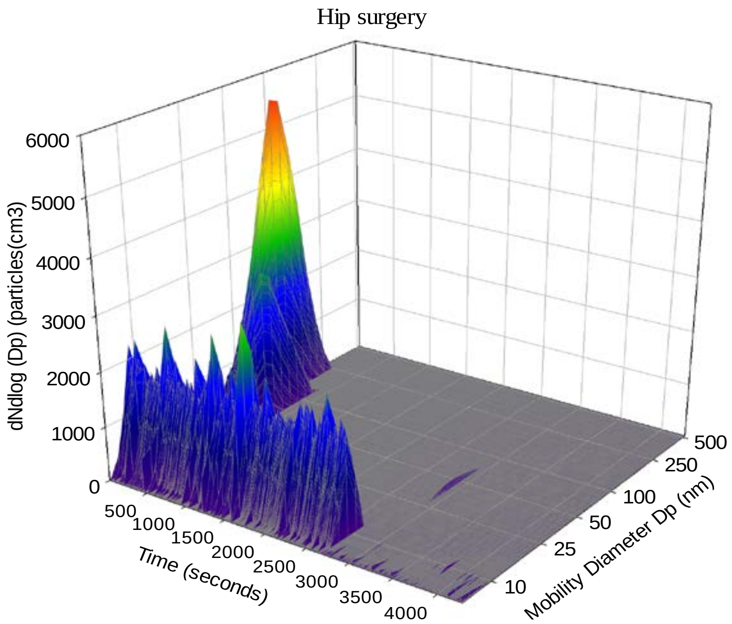

Figure 3-11: The particle size distribution at different times during surgery and when ES was used. Note that this figure presents the same measurement as graph 3-10.

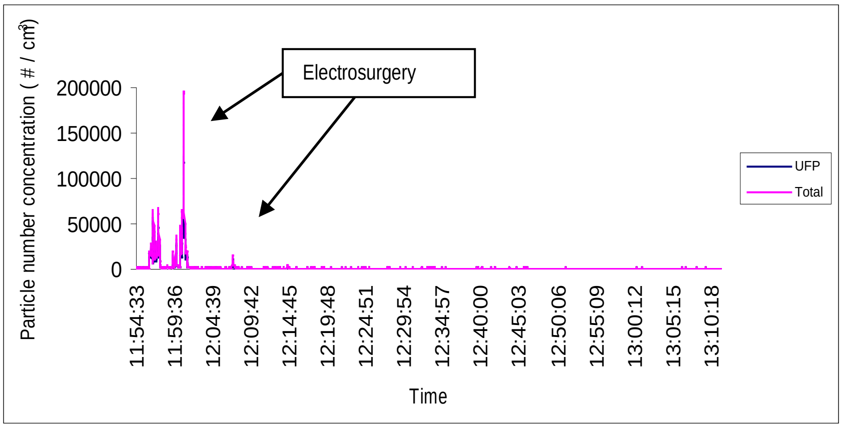

Figure 3-12. The personal exposure to particles, in the range of 5.6-560 nm, measured during a hip replacement surgery in OR eight. Peaks related to the use of ES are identified with arrows.

The exposure to total and ultrafine particles were quite similar for the main surgeon, assistant surgeon and the anesthetic nurse, with the exception of the maximum peak exposure that was almost 50 times higher for the main surgeon compared to the other job groups. See table 3-5 that shows the maximum peak exposures on the assistant surgeon and figure 3-12 that shows the measurement during the procedure.

The measurements performed at hospital II, was under somewhat different sterile conditions than the operating rooms at hospital I. Due to lack of Laminar Air Flow, the surgeons at hospital I was dressed in a sterile coat and a helmet that was supplied with fresh filtered air. The helmet created a sterile shield between the surgeon and the patient. It was not possible to relate the peak to the use of ES. In the second part of the surgery, a greater number of particles were observed in combination with humidity and water aerosols inside, the helmet, see figure 3-13 that shows the measurement inside the helmet in OR number one.

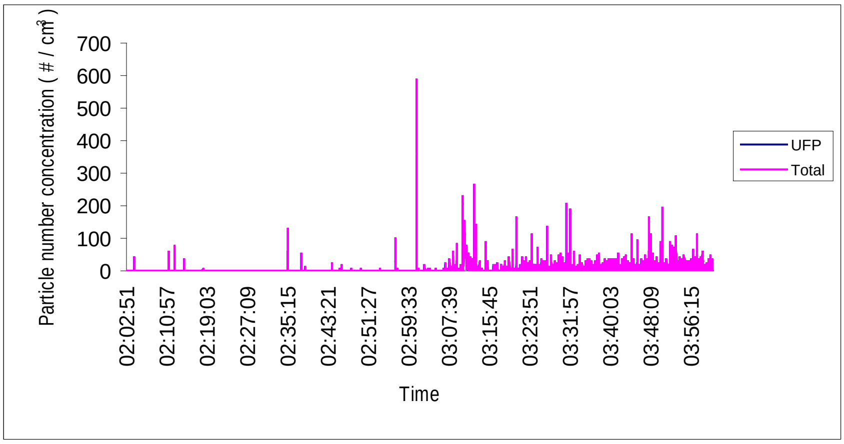

Figure 3-13. Main surgeon`s exposure to particles in the range from 5.6-560 nm when wearing a filtered air supplied helmet and coat.

Hip surgeries were performed in three different operating rooms, and linear mixed effects models including only measurements performed during hip surgery, showed that operating room was a significant determinant of exposure, see table 3-7. OR number one had the lowest exposure.

Table 3-7. Exposure estimates from the linear mixed effect model that came out as determinants for the exposure to surgical smoke during hip surgery. The background levels are given in concentrations and the parameter effects as geometric mean ratios (GMR)

		Total particles (# / cm^3)	Ultrafine particles (# / cm^3)
Background level		538	505
Operating room[A]	7	0.59*	0.62
	1	0.05*	0.05
	8	1(reference)	1(reference)

[A] The covariates that were found to give the best fit of the model

* P< 0.05

Example calculation: exposure to total particles in operating room one: Background level x operating room one= 538 x 0.05= 26.9 particles / cm^3.

3.8 Component analysis

Sampling for characterization of volatile organic compounds and aldehydes in surgical smoke was performed on the main surgeon for three selected procedures; nephrectomy, breast reduction and TURP. The compounds identified from the VOC samples are listed in table 3-9. Formaldehyde was only detected in the sample from breast reduction with a concentration of 0.01 ppm, whereas acetaldehyde was not demonstrated in the sample. Aldehydes were detected in in the other procedures, but in levels below the detection limit, see table 3-10.

Table 3-9. The table shows the volatile organic compounds identified in the Markes ATD tubes for each surgical procedure.

	Nephrectomy (µg/ m³)	Breast reduction (µg /m³)	TURP (µg /m³)	OEL[A] (µg /m³)
Air volume Duration [B]	Air volume 3.9 l 184 minutes	Air volume 2.7 l 116 minutes	Air volume 1.1 l 40 minutes	Occupational exposure limit
Compound				
di-tert-butylbenzen	14		63	
2.2.4–trimetyl-1.3-pentandioldiisobutyrat (TXIB)	40			
2-chloroethanol		98		3000
1-propanol			111	245 000
2-propanol			468	245 000
TVOC[C]	588	272	746	400

[A] The Norwegian Occupational Exposure limit.

[B] Duration of sampling.

[C]TVOC is the total amount of volatile organic compounds in the sample.

Table 3-9 shows the quantification of VOC for each surgical procedure. The highest total amount of VOC obtained from the TURP was, 746 µg/m^3. The main components identified and quantified in the sample was 1-propanol, 2-propanol and di-tert-butylbenzene

For the nephrectomy the total concentration of VOC in the samples was, 588 µg/m^3. The sample contained several semi-volatile compounds and was difficult to identify. Two of the compounds identified were 2.2.4–trimetyl-1.3-pentandioldiisobutyrat and di-tert-butylbenzen. In addition to the quantified compounds the sample contained 2-propanol, 1-propanol and the aromatic compounds benzene, toulene and m&p-xylene in very small amounts. The aromatic compounds identified, represented normal concentrations in both indoor and outdoor air.

The lowest total amount of VOC in the sample obtained from the breast reduction was 272 µg/m^3. The main component is likely to be 2-cloroethanol that makes up 36% of the sample.

Table 3-10. Aldehydes identified in Waters Sep-Pak DNPH Silica Cartridge for each procedure.

	Nephrectomy	Breast reduction	TURP
Air volume [A] Duration [B]	5.0l 184 minutes	3.468 l 116 minutes	1.4l 43 minutes
Aldehydes	ppm	ppm	ppm
Formaldehyde	< 0.01	0.01	< 0.01
Acetaldehyde	<0.01		< 0.01

[A] The calculated air volume for the pumps.

[B] The duration of each procedure.

4. Discussion

Background measurements were performed to see if the particle number concentrations in the OR increased during surgical procedures, when ES was used, and there was no significant difference between the background levels before and after surgery. The use of ES during surgical procedures resulted in elevated exposure levels of mainly ultrafine particles in the breathing zone of OR personnel in all surgical procedures, except TURP. Measurements of VOC and aldehydes on the main surgeon during three selected procedures showed concentrations below the Norwegian OEL for VOC and below the detection limit for the method for aldehydes.

For all surgical procedures, the ultrafine fraction was dominant. 80 % or more of the measured particles was <100 nm. However, the different surgical procedures resulted in different size fractions. Hip replacement surgery, TURP and nephrectomy produced most particles in the sizes <10. 8 nm compared to breast reduction and abdominoplasty that produced most particles in the size fractions > 39 nm and > 45 nm respectively.

A previous study proposed the FMPS to be inaccurate when measuring particles in the size range between 9-11 nm, and the discrepancy is suggested to be caused by a weakness with the algorithm that calculates size, and thus inflates the particle numbers on these channels (Jeong 2009). When investigating figure 3-3, 3-5, 3-7, 3-9 and 3-11, this noise may be apparent during measurements. However, by doing a thorough check on the instrument before every measurement, indications of that something was wrong, was never experienced.

4.2 Determinants of exposure

Type of surgery was the only covariates that came out as a determinant of exposure to surgical smoke in the multivariate linear mixed effect model. Further, observations during the surgical procedures will be discussed to explain the variance in exposure to surgical smoke in the different types of surgeries.

The highest geometric mean (GM) exposure to total particle and ultrafine particles, were measured on the main surgeon during three abdominoplasty procedures, and the measurements showed only a small variance in the measurements. Considered that all three measurements where performed on the main surgeon only, and during a surface surgery, the high exposure was expected. The main surgeon had the highest exposure to surgical smoke during abdominoplasty of all types of surgical procedures, almost three times higher than the main surgeon during breast reduction, which also was a surface surgery. During the procedure two ES pencils was used and shared the same smoke evacuator. The smoke evacuator was not dimensioned for two ES pencils, and the effect was to low to evacuate the produced smoke. In addition, a larger area of fat tissue removed, could contribute to the higher emissions during this type of surgery.

Nephrectomy had the second highest GM exposure to surgical smoke and had a moderate variance in the results. It was the only surgical procedure where bipolar ES were applied, and where the surgeons changed between a short pointed and long pointed needle while using the unipolar ES. The kidney is located at the rear of the abdominal cavity and the long pointed needle is needed to reach down to the operating sites during the procedure. By applying the long pointed needle, a greater distance between the built-in smoke evacuator on top of the ES pencil and the site of use was created. The greater distance seemed to result in a decreased efficiency in trapping the smoke, and could explain the high peak exposures during surgery. The exposure also seemed to depend on the patient`s weight and anatomy. Overweight patients with excess fat in the abdomen area, resulted in a further distance between the opening wound, and the patient`s kidney readily retaining the smoke inside the patient, and thus reducing the exposure of the smoke to the surgical staff. When operating on slim patients, the distance between the opening wound and the kidney was smaller and less smoke was retained inside the patient, thus exposing the surgical staff to higher levels of surgical smoke. In addition, the bipolar ES did not have a built-in smoke evacuation system connected to the smoke evacuation instrument, a fact that could result in visible smoke and higher particle concentrations when using this instrument. The main surgeon had the highest exposure to surgical smoke during nephrectomy, and it was a low variance in the measurements. However, the assistant surgeon received only half of the exposure compared to the main surgeon and was similar to the anesthetic nurse`s exposure, and both job groups had a higher GSD than the main surgeon. The highest peak exposure was measured on the assistant surgeon, see table 3-5. The measurement performed on that particular day differed from the other ones, generally reaching higher particle concentrations during surgery. This may indicate that conditions, such as the smoke evacuation system, did not function properly that day. The GM exposure to the anesthetic nurse was the highest during nephrectomy procedures compared to all types of surgeries, and one of the measurements was much higher than the others.(Graph AII-9) This was the only measurement performed in a different OR than the other nephrectomy procedures, which also included a different smoke evacuator. Table 2-2 shows the smoke evacuator that was used during this procedure, and one could suggest that the smoke evacuator did not work sufficiently enough, during this procedure. Peak exposure to ultrafine particles related to the use of ES in the anesthetic zone, was observed in all the types of surgical procedures, except TURP. This may indicate that ultrafine particles produced from surgical smoke, does not aggregate or agglomerate immediately after production, but are diluted by the positive pressure from the ventilation system, and distributed in the room.

Breast reduction gave the third highest GM exposure to surgical smoke and was the only procedure where all four job groups were included in the measurements. Linear mixed effects models, including only measurements performed during breast reduction, showed that reduction of one or two breasts was a significant determinant of exposure. Reduction of two breasts lead to a seven fold exposure to the surgical staff compared to reduction of one breast. During unilateral breast reduction, only one surgeon used the ES pencil continuously, compared to bilateral breast reduction, where both surgeons reduced one breast each simultaneously and shared the same smoke evacuator with both ES pencils connected to the same tube. The smoke evacuator was not dimensioned for the use of two ES pencils, and therefore not extracting the surgical smoke efficiently enough and could contribute to explain the higher exposure when reducing two breasts. The exposure between the main surgeon, assistant surgeon and the surgical nurse was quite similar, while the anesthetic nurse, who is placed farthest away from the surgical smoke, had lowest exposure.

TURP had the second lowest particle concentration. Since this was an endoscopic procedure and ES was used inside the patient`s prostate gland during the procedure, low particle concentrations were expected. None of the peaks on the graph could relate to the use of ES and 73 % of the total particles were less than 10.8 nm. It was observed that the concentration of particles could increase during the rinsing process, but since this result was not consistent, it was difficult to define such relationship.

Hip replacement surgery was the surgical procedure with the lowest GM exposure to total and ultrafine particles and had the highest GSD among the selected surgeries for the current thesis. Linear mixed effects models including only measurements performed during hip surgery showed that operating room was a significant determinant of exposure. Differences in exposure are connected with the different conditions during sampling in the three OR`s. The measurements on the main surgeon in OR number one was sampled inside an air supplied helmet, and was therefore not directly exposed to the smoke. The anesthetic nurse in OR number one, which did not have an air supplied helmet, was exposed to low levels of particles. In fact, lower than the one observed at the anesthetic nurse in OR seven. In OR seven, the anesthetic nurse had peak exposures to surgical smoke, initial to the procedure. In OR number one, it was difficult to identify peaks related to the use of ES. It is possible, that the surgeons technique and the amount of bleeding during the procedures in OR number one, was different than the one in OR number seven, and therefore resulting in lower exposure to surgical smoke. Also, limited door traffic was registered during measurements in OR number one, due to very strict requirements because of the lack of LAF. The highest maximum peak exposure was sampled from the main surgeon in OR number eight. Since this particular measurements stands out from the other measurements, it may indicate that the smoke evacuator did not function properly that day. Nine measurements were performed in OR number seven. It was not observed anything unusual during these, measurements, except for initially high peaks of two of the measurement on the main surgeon. These peaks could result from a delay from the smoke evacuation system, but this was not observed. The assistant surgeon had the highest exposure to surgical smoke, and the main surgeon and anesthetic nurse had quite similar exposure. However, since measurements on the main surgeon was the only job group performed in all three operating rooms, the variance between these measurements gave the highest GSD of all job groups, which reflects the different conditions in the OR`s.

Several determinants of exposure were included in the linear mixed effects models, but did not come out as significant in the multivariate model. It was expected that length of the use of ES during procedures would influence the exposure of surgical smoke. The use of ES was registered by recording the minutes. However, using a stopwatch to record the exact time when ES was used would give a more correct estimate of the use, as it sometimes only lasted a few seconds. It was not possible to do this, as the person recording the time had to pay attention to other parameters. The recorded inaccuracy of ES use could explain why it was not a significant determinant of exposure. However it was observed that the exposure to surgical smoke was affected by factors like what tip was used on the ES pencil and if ES was used superficially or not. It is probable that not even a more precise measurement for the time ES was being used would be sufficient.

Type of ESU was stationary for each operating room and the effect was tuned in on a fixed mode for each procedure. Although ESU did not come out as a determinant in the multivariate analysis, the effect from the ESU and target tissue, could contribute to different exposure to surgical smoke. Fat tissue gives a higher resistance, than for example, muscle tissue, and needs a higher effect on the ESU, conditions that may contribute to higher emissions. Also the amount of bleeding during the procedure could inflect on how much the coagulation mode was used, thus contributing to the creation of more smoke. However, during the experiments, it was not observed any unnaturally high blood losses during surgery.

Like the ESU, the smoke evacuation system, was stationary in each operating room, but did not come out as significant in the multivariate analysis. Variable effects from the smoke evacuator were observed. In addition to the decreased effect when connecting two ES pencils to the smoke evacuator, a day to day variance in effect during use, was observed. It was observed that the smoke evacuator could fluctuate in effect when it was in use. Also, it was observed, that the smoke evacuator, sometimes, could have a delay, initial to the procedure, thus not evacuating the first emissions.

Persons walking in and out of the OR during surgery were also considered to influence the number of particles, since the positive pressure in the OR will collapse when doors open. Although door traffic did not come out as a significant determinant in the univariate analysis, door traffic varied between the types of surgeries. Hip surgery, which had the lowest exposure to particles, also had the strictest routines connected with door traffic, which was kept to a minimum during the procedures.

The six meter long silicon tubing was used to sample air in the breathing zone and was lying on the floor between the FMPS and the person during measurements. Registration of steps on the tube during measurements was performed, due to the idea that steps could hinder the air to flow in to the FMPS, and thus influence the collection of particles. Prior to the experiments the influence of stepping on the silicon tubing was tested. It was registered that only steps of long duration seemed to impact the measurements that resulted in dips on the graph. Surgical personnel could step or sit on the tube during measurements by incident and this could be registered as dips on the graph. Some of these dips might have inflected the particle number concentration. However, people in the operating room were aware of the tube, and were trying to avoid stepping on it, and stepping on the tube did not come out as a significant determinant of exposure. The tubing could have inflected the measurements in other ways, than only stepping on it. One could expect particles to deposit inside the six meter long tubing during sampling or lead to a different size distribution, impossible for the FMPS to detect. Also, the position of the nozzle of the tubing could inflect the measurement. Although trying to standardize the positioning of the tubing on the persons left shoulder, the distance between the breathing zones probably differed. The nature of the surgical procedure varied in how much the surgeon had to reposition, and it was observed that this contributed to a variance in the distance from the breathing zone and the nozzle of the tubing. Also the surgeon`s technique differed in how much they moved during surgery. This variance was seen from person to person, and between different types of surgeries.

The use of Bairhugger or not, was also suggested to be a determinant of exposure. Warm air from the Bairhugger is pushed down to the floor and could potentially whirl up dust, and thus influence the number of particles. However, not all surgeries used Bairhugger as it was not always considered as necessary. The use of Bairhugger or not did not come out as a significant determinant in the univariate model, and did not influence the concentration of particles for the current thesis.

LAF was only used for hip replacement procedures in operating room seven and eight and it did not come out as a significant of exposure in the univariate analysis. However, the ventilation systems of all operating rooms was of high efficiency, and it was observed, when using electrosurgery with the built in smoke evacuator, the exposure was characterized of short term high peaks. Every morning, the ventilation system was set on full effect mode.

4.3 Comparison to other studies

To my knowledge, only one previous study has been published with the aim to measure the exposure to ultrafine particles during use of ES in the OR (Bruske-Hohlfeld, Preissler et al. 2008). Similar to the current study, one found that the use of ES resulted in short term high peak exposures of surgical smoke (Bruske-Hohlfeld, Preissler et al. 2008), this being in good agreement with my results.

Brüske-Hohlfeld et al. (2008) measured the amount of particles generated in the surgical smoke during six selected surgical procedures, and the measurements was performed in different OR`s. They used a condensation particle counter (CPC) to measure the particle exposure, and tried to standardize the measurements by placing the CPC at the anesthetic side with the suction tube fixed to the middle of the surgical cover, corresponding roughly to the breathing zone of the surgical staff. The CPC measures the number concentration of particles in the size range of 10 nm – 1 µm and cannot separate on particle size (Brouwer, Gijsbers et al. 2004). The mean particle exposures did vary between 74-12200 particles/cm^3 compared to the current study which varied with 3.58 – 9917 particles/cm ^{3}. The peak exposures for the surgeon varied with 379-490 000 particles/cm ^{3}, compared to the current study where the peak exposures on the surgeon varied between 2759-312548 particles/cm^3. Bruske-Hohlfeld, Preissler et al. (2008) measured a maximum peak concentration at 292 000 particles / cm ^{3} during a mesh hernia repair compared to my maximum peak concentration at 312 548 particles/cm^3 obtained during a bilateral breast reduction, which is the best comparable result between these two studies. However, the Bruske-Hohlfeld et al. (2008) only included six measurements, which were too few to conclude that the measurements were typical for the procedures. In comparison, the current study included several personal exposure measurements on different job groups in the OR, and gives a better indication of what is a typical exposure for the selected procedures. In addition they used the CPC that could contribute to higher particle concentration than the FMPS because of the differences in the detectable particle size range.

Similar to surgical smoke, cooking fumes are known to contain fine and ultrafine particles. (Dennekamp, Howarth et al. 2001; Sjaastad, Jorgensen et al. 2010). Previous studies associate the exposure to cooking fumes with an increased risk of respiratory symptoms (Svendsen, Sjaastad et al. 2003) and respiratory cancer (Zhong, Goldberg et al. 1999). Ultrafine particles arise by the nucleation route as combustion products (Schneider 2007). Both beef frying and use of ES during surgical procedures involves heating of biological material. Thus, it is natural to compare particle number concentrations obtained during beef frying with the particle number concentrations generated in surgical smoke. Sjaastad et al (2009) demonstrated by using a TSI 3936 Scanning Mobility Particle Sizer (SMPS) that the peak particle number concentrations measured in the breathing zone of the cook to be between 896 000 - 893 0000 particles/cm^3 while frying beef on a gas stove. This result is three times higher than the maximum peak concentration of 312 000 particles/cm^3 found in the current study. However, when frying beef on an electric stove, lower maximum peak concentrations was achieved at 60 000 particles/cm^3 and 146 000 particles/cm^3 and are very much comparable to the results in the current study. Dennekamp et al. (2001) also demonstrated similar results when frying bacon on the gas stove with the use of a TSI 3934 Scanning Mobility Particle Sizer (SMPS), but did not reach maximum peaks as high as Sjaastad et al. (2010), and only reached 590 000 particles/cm^3. On the electric stove, however, the concentration reached 159 000 particles/ m^3 and was comparable with the results from the current study and also the results from Sjaastad et al. (2010). Dennekamp et al. (2001) registered these levels with closed windows without mechanical ventilation (Dennekamp, Howarth et al. 2001). The study from Dennekamp et al (2001) showed that when cooking on a electric stove or gas, the particle sizes was mainly in the ultrafine fraction (50-100 nm) and was in good agreement with Sjaastad et al. (2010), which showed that use of the gas stove gave mean peak number concentrations that consisted of smaller particles in the ultrafine fraction (Dp= 40-60 nm) when cooking on the gas stove and the electric stove (Dp=80-100 nm) (Sjaastad, Jorgensen et al. 2010). Five selected procedures from the current study, showed peak particle concentrations in the ultrafine fraction with particles in a broader size range and differed between Dp 6.4-93.1. The size fractions sampled from the main surgeons in the abdominoplasty (Dp=6.4-69.8), nephrectomy (Dp=9.4-23.04) and the bilateral breast reduction (9.31-34.75). Similar to cooking fumes, peak particle concentrations were defined in the ultrafine fraction, but distributed in different particles sizes. Heat applied, energy used and target tissue, may contribute to explain the broader size ranges that are produced during the use of ES.

Compared to other working environments the exposure to ultrafine particles in the OR is low. Stationary measurements performed in bars and restaurants found mean exposure to ultrafine particle levels to be approximately 51000 particles/cm^3 by using CPC (Valente, Forastiere et al. 2007). Exposure to welding fumes with stationary measurements by the SMPS found median exposure to be 53600 - 126800 particles/cm^3 (Lehnert, Pesch et al. 2012), median exposure to asphalt fumes to be 34000 particles/cm^3 by using the P-trak (Elihn, Ulvestad et al. 2008); median exposure to fettling of aluminium; 130000 particles/cm^3, core making and moulding, 25000-75000 particles / cm^3, grinding; 15000 – 23000 particles/m^3 by using a CPC (Elihn and Berg 2009). However, since these measurements were stationary, they do not represent personal exposure in the working environment. Therefore it may be assumed that personal sampling would have revealed even higher numbers of UFP`s.

4.5 Chemical compounds

In the current study, formaldehyde was only detected in the sample from breast reduction in a concentration of 0.01 ppm. The other samples contained concentrations of both formaldehyde and acetaldehyde below the detection limit (< 0.01 ppm). All samples was below the Norwegian OEL which is 0.5 ppm with a threshold value of 1 ppm for indoor air for formaldehyde and 25 ppm for acetaldehyde (The Norwegian Labour Inspection Authority 2011). Formaldehyde is a colorless gas with an irritating odor even in low concentrations. Exposure to formaldehyde even in low concentrations can lead to headaches, nausea, irritation of the eyes, nose and throat (Liteplo 2002; King 2006). Acetaldehyde is an irritant of the mucosa membranes and the eyes. Previous studies have found formaldehyde and acetaldehyde present in ambient air when doing measurements before and during surgery in the operating room, and within the breathing zone of the surgical staff. The concentration for both formaldehyde (0.002-0.004 ppm) and acetaldehyde (0.001-0.002) was bellow the OEL`s at and their occurrence could not relate to surgical smoke (Hollmann, Hort et al. 2004; King 2006). Formaldehyde was identified in one study by Weston et al. (2009), but in concentrations (5.8 ppb) well below the OEL (0.5 ppm) while continuously measuring 15 cm above the resectoscope (Weston, Stephenson et al. 2009; The Norwegian Labour Inspection Authority 2011). Although both formaldehyde and acetaldehyde are only found in low concentrations in previous studies, one should be aware of their occurrence since both are classified as carcinogenic (The Norwegian Labour Inspection Authority 2011).

Personal sampling during TURP identified three different VOC. The total amount of VOC in the sample was 746 µg/ m^3. The OEL for both 1-propanol and 2-propanol was 245 000 $µg/m^3$, thus none of them exceeded the Norwegian OEL. 1-propanol is used as a solvent, and can be absorbed through the skin and is listed as an skin irritant by the Norwegian Labour Inspection Authority and can be severely irritating to the eyes (The Norwegian Labour Inspection Authority 2011). Acute symptoms by inhalation may lead to ataxia, nausea, drowsiness, dizziness and headache and confusion (NIOSH 1999). 2-propanol is not listed as a skin irritant by The Norwegian Labour Inspection Authority, but is also used as a solvent (The Norwegian Labour Inspection Authority 2011). Two previous studies have investigated the chemical composition of surgical smoke collected during TURP. One of the studies collected the smoke 15 cm, above the resectoscope (Weston, Stephenson et al. 2009) and the other one performed sampling in a chamber under regulated conditions (Chung, Lee et al. 2010).

Carcinogens such as 1-3 butadiene, vinyl acetylene and acrylonitrile were identified in both studies. Even though the smoke was sampled close to the emission or in concentrated form, the results showed concentrations below the OEL (Weston, Stephenson et al. 2009; Chung, Lee et al. 2010).

In the nephrectomy a total of 588 µg/m^3 TVOC was detected and two compounds were identified. TXIB is mainly used as a plasticizer, and may appear in many different consumer goods such as polyvinyl flooring (PVC), water based paint and wallpaper. It may contribute to odor at ppm concentrations, but does not propose as a sensory irritant (Cain, de Wijk et al. 2005). The other compound that was identified and quantified was Di-tert-butylbenzen which was an aromatic hydrocarbon. The identified volatile compounds in the sample only made up 9 % of the TVOC. The quantitative mass of the three unidentified VOC in the nephrectomy sample was 26, 39 and 29 µm/m^3 and made up 16 % of the TVOC. This means that 75 % of the total volatile compounds was unidentified, and not in the detectable range for the analyzing method.

Personal sampling performed during breast reduction only identified and quantified 2-chloroethanol, with an amount of 98 µm/m^3. This made up 36 %, of the TVOC (272 µg /m^3) in the sample. The identified compound and TVOC was below the Norwegian OEL`s, which is 3000 µg/ m^3 and 400 µg /m^3, respectively. 2-chloroethanol is formed during sterilization of supplies such as surgical instruments with ethylene oxides, and may be the reason for its occurrence in the operating room (Shore, Gardner et al. 1993). Acute symptoms are cough, dizziness, headache, nausea and sore throat (NIOSH 2003). Earlier studies have found surgical smoke from breast reduction to be carcinogenic in the Ames test (Gatti, Bryant et al. 1992). Samples of VOC from bilateral breast reductions found high concentrations of 1-decene (190 ppm, no OEL) and significant levels of 1,3 butadiene (1.5 ppm (OEL 5.0 ppm)) which are both considered carcinogenic, but did not exceed the OEL. The furfural (2-furancarboxaldehyde) levels at 24 ppm and toluene at 17 ppm that was found exceeded the OEL. However, the sampling was performed at the tip of the ES pencil and only when ES was used. Therefore it would be a poor measure for personal exposure (Hollmann, Hort et al. 2004). Another previous study was investigating the presence of toluene, styrene, xylene, phenol and furfural in surgical smoke collected during five breast reductions, where surgical smoke was trapped in an acrylic chamber, but only low concentrations of toluene (1.45 ppm) was found (Lin, Fan et al. 2010).

TVOC obtained from the nephrectomy and the TURP exceeded the Norwegian recommendations for TVOC in indoor air (Folkehelsa 1996). The limit is defined to control the levels of VOC indoors. It is normal for these limits to be exceeded in new houses and newly painted houses, but the concentrations will naturally decrease over time as a house outgasses. In the current study background levels was not investigated and only one random sample was executed for each selected surgery. It is therefore difficult to say if the identified TVOC was directly related to the exposure to surgical smoke, or if it stems from outgassing from the operating rooms, since they are quite recently built; or if the compounds identified could be constituents or by products related to sterilization of equipment and/or persons in the OR.

Exposure to polycyclic aromatic hydrocarbons (PAH) was not examined in the current study. However, a recent published study identified and quantified personal exposure to 16 different types of PAH in surgical smoke during 40 peritonectomy procedures (Naslund Andreasson, Mahteme et al. 2012). This type of surgery is known to produce large amounts of smoke and UFP´s and it is thought that PAH absorb to the UFP`s (Andreasson, Anundi et al. 2009). All 16 types of PAH were identified in the personal samples and higher levels of the most carcinogenic substances was found in single procedures indicating that higher cumulative amounts were being inhaled by the surgical staff (Naslund Andreasson, Mahteme et al. 2012). PAH has also been identified in cooking fumes, but in concentrations 10-1000 times higher than those found in surgical smoke in the study from Naslund Andreasson, Mahteme et al. (2012). For example the concentration of Benzo(a)Pyrene (B(a)P) a carcinogen, in cooking fumes was 0.14 µg /m^3 compared to 0.00016 µg/m^3 in surgical smoke and the naphthalene concentration was 0.27 in cooking fumes compared to 0.063 µg/ m^3 in surgical smoke (Sjaastad, Jorgensen et al. 2010; Naslund Andreasson, Mahteme et al. 2012). Both studies showed B(a)P and naphthalene to be under the OEL (0.04 mg/m^3 and 50 mg/m ^{3}) (The Norwegian Labour Inspection Authority 2011).

4.6 Methodological considerations

Gravimetric methods involve the collection of particles on a filter, and the exposure is estimated by the mass of the particles, instead of the number of particles (STAMI 2011). These methods are the most commonly used for occupational exposure assessment of airborne particles, and OEL`s are based on these. Smaller particles, however, have a low mass compared to their actual number, thus gravimetric methods are not well suited for estimation of exposure. However, Andrèasson et al. (2009) did investigate the mass exposure of particles, during 14 peritonectomy procedures by using a Dust-Trak Model 8520 and a cyclone with a 4 µm cut off, for stationary sampling (Andreasson, Anundi et al. 2009). They showed that the AM exposure was only between 0.002 and 0.009 mg/m^3 and thus far below the Norwegian OEL for respirable dust (5 mg/m^3). Although the samples did not represent personal exposure, they gave an indication of low mass exposure in the operating room.

Particle number concentrations and size distribution can be estimated with different types of instruments, but few instruments are available for combining the measurements of both, in terms of the ultrafine and fine fraction. The instruments available are of large size, such as the FMPS, and therefore not well suited for personal exposure measurements for all kinds of working environments. For the current thesis, measurements were performed on the job groups that was more or less static during the surgery and only on one person at the time, giving only results from one job group at a time. For better results on how the particles generated from ES distributes between job groups during a surgical procedure, measurements should have been performed on all job groups simultaneously. In the current study, the amount of measurements executed, is below the amount recommended in the Norwegian Inspector Authority guidelines for surveys (The Norwegian Labour Inspection Authority 2008). Therefore, for a better comparative foundation between the work groups, there should have been five measurements carried out in each work group, and in addition, at least two of these on the same person. By following these guidelines, it would have been easier to identify factors that could have influenced the exposure. However, the current study included a higher number of measurements than other previous studies, and it also included personal exposures for different job groups. In addition, it was the first study to characterize particle number distributions in the ultrafine fraction in surgical smoke.

To characterize the exposure to VOC and aldehydes, several samples had to be executed to see if the exposure was connected with the working process of the surgeon. Thousands of chemical compounds may be present in a room, and they are not distributed equally at a given time, thus the random samples for the current thesis will not explain the exposure.

5. Conclusions

The exposure to surgical smoke varies between types of surgeries, and type of surgery was found to be a determinant of exposure. The use of ES resulted in short term high peaks with exposure of mainly ultrafine particles, and the job groups closest to the emissions was usually the highest exposed. Compared to other working environments, the exposure to ultrafine particles was low. The concentrations of VOC`s and aldehydes was below the Norwegian OEL.

6. Future perspectives

Carcinogenic compounds have been identified in surgical smoke. For the best interest of the surgical staff, one should continue to keep the exposure levels as low as possible when using ES. Systematic monitoring of exposure is recommended, due to the development in surgical techniques and the use of ES.

To my knowledge, only one previous study has investigated the risk of lung cancer among registered operating room nurses (Gates, Feskanich et al. 2007). The risk of lung cancer was not associated with a history of operating room employment. However, further epidemiological research is demanded to define such relationship.

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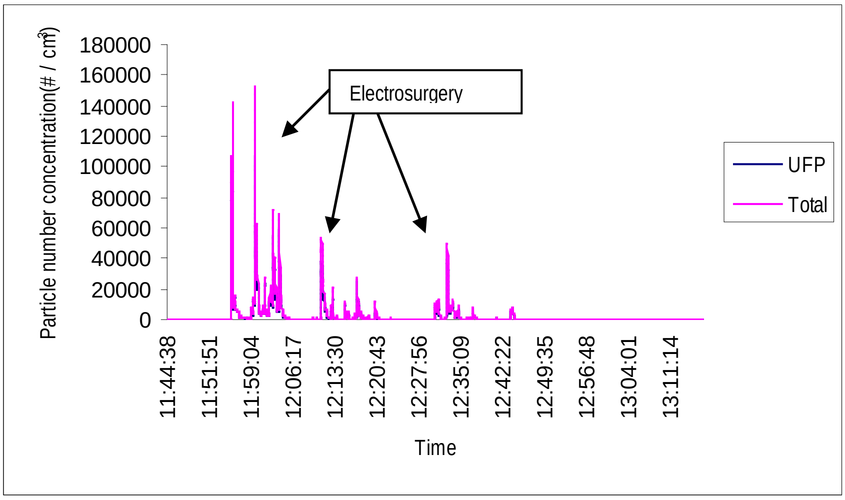
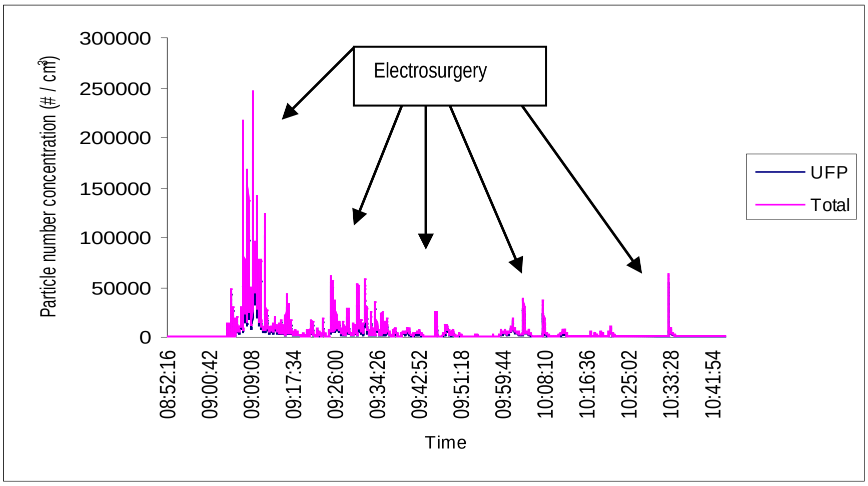
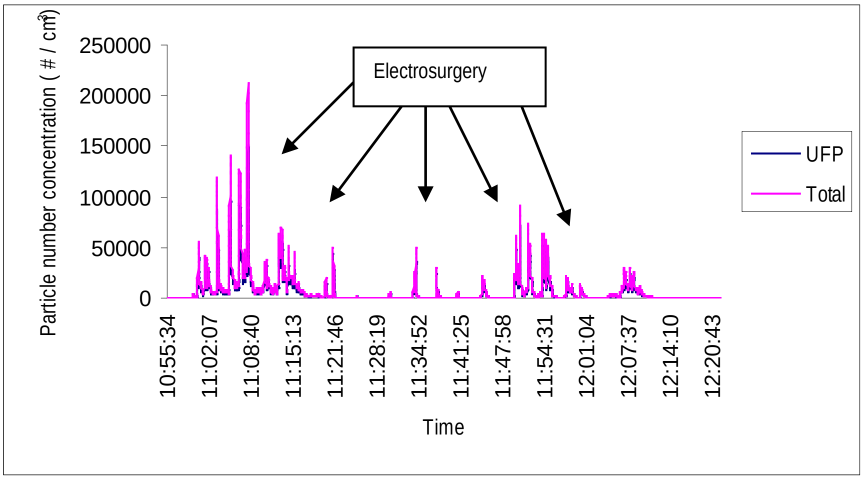
Appendix I Abdominoplasty



Graph AI-1. The graph shows measurement number one on the main surgeon .

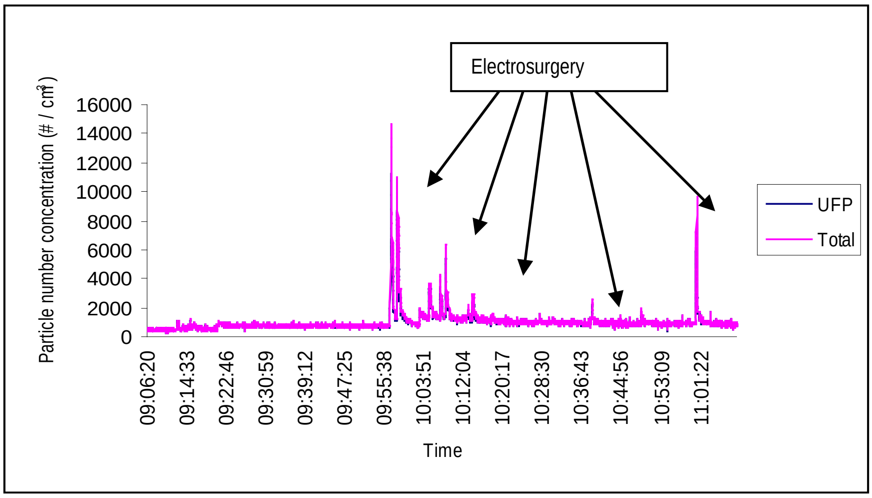


Graph AI-2. The graph shows measurement number two on the main surgeon.

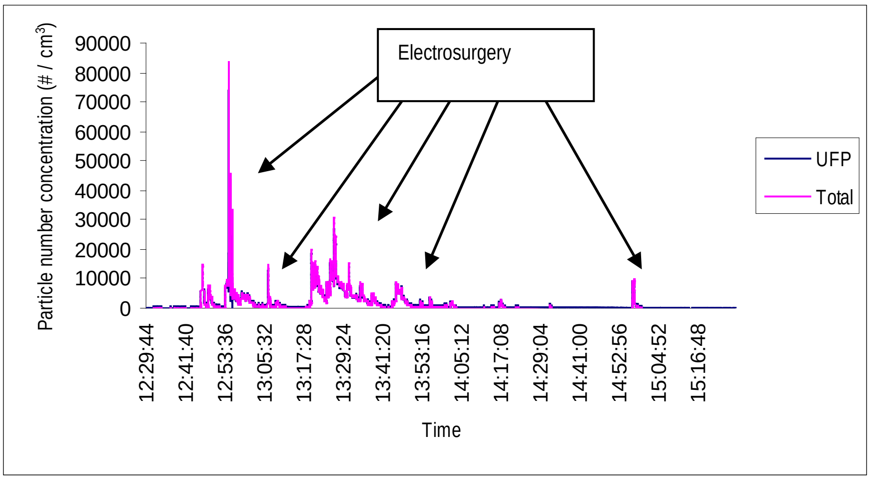


Graph AI -3. The graph shows measurement number three on the main surgeon.

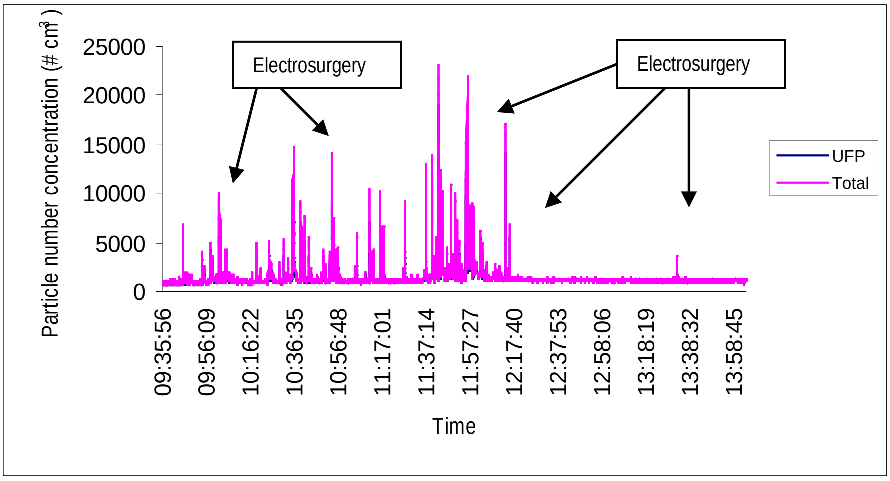
Appendix II Nephrectomy



Graph AII-1: The graph shows measurement number one on the main surgeon.



Graph AII-2. The graph shows measurement number two on the main surgeon.



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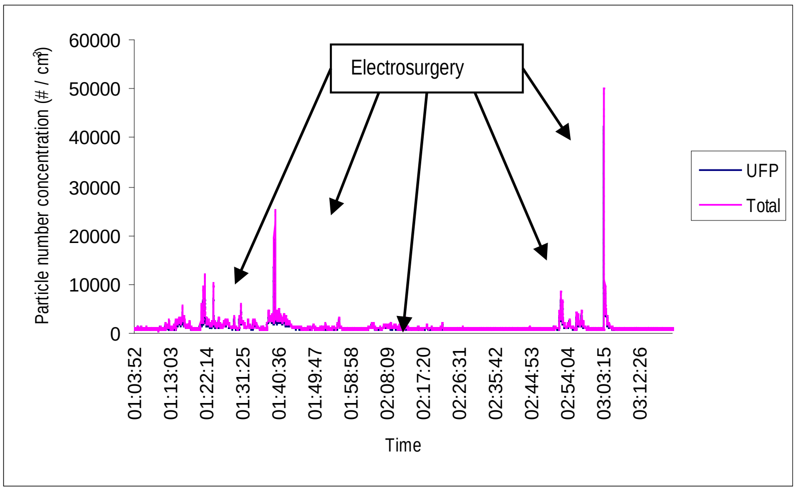
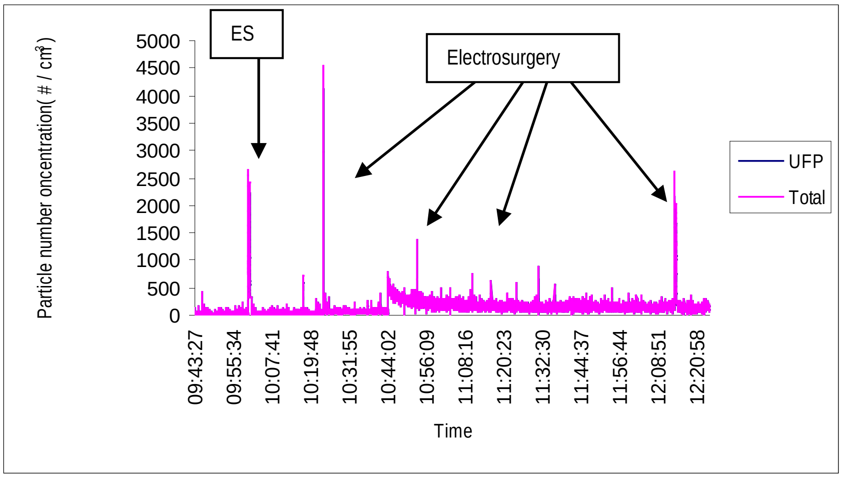
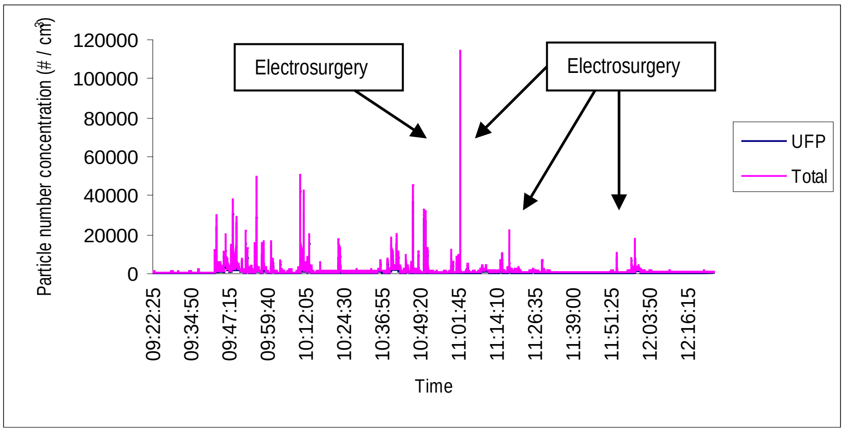


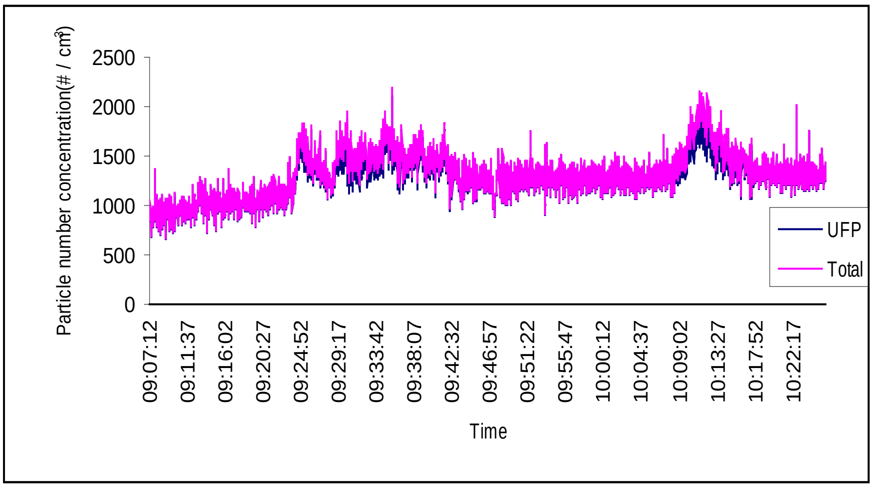
Graph AII-4. The graph shows measurement number one on the assistant surgeon.



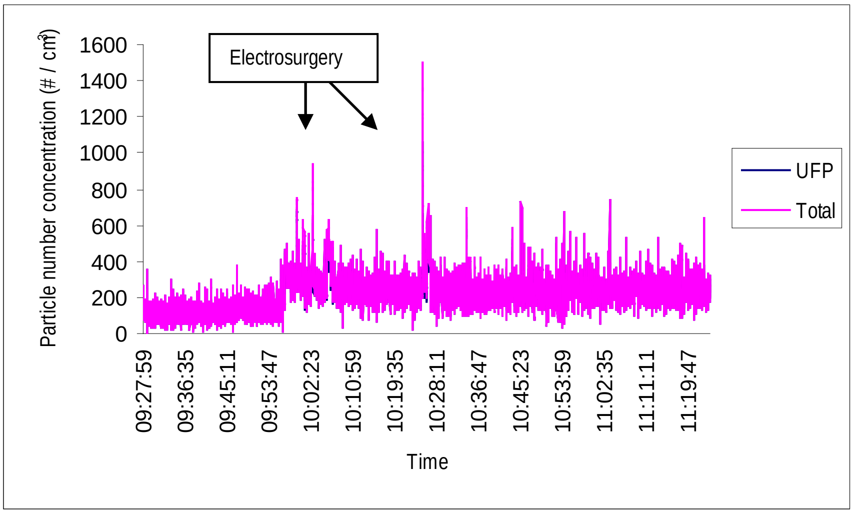
Graph AII-5. The graph shows measurement number two on the assistant surgeon.



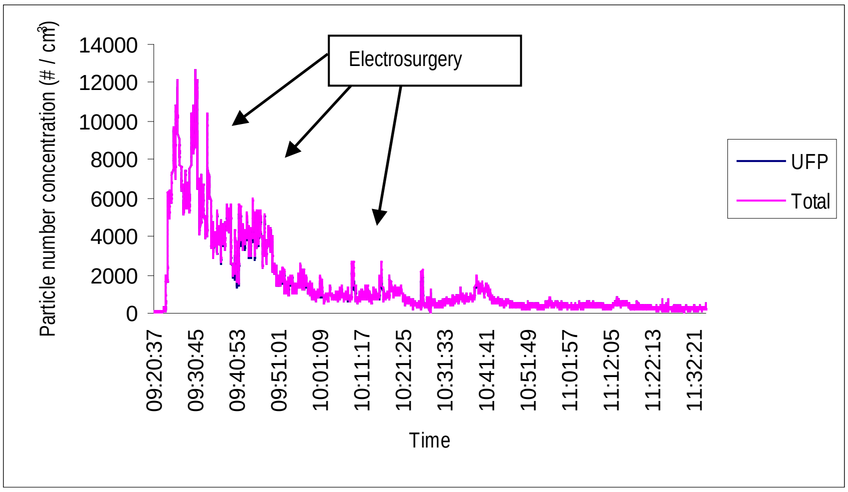
Graph AII-6. The graph shows measurement number three on the assistant surgeon



Graph AII-7. The graph shows measurement number one on the anesthetic nurse.

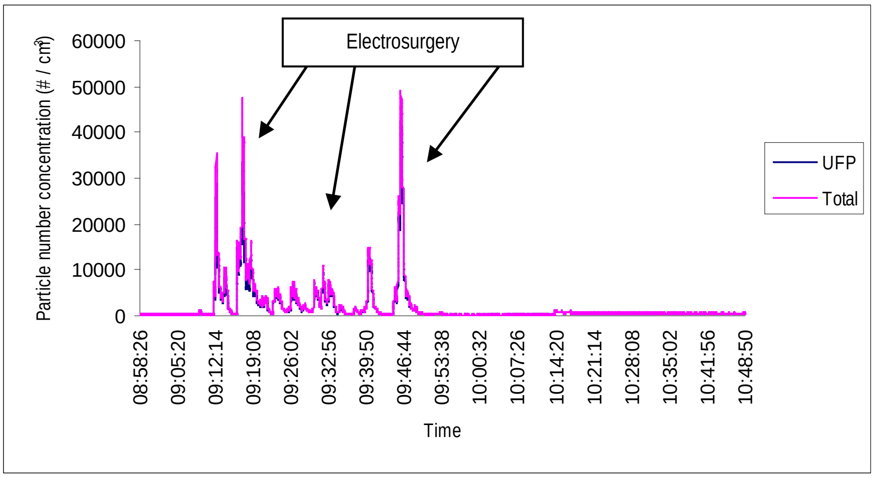


Graph AII-8. The graph shows measurement number two on the anesthetic nurse.

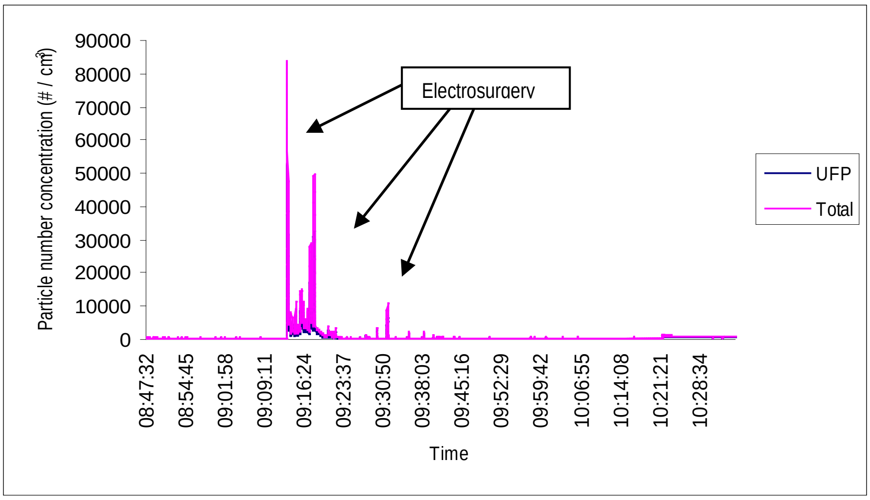


Graph AII-9. The graph shows measurement number three on the anesthetic nurse in OR number two.

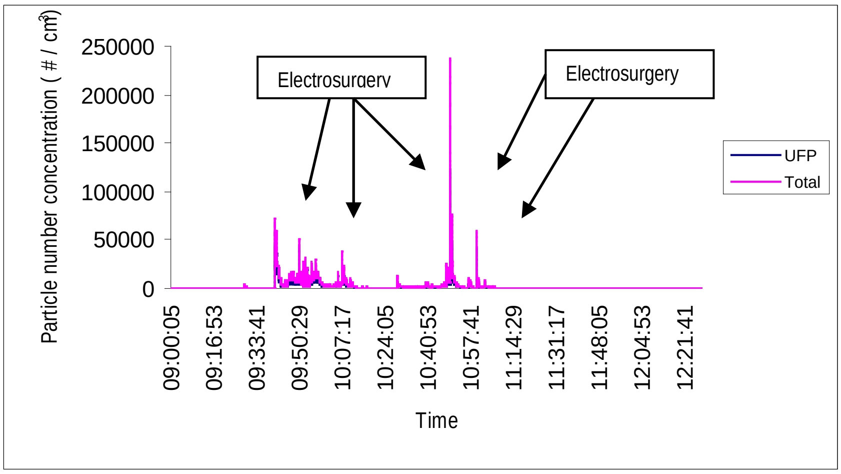
Appendix III Breast reduction



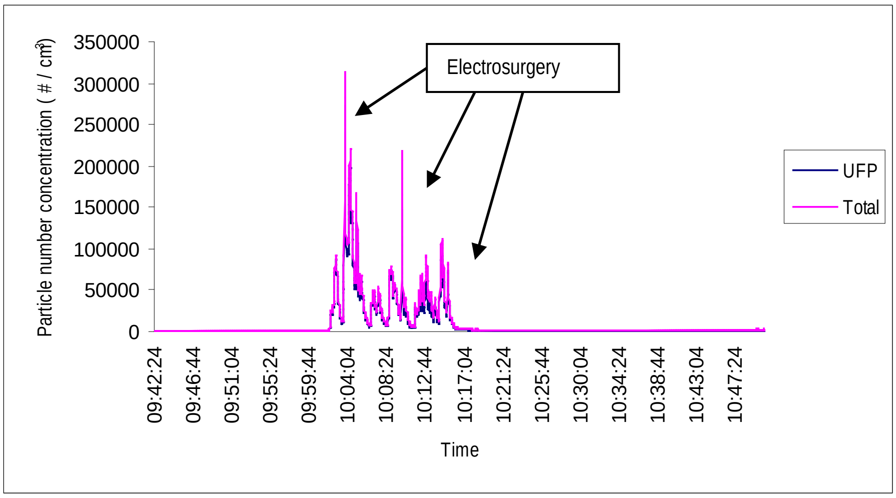
Graph AIII-1.The graph shows measurement number one on the main surgeon during reduction of two breasts.



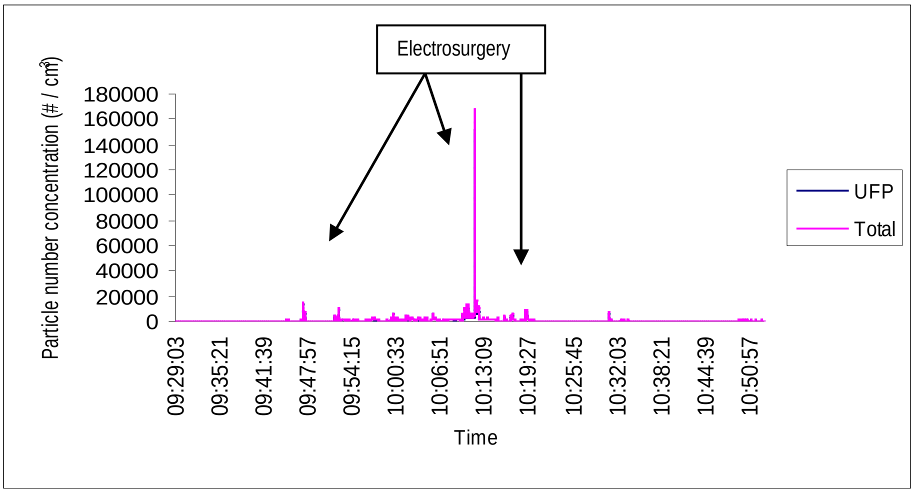
Graph AIII-2. The graph shows measurement number two on the main surgeon during reduction of two breasts.



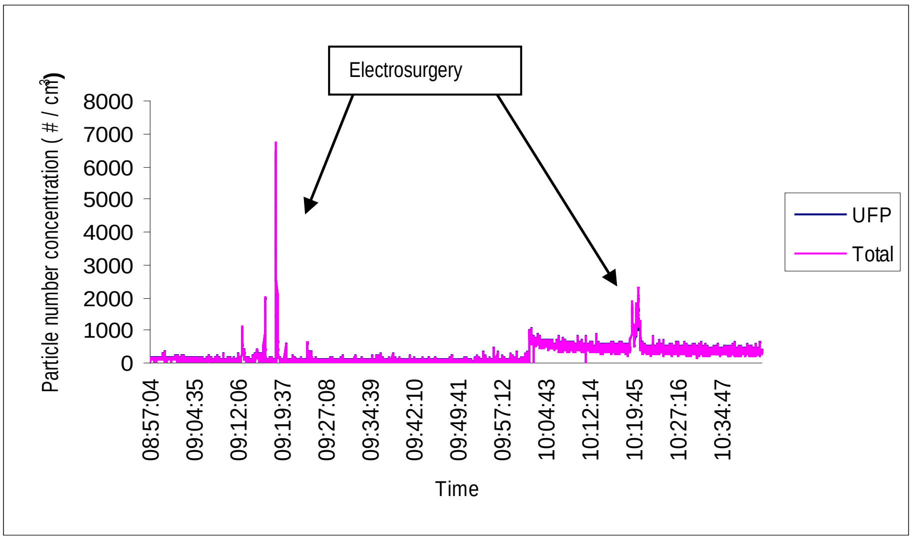
Graph AIII-3. The graph shows measurement number three on the main surgeon during reduction of two breasts.



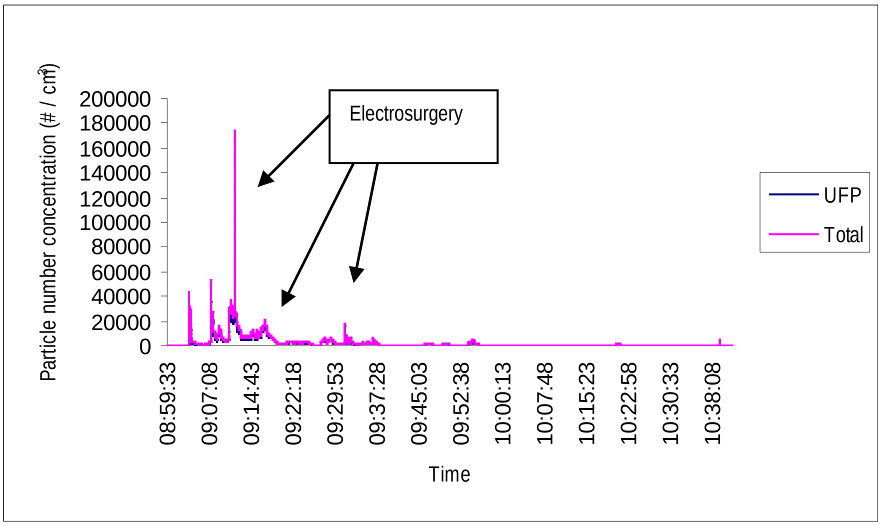
Graph AIII-4. The graph shows measurement number one on the assistant surgeon during reduction of two breasts.



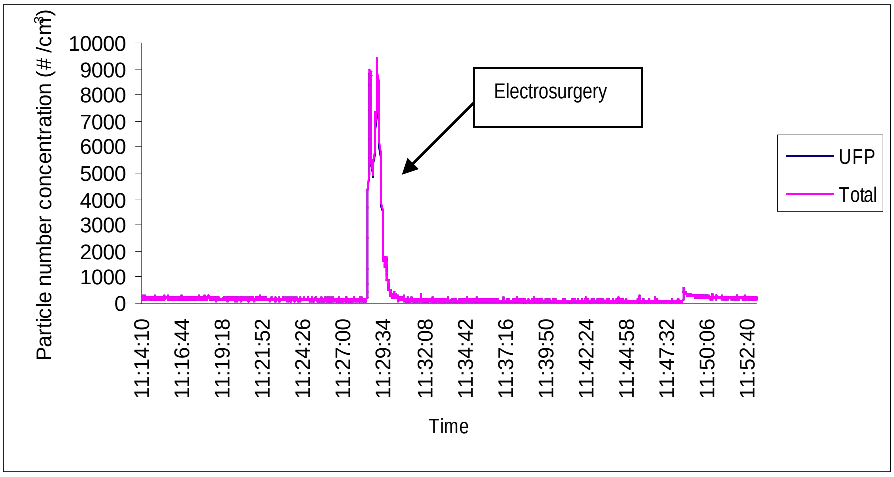
Graph AIII-5. The graph shows measurement number two on the assistant surgeon during reduction of two breasts.



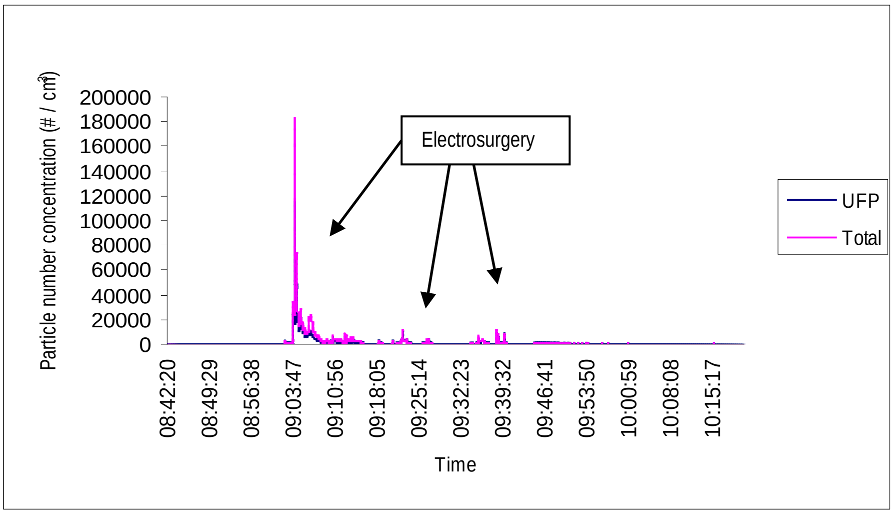
Graph AIII-6. The graph shows measurement number three on the assistant surgeon during reduction of one breast



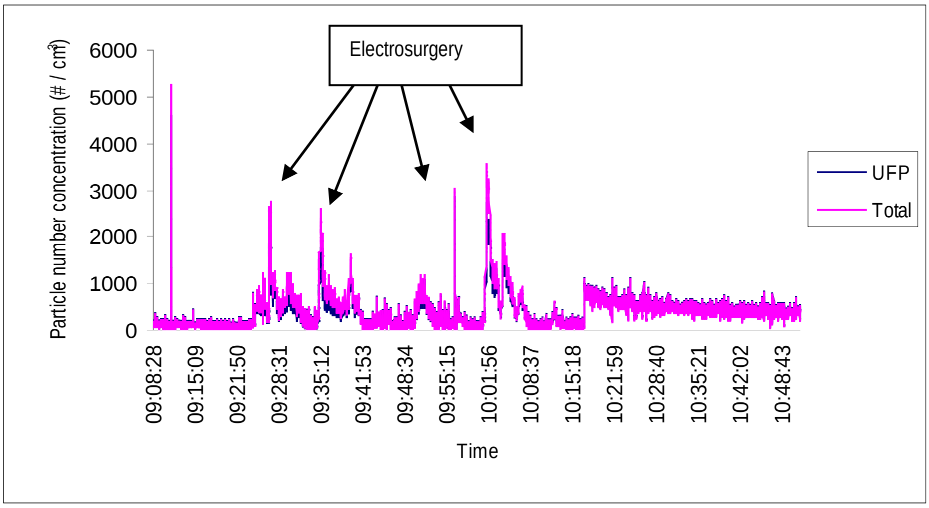
Graph AIII-7. The graph shows measurement number one on the surgical nurse during the reduction of two breasts.



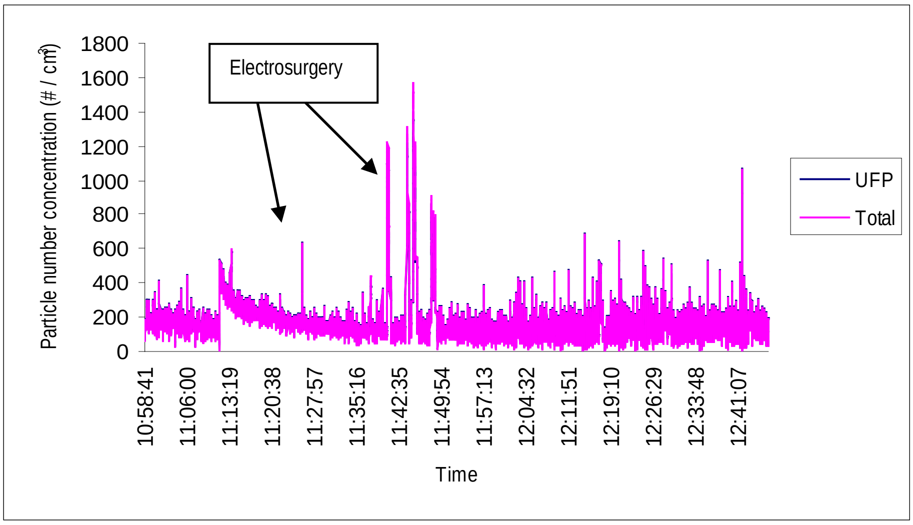
Graph AIII-8. The graph shows measurement number two on the surgical nurse during the reduction of one breast.



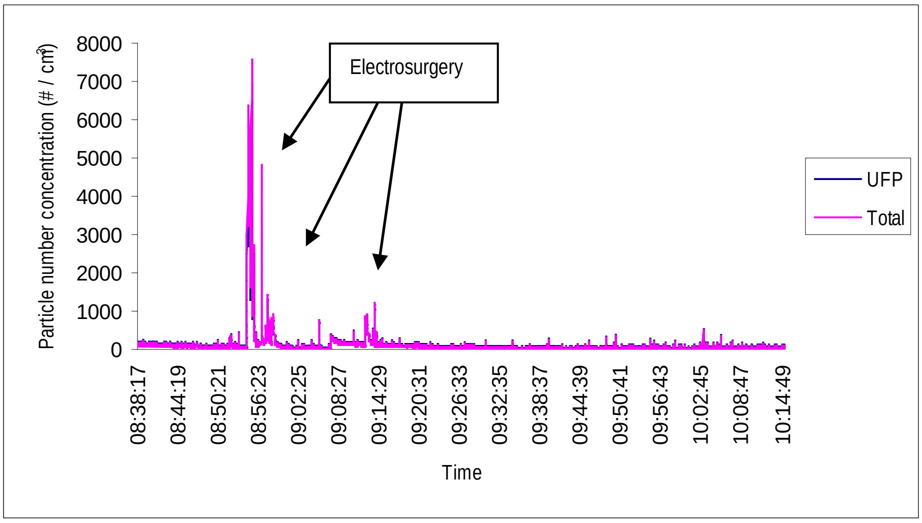
Graph AIII-9. The graph shows measurement three on the surgical nurse during the reduction of two breasts.



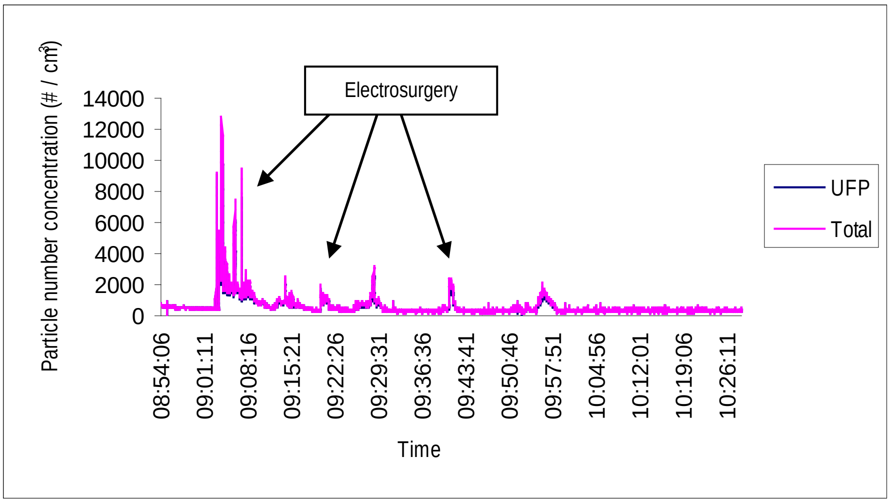
Graph AIII-10. The graph shows measurement number one on the anesthetic nurse during the reduction of two breasts.



Graph AIII-11. The graph shows the measurement number two on the anesthetic nurse during the reduction of one breast.

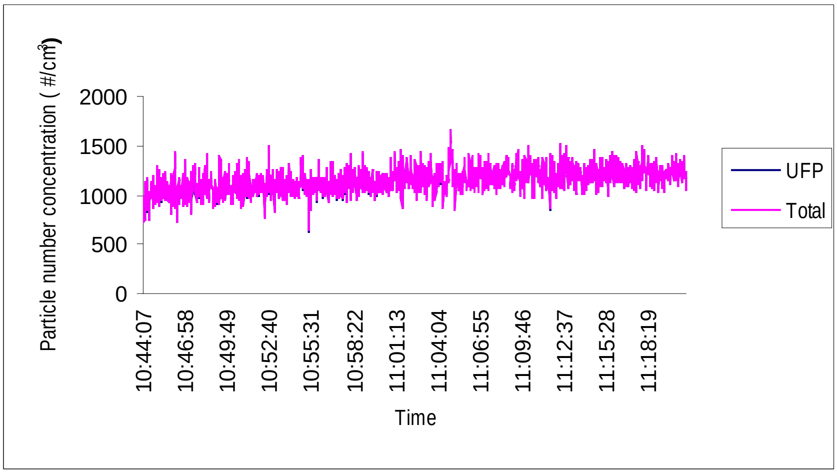


Graph AIII-12. The graph shows measurement number three on the anesthetic nurse during reduction of one breast.

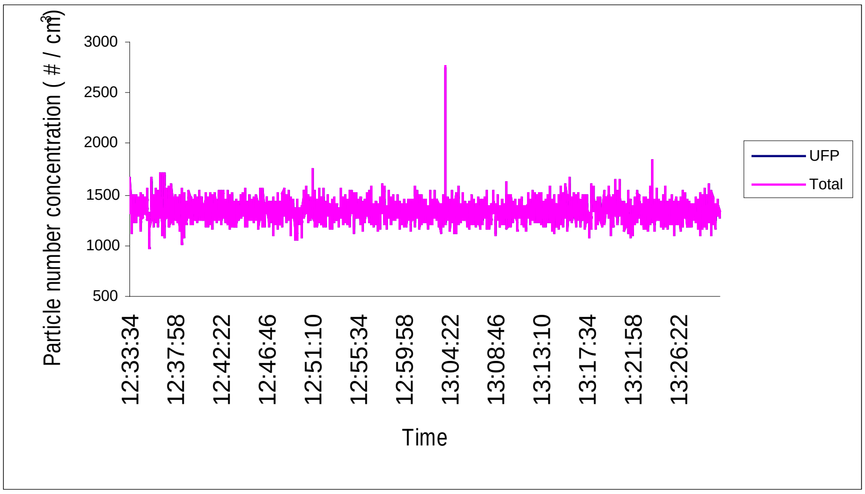


Graph AIII-13. The graph shows measurement number four on the anesthetic nurse during reduction of two breasts.

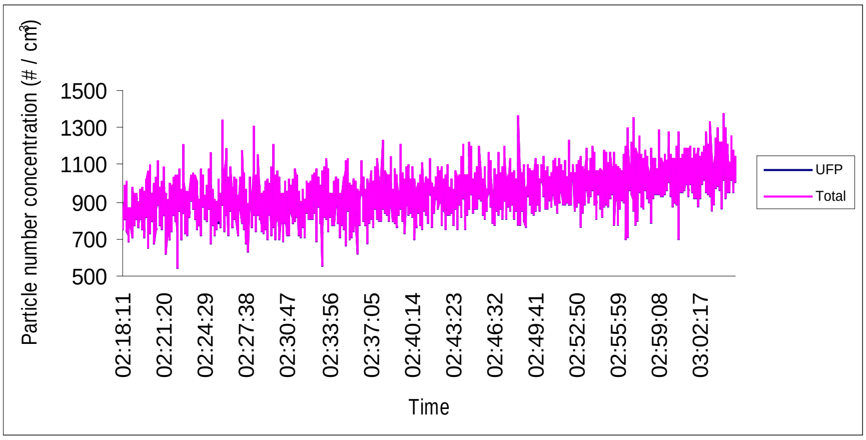
Appendix IV TURP



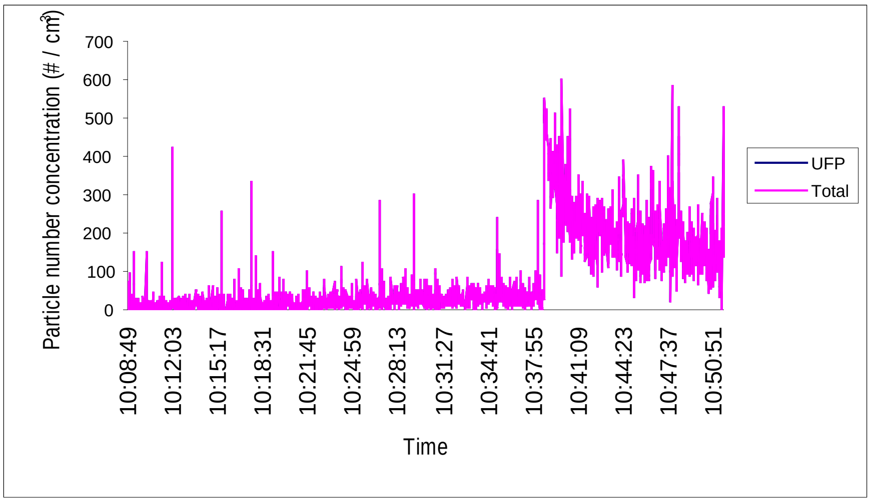
Graph AIV-1. The graph shows measurement number one on the main surgeon.



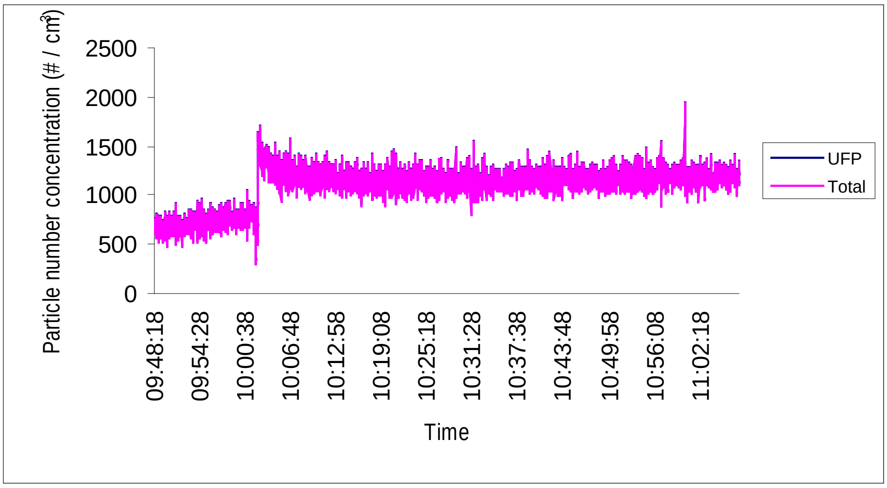
Graph AIV-2. The graph shows measurement number two on the main surgeon.



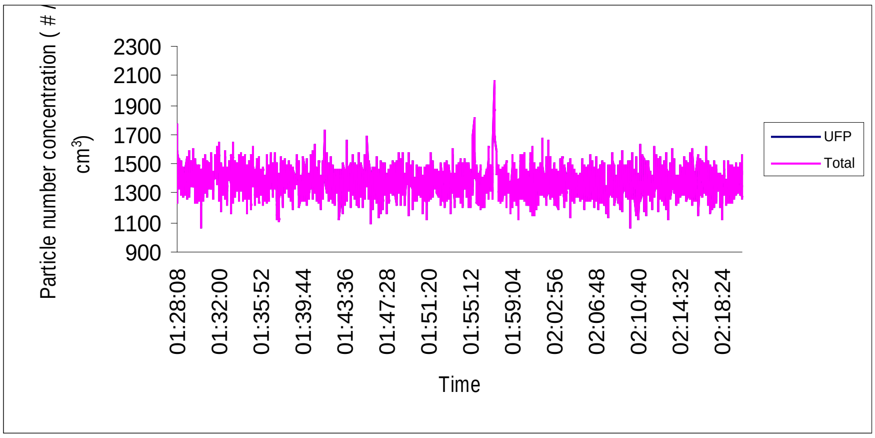
Graph AIV-3. The graph shows measurement number three on the main surgeon.



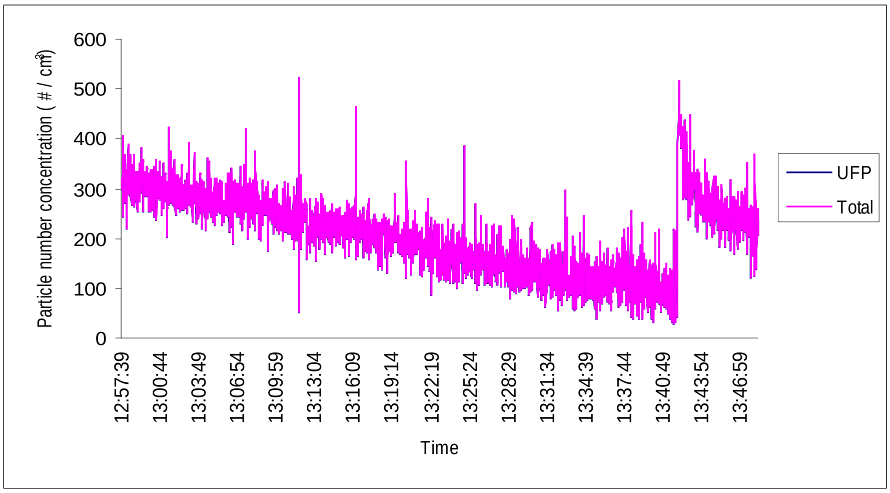
Graph AIV-4. The graph shows measurement number four on the main surgeon.



Graph AIV-5. The graph shows measurement number one on the anesthetic nurse.

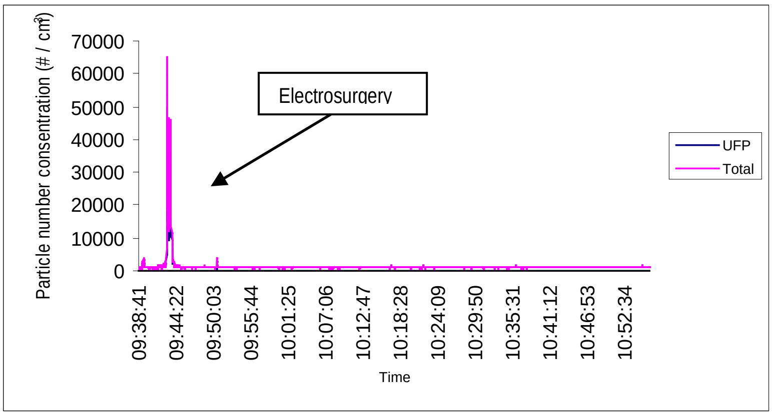


Graph AIV-6. The graph shows measurement number two on the anesthetic nurse.

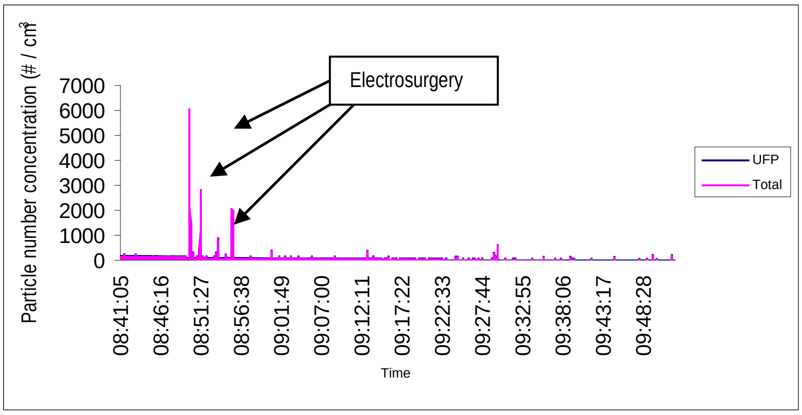


Graph AIV-7. The graph shows measurement number three on the anesthetic nurse.

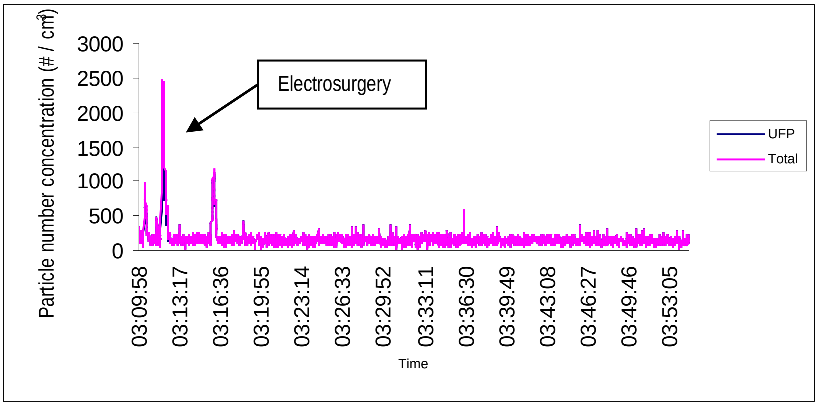
Appendix V Hip replacement surgery



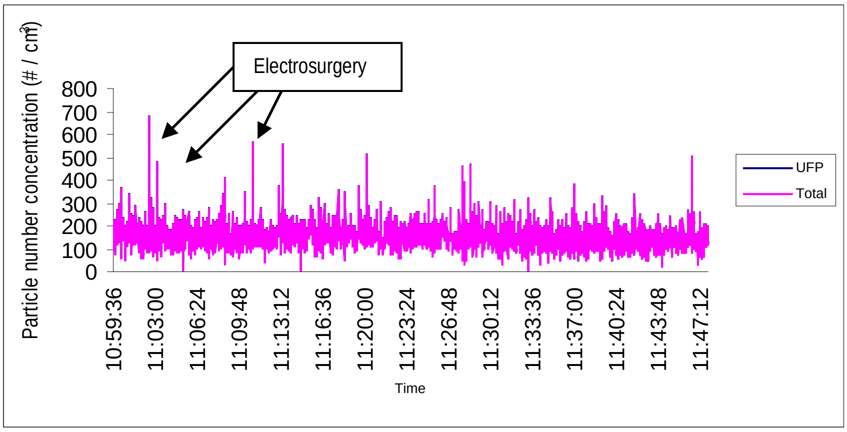
Graph AV-1. The graph shows measurement number one on the main surgeon in OR seven.



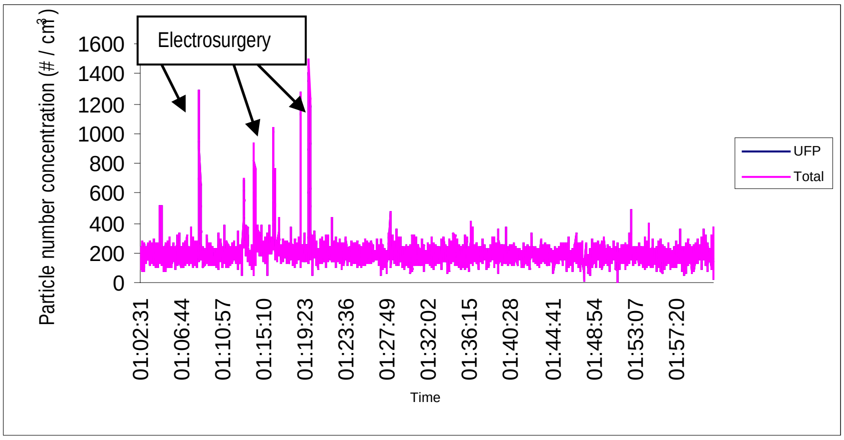
Graph AV-2. The graph shows measurement number two on the main surgeon in OR seven.



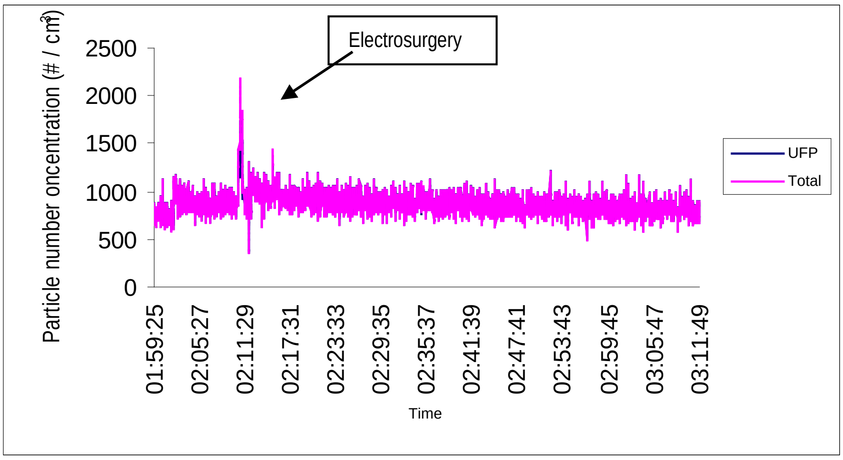
Graph AV-3. The graph shows measurement number three on the main surgeon in OR seven.



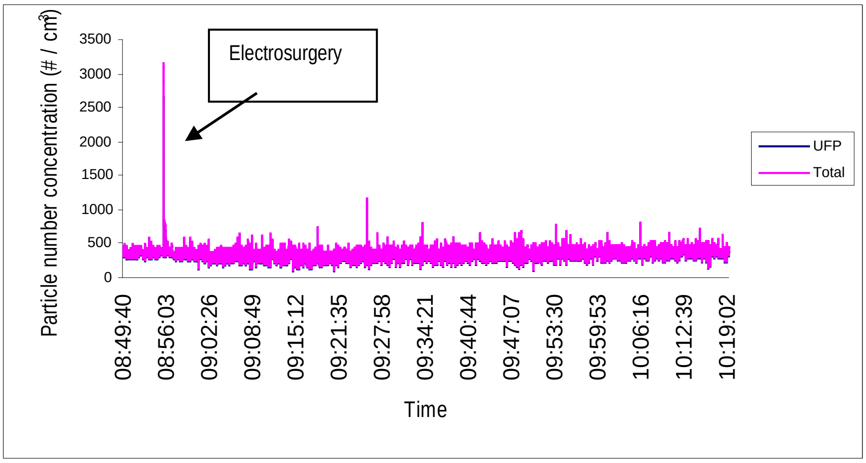
Graph AV-4. The graph shows measurement number one on the assistant surgeon in OR number seven.



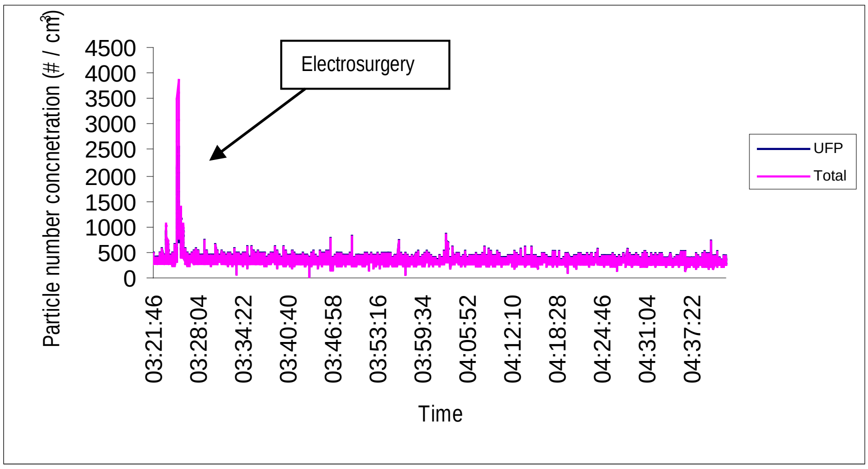
Graph AV-5. The graph shows measurement number two on the assistant surgeon in OR number seven.



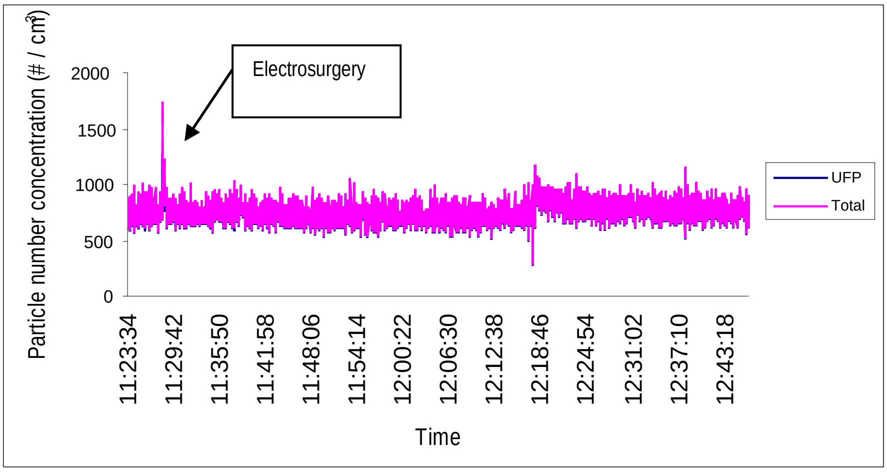
Graph AV-6. The graph shows measurement number three on the assistant surgeon in OR number seven



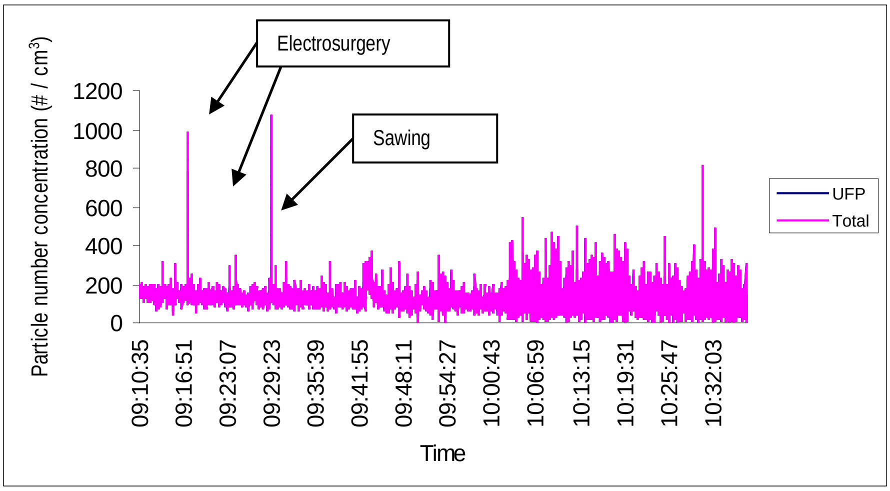
Graph AV-7. The graph shows measurement number one on the anesthetic nurse in OR number seven.



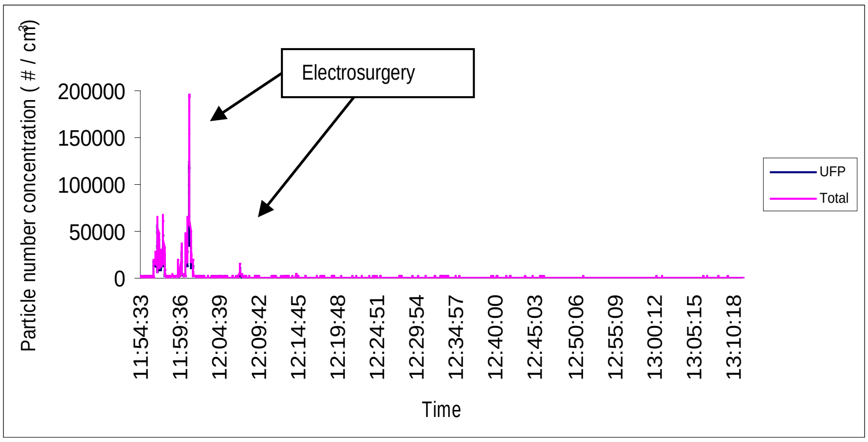
Graph AV-8. The graph shows measurement number two on the anesthetic nurse in OR seven.



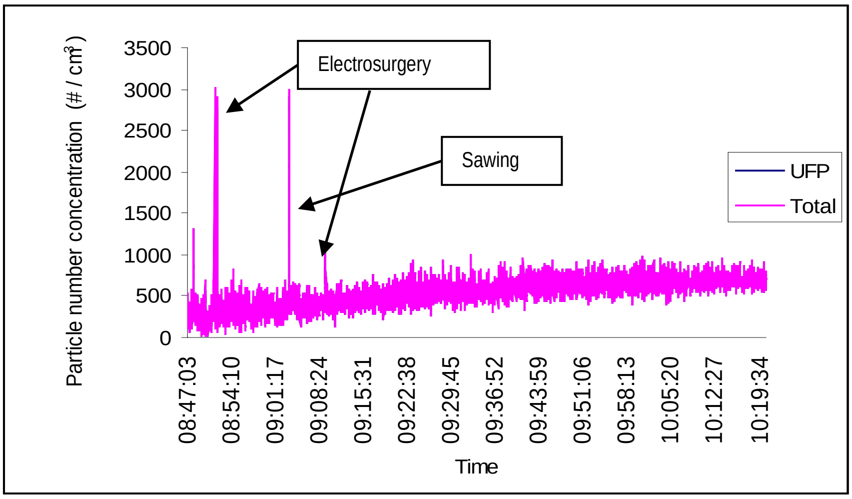
Graph AV-9. The graph shows measurement number three on the anesthetic nurse in OR seven.



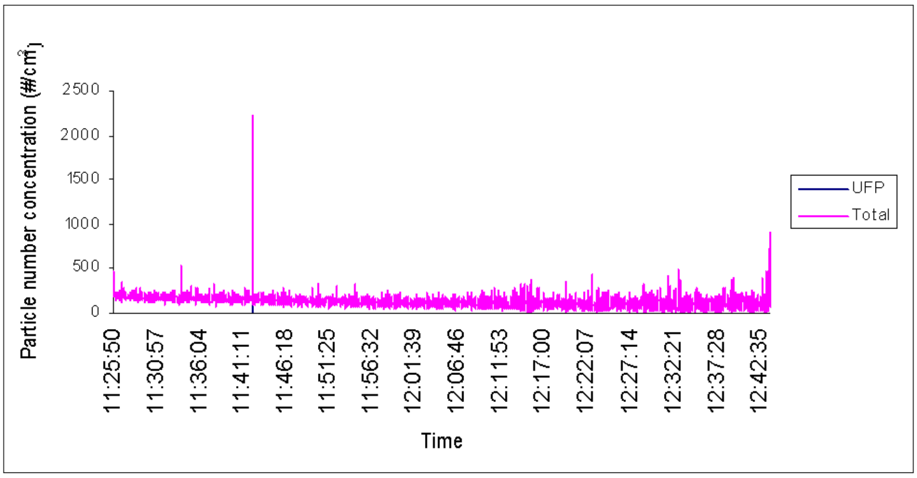
Graph AV-10. The graph shows measurement number one on the main surgeon in OR number eight.



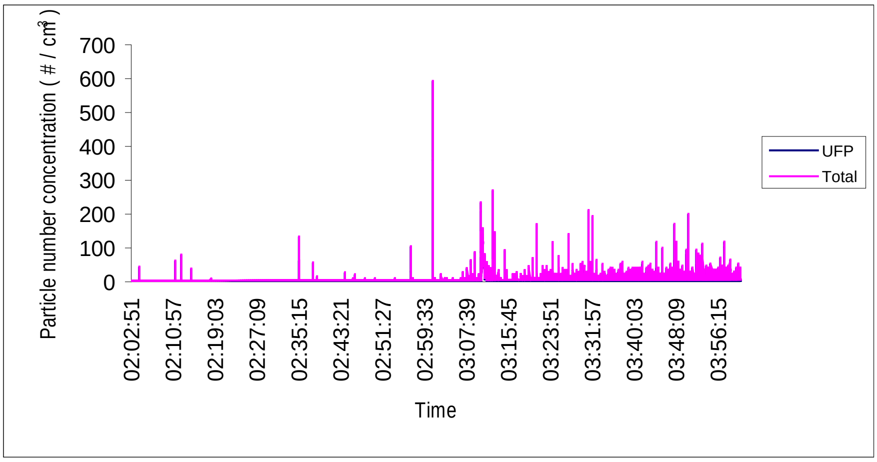
Graph AV-11. The graph shows measurement number two on the main surgeon in OR number eight.



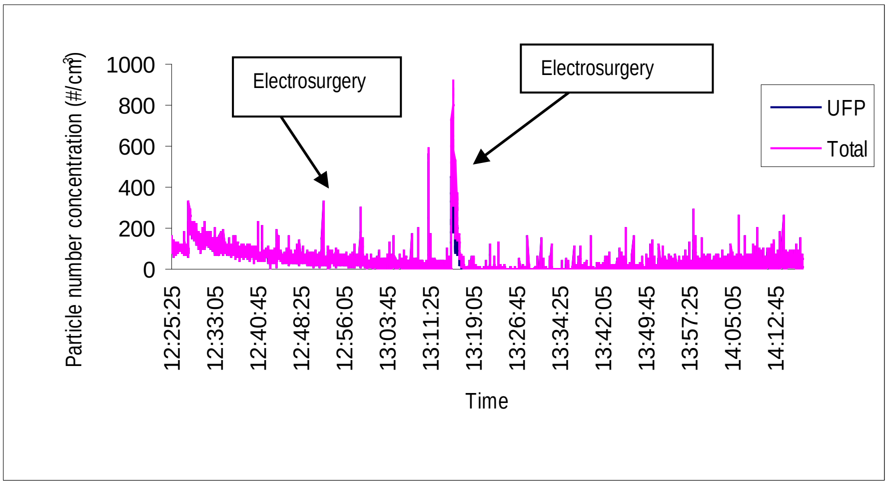
Graph AV-12. The graph shows measurement number one on the assistant surgeon in OR number eight.



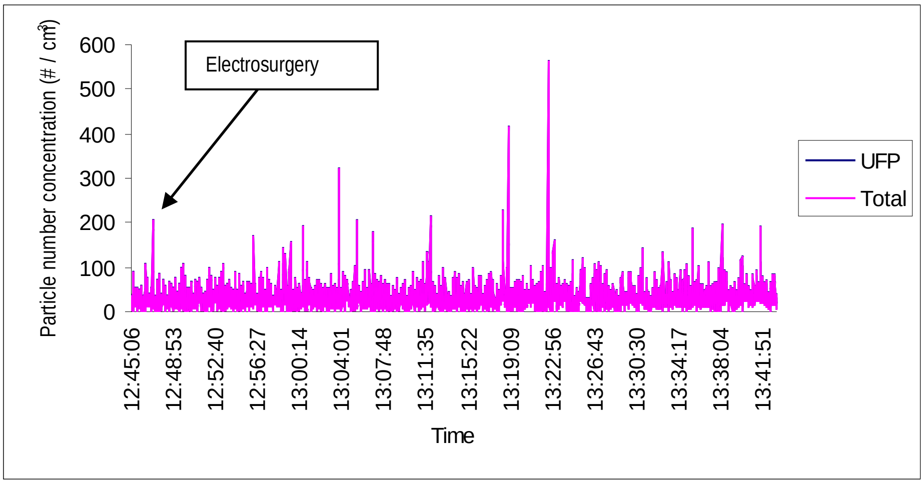
Graph AV-13. The graph shows measurement number one on the main surgeon in OR number one. It was difficult to relate the peaks to the use of ES.



Graph AV-14. The graph shows measurement number two on the main surgeon in OR number one. It was difficult to relate the peaks to the use of ES.



Graph AV-15. The graph shows measurement number one on the anesthetic nurse in OR number one.



Graph AV-16. The graph shows measurement number two on the anesthetic nurse in OR number one.

Appendix VI Registration form I

ST. OLAVS HOSPITAL UNIVERSITETSSYKEHUSET I TRONDHEIM	NTNU 100 skapende år	EKSPONERING FOR DIATERMIRØYK HOS OPERASJONSPERSONELL VED ST. OLAVS HOSPITAL
Navn:	**Yrkestittel:**	**Løpenr:**
Avdeling og sted:	**Operasjonsstue:**	**Dato:**
Type operasjon:	**Antall operasjoner tidligere på dagen:** **Med diatermi:** **Uten diatermi:**	
Type diatermi instrument: **Avsug:**	**Antall personer tilstede, spesifiser rolle:**	
Varmeteppe på/av:	**Ventilasjon (Laftak):**	

Bakgrunnsmåling FMPS

Før	**Plassering**	**Start kl**	**Stopp kl**	**Kommentar**
Etter	**Plassering**	**Start kl**	**Stopp kl**	**Kommentar**

FMPS

Zero	**Fortynning**	**Start kl**	**Stopp kl**	**Filnavn**

Merknader

Spørsmål til personen etter operasjonen:
Har inngrepet foreløpt som forventet? **Merknad:**
Har bruken av diatermi vært som normalt i forhold til inngrepet: **Merknad:**
Hvordan har eksponeringen for diatermirøyk vært? **Mindre enn normalt** **Som normalt** **Mer enn normalt**

Appendix VII Registration form II

EKSPONERING FOR DIATERMIRØYK

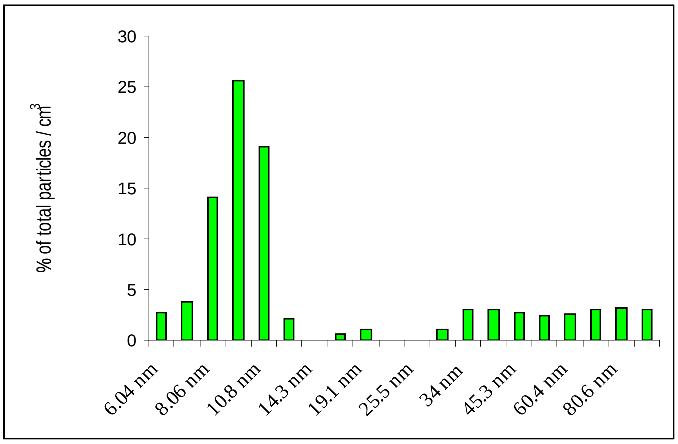
HOS OPERASJONSPERSONELL VED

ST. OLAVS HOSPITAL

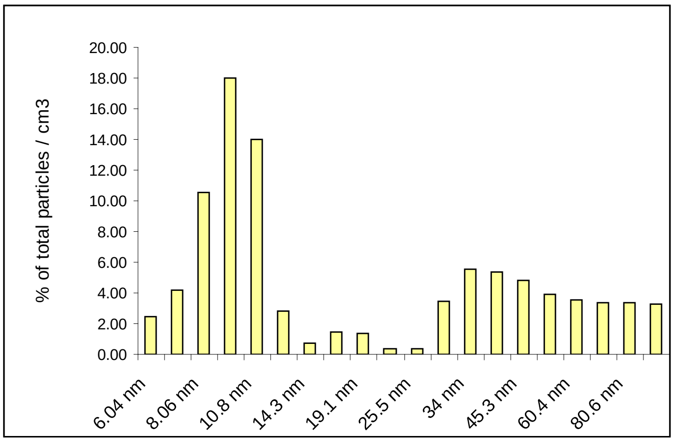
Dato:	Navn:	Yrkestittel:

Diatermipenn						Dør		Bevegelse	
Lang	Kort	Ligasure	Start	Stopp	Avsug Ja/nei	Automatisk	Merknad	Tråkk på slange	Fra seng

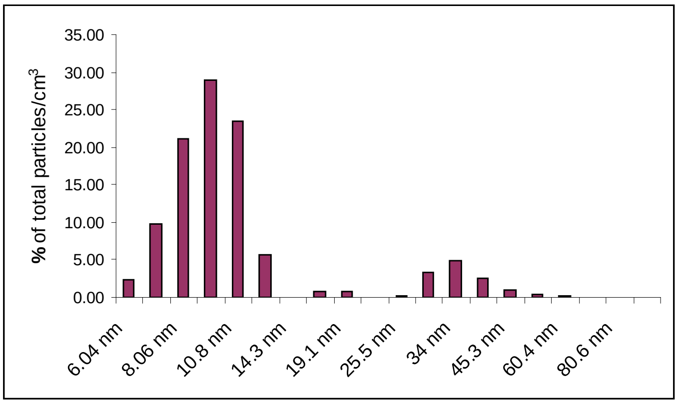
Appendix VIII Distribution of ultrafine particles



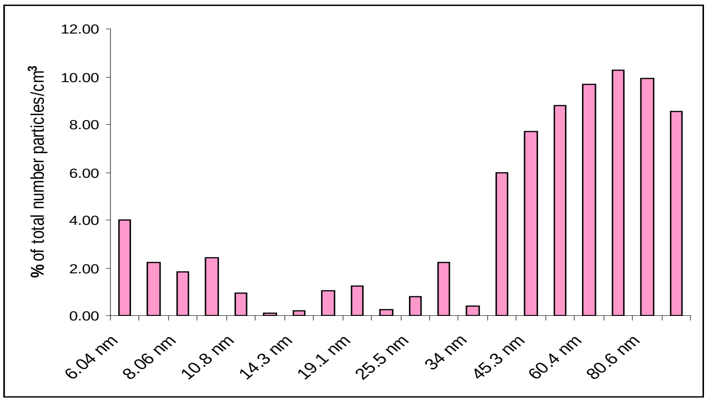
Graph AVIII-1. The distribution of particles < 100 nm from all hip replacement procedures.



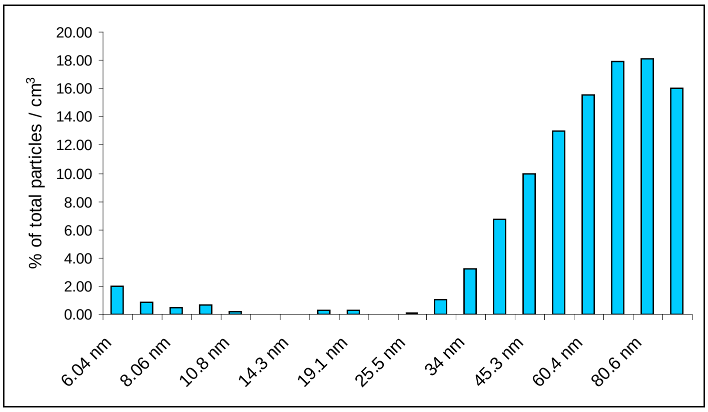
Graph AVIII-2. The distribution of particles < 100 nm from all nephrectomy procedures.



Graph AVIII-3. The distribution of particles < 100 nm from all TURP procedures.



Graph AVIII-4. The distribution of particles < 100 nm from all breast reduction procedures.



Graph AVIII-5. The distribution of particles < 100 nm from three abdominoplasty procedures.