Surgical smoke: is it safe?

Edited by the perioperativeCPD team

Learning objectives

- Define surgical smoke and surgical plume
- Know how theatre personnel may be affected by surgical smoke
- Be aware of the risks and hazards surgical smoke can cause to patients
- List the methods used to reduce the risk of exposure

Surgical smoke is now recognised as a hazard that is encountered in all operating theatres. Unfortunately, the dangers and health risks associated with it continue to be overlooked by many surgeons, nurses and theatre staff. It is important to be aware of the dangers of surgical smoke and for everyone to help minimize the risks.

What is surgical smoke?

Surgical smoke or surgical plume is generated during surgical procedures. It is most commonly associated with the use of diathermy and lasers, although it can be produced by any means in which tissues are rapidly heated and cells vaporised. This can include any aerosolised substance produced by the use of high-energy medical devices including ultrasonic devices, and high-speed electrical drills and burrs.

Surgical smoke is composed of approximately 95% water, 5% biological or cellular debris and other chemicals.[1] It has been shown to pose a theoretical risk for those who inhale it. Although high quality, conclusive evidence has not been produced proving it is detrimental to our health, a common sense approach suggests we should minimise our exposure to it. In addition, surgical smoke is odorous, noxious and reduces the view of the operative field, especially during laparoscopic procedures.[2]

The terms “smoke” and “plume” often are used synonymously, but technically there is a difference depending on the size of their airborne particles. The particle size in surgical smoke is dependent upon the method of generation (See Table 1). A plume contains larger particles, which are thought to be more dangerous from a biohazard standpoint, as they are capable of adhering to the lining of the upper respiratory tract (See diagram 1). Smoke contains smaller particles, which can pass easily into the deepest regions of the lungs. The smaller they are, the more they travel, and they can spread throughout the whole operating theatre. These are of concern due to the harmful chemicals they contain.[3]

Table 1. Sizes of Particles produced by various surgical devices[3]	
Diathermy	0.007-0.42µm
Laser	0.1-0.8µm
Ultrasonic scalpel	0.35-6.5µm

Where does it come from?

As much as 80% of smoke encountered in the operating theatre is produced by the use of traditional diathermy devices. During electrosurgery, the individual cell temperatures are raised above the boiling point. As a consequence, the cell walls explode, and the vaporised fluid is dispersed into the air.[4]

This type of smoke often is considered to be less of a hazard than smoke generated by other means, because the airborne particles are smaller. The average particle size found in diathermy smoke ranges from 0.007-0.42µm (micrometres).[5] This small size, however, means they are capable of traveling further in the air and reaching all areas of the theatre and all theatre staff. Although it appears that it should be a lower health risk this is offset by its sheer prevalence, as diathermy is used in the majority of modern surgical procedures.[6]

A source of larger particles is lasers. Lasers produce extreme heat (100 to 1000^{o} C), which also boils and explodes cells, releasing steam and cellular contents.[7] Most studies on laser plume have involved the CO_2 or Nd:YAG laser and this laser plume is associated with a higher risk of disease transmission due to larger particulate matter, ranging in size from 0.1-0.8µm.[5]

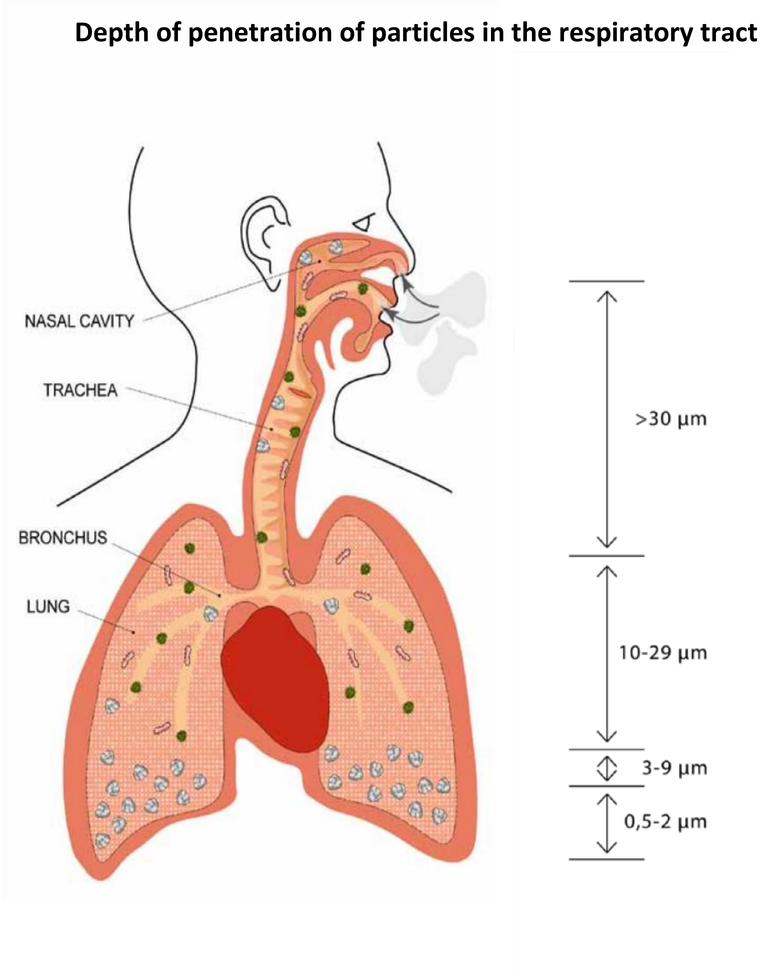

Diagram 1: Depth of penetration of particles in the respiratory tract
Diagram from Safeair, Surgery without smoke.

The growing popularity of ultrasonic scalpel devices has also added another source of surgical smoke or aerosol to the operating theatres. Ultrasonic scalpels have become a popular alternative to traditional diathermy for dissection because they produce less thermal damage to the surrounding tissue. They utilize high frequency vibration at speeds of up to 55,000 times per second (55kHz) to cut and coagulate tissue. This low temperature vaporisation comes at a price as the vapours generated are more likely to carry infectious particles than vapour generated by higher temperatures.[8]

Finally, a common but often ignored source of dangerous aerosol in operating theatres are power instruments such as saws, drills and burrs.[9] The rapid movement of bone saws and drills generates heat and disrupts cells, sending potentially hazardous material into the air. Surgical burrs are often forgotten because the plume produced is not associated with the purposeful burning of tissue. Nonetheless, all of these instruments produce heat which, when combined with organic tissue and standard irrigation, produce aerosolized particles capable of causing harm to those exposed.[8]

What are the risks?

The hazards associated with surgical smoke can range from mild irritation to life threatening illnesses, affecting both scrubbed and non-scrubbed staff. It has been shown that the smoke issued from the ablation of 1 gram of tissue can be compared to smoking 3-6 cigarettes in 15 minutes.[10]

It must be realised that much of the literature regarding the adverse effects of surgical smoke consists of primarily anecdotal evidence and guidelines are based on theory and animal models.[10] Despite this, it is fact that surgical smoke contains many chemicals, with several known to be carcinogenic, such as benzene, formaldehyde, cyanide and ethanol. Estimates are that there are over 600 more compounds within surgical smoke that have yet to be identified[11] (See Table 2).

The most common and least threatening symptoms associated with exposure include eye irritation, headaches, light-headedness and respiratory irritation. Inadvertent inhalation of these chemicals can lead to acute and chronic conditions including emphysema, asthma and bronchitis.[12]

Multiple studies have shown that surgical smoke contains viable bacteria and viruses. One study cultured the laser plume from 13 surgical procedures – of these, five specimens grew Staphylococcus. Among those five specimens, two of them also grew Corynebacterium (associated with diphtheria) and Neisseria.[5]

One of the most publicised risks to theatre staff is the potential transmission of human papillomavirus (HPV). This comes from a well-documented case of a surgeon who developed laryngeal papillomatosis after treating a patient for anogenital papilloma with a Nd:YAG laser. Further study of the surgeon revealed HPV types 6 and 11 in his larynx, the same types found in anogential papilloma. This virus could have only been transmitted through inhalation and although it is not possible to conclusively prove the link it is widely accepted to be from the laser plume. Viable human immunodeficiency virus (HIV) also has been found in aerosols generated by power oscillating saws, although there have been no proven cases of transmission or know even if transmission is possible and further study is needed.[12]

Table 2. Some common chemicals in Surgical Smoke[8,10]
Acrolein, Acetonitrile, Acrylonitrile(c), Acetylene, Alkyl benzenes
Benzene(m)(c), Butadiene(c), Butene
Carbon monoxide, Creosols(c), Cyanide(c)
Ethane, Ethylene, Ethylbenzene(m), Ethanol(c)
Formaldehyde(c), Free radicals
Hydrogen cyanide
Isobutene
Methane
Phenol, Polycyclic aromatic hydrocarbons(c), Propene, Propylene, Pyridene, Pyrrole
Styrene
Toluene(m)
Xylene(m)

(c) = carcinogenic (m) = mutagens

Is there a risk to patients?

While most of the concern regarding hazards of surgical smoke leans toward theatre staff, patients are also at risk, particularly in laparoscopic procedures. One of those risks is carbon monoxide (CO) toxicity. CO contained in surgical smoke is absorbed into the patient's body through the peritoneum. Overexposure to CO has been shown to cause headaches, fatigue, nausea, vomiting and cardiac dysrhythmias. Increased peritoneal CO increases carboxyhaemoglobin levels in the blood. Carboxyhaemoglobin is produced when CO binds to haemoglobin. Carbon monoxide has an affinity for haemoglobin more than 200 times greater than oxygen[13]. This reduces the oxygen carrying capacity of red blood cells. (See diagram 2) Pulse oximeters interpret carboxyhaemoglobin as oxyhaemoglobin, giving an inaccurate SpO_2 reading and potentially resulting in unrecognized hypoxia in the surgical patient.[14]

Surgical smoke is also thought to be responsible for port site metastasis following laparoscopic tumour resection. Malignant cells have been identified in trocar sites other than the ones used to deliver the cancerous specimen, suggesting that viable cancer cells spread to that location through surgical smoke. This phenomenon has become known as "the chimney effect." Tumour cells carried by the carbon dioxide used for inflating the peritoneum leaks around the trocar and becomes trapped in the wound surface, leading to malignant seeding at the trocar site.[15]

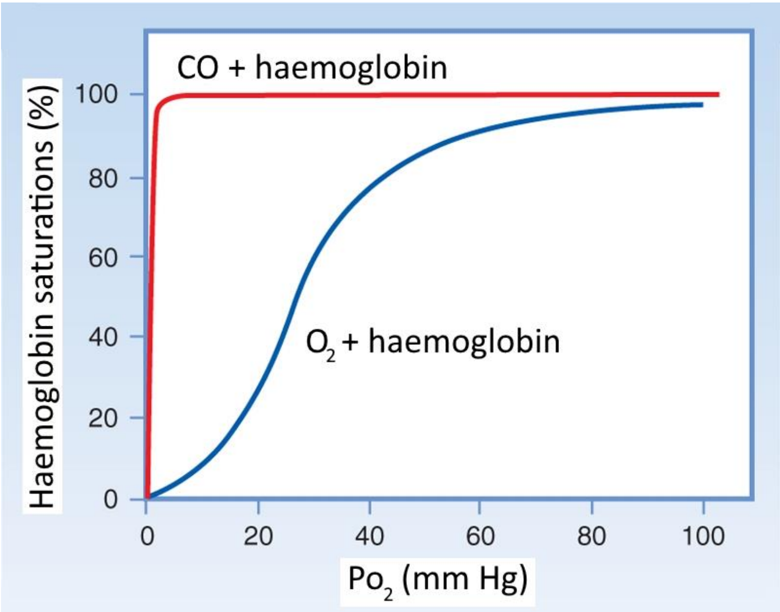

Diagram 2: CO vs O_2 binding to haemoglobin

Reducing the risk to perioperative staff

Millions of theatre staff around the world are exposed to surgical smoke each year, however, there are very few official mandates relating to the prevention of surgical smoke production or inhalation. Without regulations in place, many hospitals have been slow to adopt preventive measures, leaving surgeons and theatre personnel to protect themselves from harm. Recently many nursing organisations have produced recommendations and these concentrate in three key areas: [16]

Proper ventilation
Personal protective equipment (PPE)
Smoke evacuation

Proper ventilation

Smoke which is not captured at source is dispersed in the air of the room. Particle concentration in the theatre can increase by a factor of 17 within five minutes of electrosurgical devices beginning to be used.[17] The room's ventilation system dilutes pollutants and removes them from the breathing zone of operators but while the air in the operating theatre should be exchanged a minimum of 15 times per hour, this rate is far from adequate to remove the noxious surgical smoke before it affects other people present in the theatre.[18] It can take up to 20 minutes at the end of an electrosurgical operation to bring the concentration of particles back to a baseline level with theatre ventilation only. [17]

Personal protective equipment

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 because as many as 77% of particles in smoke are 1.1µm or smaller. They also are rarely tight fitting so a large percentage of the smoke filled air that is breathed in will bypass the mask totally and not be filtered at all. [19]

Laser masks can provide better protection by filtering particles as small as 0.1µm. Respirator masks (N95 and higher) are likely to provide the best protection against surgical smoke but they are expensive, uncomfortable and not totally practical.[7]

Smoke evacuation

Wall suction

A common and quick method of dealing with surgical smoke is to place a standard surgical suction tip, connected to wall suction, at the surgical site. While this method may be effective for removing small amounts of smoke, wall suction is not strong enough to be effective when large amounts of smoke are involved. Additionally, for this method to be effective, an “in-line” smoke filter should be used between the suction tubing and canister. Without the use of inline filters, smoke can easily escape from suction canisters and permeate back into the room air[20].

Smoke evacuation systems

Surgical smoke evacuators are multistage systems consisting of a capture nozzle, a pre-filter to capture larger debris and aerosols (as small as 5µm), a HEPA or ULPA (ultra-low particulate air) filter, which can filter particles as small as 0.01µm, and a carbon filter to neutralize odours[4]. Recommended smoke evacuation systems pull at a rate of 30-45 m^2 per minute, compared with around 1.5 m^2 per minute with wall suction[21]. Capture nozzles vary in size and style. Traditional wand-style devices should be placed no more than 2-3 cm from the smoke source. Smoke evacuation adapters are designed to attach to standard ESU pencils and allow the nozzle inlet to be much closer to the smoke source without obstructing the surgeon’s view[22].

Barriers to compliance

As previously stated, surgical smoke is one of the most overlooked hazards in the operating theatre. Despite the abundant studies about its potential dangers and the recommendations of multiple authoritative and national organizations, studies of healthcare workers show that compliance with smoke evacuation guidelines is alarmingly low[23].

So why do so many surgeons, nurses, theatre practitioners and hospitals not take the appropriate action against the hazards of surgical smoke? The top four barriers to compliance appear to be:

- the surgeon said it was unnecessary
- smoke evacuators were not available
- smoke evacuators are thought to be too noisy
- and staff complacency[23]

Most of these barriers are all easily overcome with proper education, and a realisation that the issues are serious for the long term health of everyone working in operating theatres. Most likely, it will not be long before conclusive evidence of the health dangers of surgical smoke, but it is important not to wait until then as exposure and potential harm is occurring every day.[11]

Smoke evacuation technology is available, smoke evacuation practices are easy to implement, and smoke evacuation is effective – we should use proper smoke evacuation for every surgical procedure where there is potential risk.

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