Making things clear around Surgical smoke
Foreword

Following the introduction of laser surgery in the mid 1980s, education and training programs for physicians, nurses and technicians have been developed to address safety issues. Smoke evacuation was, and still is, a major component of these safety measures.

Electrosurgery is a much older technology, but the smoke generated during the procedures has never had the same attention as laser surgery, even though a large number of scientific publications have demonstrated the hazardous nature of the plumes.

This leaflet is based on several of these publications (see the publication list). Its purpose is to summarise and clarify the facts about surgical smoke and especially the plumes generated during electrosurgery:

• How does surgical smoke occur?
• What is it made of?
• What are its effects on personal health?
• How can it be controlled?

Smoke and aerosols are generated during surgical operations using energy-based instruments, such as electrosurgery, laser and ultrasonic devices. There is, however, no general agreement about the terms used to describe these gasses and particles. Terms such as “smoke”, “plumes” and “aerosols” are commonly used for different particles[1, 4, 9]. In this review, the most common definitions are used, and the term “smoke” is applied to the result of electrosurgery and laser surgery, while the term “aerosols” is used to designate the products of ultrasonic scalpels and other high speed electrical devices.
Sources of Surgical Smoke

Electrosurgery
During electro surgery, cutting is achieved by raising the cells’ temperature above the boiling point. As a consequence, the cell walls explode, and the vaporised fluid is dispersed into the air.
For coagulation effect, the current increases the tissue temperature more slowly. Carbonisation will take place eventually if the current is applied for a long time. Carbonised tissues will thereby also contribute to the debris released into the air.

Laser surgery
Laser surgery is a heat-releasing technology which results in the same type of surgical smoke as that obtained with electro surgery, with similar types of particles\(^9\).

Ultrasonic scalpels
Ultrasonic scalpels apply vibrations at a very high frequency for cutting and coagulating. The tissue is vaporised at lower temperatures than during electrosurgery, and aerosols are created.

Orthopaedic surgery
High speed electrical devices such as saws or drills mainly used in orthopaedic surgery get warm while in use and are cooled down by means of an irrigating fluid. The combination of fluid, instrument motion, warmth and disrupted tissue sends a mist of aerosols into the OR.
The Effects of Surgical Smoke

There are several ways by which surgical smoke affects patients and health care professionals present in the operating room:

- **Nature of the components**
- **Size of the particles**
- **Concentration**

There are numerous studies reporting the hazardous nature of surgical smoke.

The composition and size distribution of the particles depends very much upon the type of surgery, the nature of the treated tissues and the energy level used\([5, 6, 8, 9]\). The data presented in the leaflet are those most often reported in the literature.
**Nature of the components**

Surgical smoke contains chemicals, non-viable particles, viable bacteria and viruses and viable cells.

**Chemicals**

The overall composition of electrosurgical smoke is 95% water and 5% cellular debris (blood and tissue particles, viruses and bacteria) and chemicals [9]. The main chemicals present in electro surgery smoke are hydrocarbons, nitriles, fatty acids and phenols[6]. Other chemicals present in smaller quantities, include hydrogen cyanide, formaldehyde and benzene[7].

During laser surgery, the released chemicals include benzene, formaldehyde, acrolein, in addition to the noxious odor, chemical toxins may lead to pulmonary irritation and inflammation of the respiratory tract[7]. In particular, benzene, xylene, toluene and ethylbenzene are mutagens which can lead to headaches as well as irritation and soreness in the eyes, nose and throat[2, 8]. Benzene is also a known carcinogen, which one should not be exposed to at all[17]. Gasses such as carbon monoxide and methane have been detected, with a mutagenic and carcinogenic potential similar to that of cigarette smoke[21].

**Chemicals identified within electrosurgical smoke** [5,7]

<table>
<thead>
<tr>
<th>Acrolein</th>
<th>Formaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylonitrile</td>
<td>2-Furancarbox aldehyde</td>
</tr>
<tr>
<td>Amonia</td>
<td>Hydrogen cyanide</td>
</tr>
<tr>
<td>Benzene</td>
<td>Methane</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>Toluene (hydrocarbon)</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Xylene</td>
</tr>
</tbody>
</table>
Compared to recommended exposure limits, the concentration of mutagenic and carcinogenic chemicals in surgical smoke cannot be seen as negligible\textsuperscript{[5, 7]}.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
& & & & & \\
\hline
\text{Concentration in} & \text{Exposure limit} & & & & \\
\text{surgical smoke} & & & & & \\
\hline
\text{Amonia} & & & & & \\
\text{1,3-Butadiene} & & & & & \\
\text{2-Furancarbox} & & & & & \\
\text{aldehyde} & & & & & \\
\text{Toluene} & & & & & \\
\text{Acrylonitrile} & & & & & \\
\text{Hydrogen cyanide} & & & & & \\
\hline
\end{tabular}
\end{table}

\textbf{Viable cells}

DNA from human papillomavirus (HPV) has been found in the smoke created during a loop electrosurgical excision procedure. More investigations are though needed to investigate the viability of the DNA\textsuperscript{[19]}.

A research team has showed that smoke issued from laser surgery contains viable bacteria\textsuperscript{[20]}.

The evaporation process of the ultrasound scalpels takes place at lower temperature and creates particles made of biological tissues, blood and blood by-product. In addition there is a higher chance that the cool aerosol will carry infectious and viable material compared to high-temperature smoke from electrosurgery and laser surgery\textsuperscript{[7]}.

Blood containing HIV-1 and exposed to high-speed orthopaedic devices creates a cool aerosol containing viable HIV-1\textsuperscript{[16]}.
Size

Non-viable particles can be harmful depending on their size. Particles created by energy-based instruments cover a broad range of sizes. The smaller they are, the more they travel, and will spread throughout the whole operating room.

Particles that are 5μm or larger settle on the walls of the nose, pharynx, trachea and bronchus. Particles up to 5μm are frequently referred to as ‘lung-damaging dust’, since they can penetrate to the deepest regions of the lungs. Rats repeatedly exposed to such smoke developed pathological changes of the lungs \(^{[10]}\).

- The smallest particles are found in electrocautery plumes, with a mean size of 0.07μm\(^{[9]}\).
- Particles in smoke from laser surgery are around 0.31μm, and 77% of the particulate matter is less than 1.1μm in size \(^{[2,7]}\).
- In aerosols from ultrasonic scalpel, particles are between 0.35 and 6.5μm\(^{[7]}\).

Size distribution of various particles\(^{[5]}\)

<table>
<thead>
<tr>
<th>Type of particles</th>
<th>Measurement (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viruses</td>
<td>0,01 to 0,3</td>
</tr>
<tr>
<td>HIV</td>
<td>0,18</td>
</tr>
<tr>
<td>HPV</td>
<td>0,045</td>
</tr>
<tr>
<td>Tobacco smoke</td>
<td>0,1 to 3,0</td>
</tr>
<tr>
<td>Surgical smoke</td>
<td>0,1 to 5,0</td>
</tr>
<tr>
<td>Bacteria</td>
<td>0,3 to 15,0</td>
</tr>
<tr>
<td>Lung-damaging dust</td>
<td>0,5 to 5,0</td>
</tr>
<tr>
<td>Smallest visible particle</td>
<td>20</td>
</tr>
</tbody>
</table>
Depth of penetration of particles in the respiratory tract\textsuperscript{[2]}
Concentration

Particle concentration in the OR can increase by a factor of 17 within five minutes after the use of electrosurgical devices begins. The high concentration level remains constant throughout the procedure and, because of the air circulation, in the entire OR[9].

A study shows that even when using a portable smoke evacuator, high-voltage electrocautery during peritoneectomy procedures produces 10 times more ultrafine particles (ranging from 0.02 to 1μm) than colorectal cancer surgeries, when measured close to the breathing area of the surgeon[8].

The smoke generated during electrosurgical procedures travels far away from the surgical site, to reach beyond the OR staff and the patient. Measured 3 meters away from the surgical site, the maximum level of ultrafine particle (0.02-1μm) is between 15% and 30% of the level measured in the breathing area of the surgeon, even when smoke evacuation is utilised[8].
Laparoscopic Procedures

The risks associated with surgical smoke/aerosols during laparoscopic procedures can extend to the patient:

**Visual obstruction of the surgical field:**
Depositing on the lens of the laparoscope or remaining as a mist, smoke and aerosols can decrease the precision of the surgical act. In addition, impaired vision can delay the operation.

**Mutagenic chemicals**
Carbon monoxide (CO) is a major component of surgical smoke. A research team showed an increased level of CO in the patient’s blood, following cholecystectomy\(^7\). This can result in the patient feeling nausea and headache.

**Tumour recurrence in a port site**
One of the proposed mechanisms for this phenomenon is the accumulation of viable cells carried by the gas leaking around a port remote from where a tumour was previously extracted. This is also known as the “chimney effect” \(^{20}\).
Clinical Effect of Surgical Smoke

The mutagen and carcinogen potential of smoke has been demonstrated on animal models[Error: Reference source not found]. The effect on patients and OR personnel is principally estimated from the composition and the harmful nature of the components. Alp et al. have developed a list of the symptoms that surgical smoke can cause[3].

Tomita et al. showed that the smoke issued from laser ablation of 1 gram of tissue can be compared to the burden derived from 3 cigarettes; for electrocautery, the number is 6 cigarettes[21].

Even though repeated exposition to surgical smoke does not seem to increase the risk of lung cancer for OR nurses[Error: Reference source not found], other research work indicates that the effect of smoke is cumulative and can be harmful:

- In Norway, a 44-year-old laser surgeon developed laryngeal papillomatosis due to the human papillomavirus (HPV) type 6 and 11. Since the surgeon had given laser therapy to patients with anogenital condylomas, which are known to harbor the same viral types, the authors of the publication suggest that the papillomas may have been caused by inhaled virus particles present in the laser plume[14].

- In America, a recent survey amongst over 750 perioperative nurses showed an increased prevalence rate of allergies, sinus problems, asthma and bronchitis, as compared to the average person in the USA. Prevalence for the nurses is, in some cases, more than twice the rate found in the rest of the populace of the United States. This result may be related to the repeated exposure of the nurses to surgical smoke[15].

<table>
<thead>
<tr>
<th>Respiratory condition</th>
<th>Survey results</th>
<th>USA prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergies</td>
<td>24,23%</td>
<td>18,38%</td>
</tr>
<tr>
<td>Sinus infections/problems</td>
<td>22,93%</td>
<td>10,33%</td>
</tr>
<tr>
<td>Asthma</td>
<td>10,87%</td>
<td>6,40%</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>9,04%</td>
<td>4,45%</td>
</tr>
</tbody>
</table>
Risks related to surgical smoke\textsuperscript{[3]}

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

**Protective Personal Equipment**

**Surgical masks**
Surgical masks are the most standard equipment used during surgical procedures to protect patients and health care professionals from microorganisms and aerosolised body fluids. However, only large droplets or particles of over 5 μm in size are blocked. Hence, surgical masks provide little or no protection from the gas phase of the smoke or the aerosol[2].

**Respirators**
These high filtration masks are effective down to 0.1μm and can help prevent exposure to airborne infectious agents. Viruses can, however, be much smaller than 0.1μm[9]. Filtration capacity of at least 95% (N95) is preferred. To be effective, respirators require regular fit testing to ensure a completely tight seal between the mask and the wearer. Fit testing should be performed by trained people and adequate, specific instruments.

**Engineering Controls (isolate or remove smoke from the OR)**

**General OR ventilation**
As a rule of thumb, the air in the operation room should be exchanged, as a minimum, 15 times per hour. Even this standard is, however, far from adequate to remove the noxious surgical smoke before it affects people present in the room. As a matter of fact, it takes up to 20 minutes at the end of an electrosurgical operation to bring the concentration of particles back to a baseline level with OR ventilation only[9].
Wall suction
A smoke wand connected to the central vacuum system can be a means of evacuating small amounts of surgical smoke. In this case, an inline smoke filter should be used to avoid occlusion of the suction line by cellular debris\textsuperscript{[15]}. However, most of the energy-based surgical procedures will require a much higher aspiration flow to effectively evacuate the generated smoke.

Portable smoke evacuation units
The most efficient way to reduce the hazards of surgical smoke is by using a portable smoke evacuation system\textsuperscript{[12,13]}. Such a system should create an aspiration in the direct vicinity of the source.

It has been shown, that diathermy pencils with a smoke evacuation function give better results than a wand held by an assistant\textsuperscript{[5,10]}. For example, the amount of ultrafine particles measured at the level of the surgeons mask is 5 time higher when using a handheld aspiration wand compared to a diathermy pencil with a smoke evacuation function\textsuperscript{[8]}. The necessary aspiration flow is a topic which very few have investigated. Recommendations vary from a capture speed of minimum 30m per minute at the suction nozzle, to an aspiration of 810l per minute at the smoke evacuation unit\textsuperscript{[9]}. The most important is though to measure the aspiration flow (l/min) at the nozzle of the aspiration device, that should be within 2cm from the source of smoke in order to achieve the best results\textsuperscript{[12, 17]}.

Het ideale rookafzuigsysteem

- Aspiration constantly close to the source of smoke emission (2cm)
- Filtration of particles under 0,1μm with efficacy of 99,999%\textsuperscript{[12]}
- Removal of odours
- No recirculation of the filtered air
- Low noise level
- Does not interfere with the surgeon procedure
Laparoscopic Surgery

Laparoscopic surgery presents a different challenge. Surgical smoke and aerosols should be regularly evacuated from the peritoneum in order not to harm the patient. On the other hand, the escaping air should be filtered in order to protect the surgical team. There are various filters called “passive surgical smoke filters” that can be connected to trocars in order to achieve that goal. The ideal profile of such a filter is defined in the literature as:\(^{[1]}\):

- Multiple filtration layer: Pre-filter, high efficiency and activated carbon filter
- Valve for release of gas without detectable odour (indicator for filter efficiency)
- Adjustable gas flow from the peritoneum. Maximum flow capacity should permit rapid gas exchange (12l/min at 15mm Hg)
- Sterile with double peel pouch packaging for presentation to the surgical field
- Ready-to-use: no assembly required
- Easy to connect to the trocar with no leakage at the connection
- Long lasting performance even when challenged with elevated levels of moisture in effluent gas from the pneumoperitoneum.

In addition to the above, connecting the filter to the central vacuum system will ensure a complete elimination of the hazards of surgical smoke, without risking contamination of the system itself.

Administrative Controls

In addition to the equipment required for evacuating smoke, hospital policies and education and training programs for the health care professionals are of utmost importance to ensure that steps are actively taken to protect the personnel and the patients against surgical smoke\(^{[15]}\).
Surgical Smoke: An Increasing Concern Worldwide

Back in the nineties, the USA and Northern Europe expressed an increasing concern about the hazardous effect of smoke caused by electrosurgery and laser surgery on the health of OR workers and patients. Nursing associations and national authorities have since developed recommendations to improve the working environment in that regard, though with widely varying results.

England

The Control of Substances Hazardous to Health Regulations (COSHH - 2002) require that exposure to substances hazardous to health are adequately controlled to prevent occurrence of ill-health.

In a device bulletin from 2008, the MHRA (Medicines and Healthcare products Regulatory Agency) recommends that smoke evacuation systems are used during laser surgery. In addition it is specified that masks and OR evacuation systems are not suitable for protection from surgical smoke.

France

In addition to a section of the Labor Code regarding evacuation of smoke from the workplace (R. 232-5-7), there are recommendations of the C. CLIN Paris-Nord and the French Society of Hospital Hygiene (SF2H) dating from 2000 and 2004, relating to the use of medical devices (scalpels, lasers) equipped with smoke evacuation, and the use of filters for exsufflation of the pneumoperitoneum during laparoscopic procedures.
Denmark

In Denmark, the European directive concerning the minimum safety and health requirements for the workplace (89/654/EEC) is implemented as a regulation with specific provisions concerning the elimination of polluted air from any working place. Recirculation of filtered air is furthermore forbidden; a dispensation request addressed to the government regarding recirculation of filtered air during surgical procedures was even dismissed in 2002.

Canada

In January 2009, a new standard was issued covering any type of smoke emitting surgery, requiring the use of a smoke evacuator (CSA 7305.13-09). The new regulation states that facility safety officers shall ensure that plume removal requirements are established, implemented, monitored for compliance, reviewed, and revised periodically.

USA

There is no regulation requiring the elimination of surgical smoke in the USA. However the concern about the posed hazard is on the rise, under the effort of the AORN (American Association of Registered Operating Room Nurses). The most important official document is the Hazard Controls No. 11 issued by NIOSH (National Institute for Occupational Safety and Health), recommending evacuation and filtration of surgical smoke[13].

Australia

The Australian College of Operating Room Nurses (ACORN) represents professional nurses across Australia. The organisation practice guidelines recommend the prevention of patients’ and healthcare personnel’s exposure to surgical smoke, by means of appropriate equipment and procedures.
Evacuation of Surgical Smoke: An Area of Expertise for SafeAir

SafeAir is dedicated to making the working environment safe for all present in the operating room, without impairing the effectiveness of the surgical procedure. The product range includes devices that match the various requirements of electrosurgical operations:

Smoke evacuation pencils

The SafeAir Smoke Pencil products are single-use electrosurgery pencils with fully integrated smoke aspiration and liquid suction functions. A slim design and no additional cable that can disturb the surgical act make this product the perfect pencil for safe electrosurgery.

Smoke evacuation units

Combined with the SafeAir Smoke Pencil products, SafeAir smoke evacuation units form a very effective solution for evacuation of electrosurgical smoke. Synchronised to the pencil, the unit provides a silent, powerful aspiration flow and effective filtration of particles and odours.
References

1. “Surgical Smoke, a concern for infection control practitioners”, Girolamo A. Ortolano, PhD, Joseph S. Cervia, MD, MBA, and Francis P. Canonica, PhD, Managing Infection Control, August 2009, pages 48-54
13. Hazard control 11 (HC11) - NIOSH - Publication no. 96-128 - September 1996