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Surgical smoke: risks and preventive measures

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A B S T R A C T

The application of the advanced technologies in medicine has led to the appearance of new risk factors for health personnel. One of these could be the surgical smoke produced by electrosurgical instruments, ultrasounds, or laser. However, there is still insufficient evidence in the published population studies on the detrimental effects of chronic exposure to surgical smoke. The main concern on the possible damage to the health of operating room staff is mainly based on the components currently detected until the date and laboratory experiments. Caution must also be used when extrapolating the results of in vitro studies to daily clinical practice.

The organisations responsible for protecting the health of the workers in different countries have still not issued guidelines for the treatment and removal of the surgical smoke generated in both open and laparoscopic procedures. In this article we try to present a view of the consequences that surgical smoke has on health and the preventive measures that can be adopted.

El humo quirúrgico: riesgos y medidas preventivas

Palabras clave:
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R E S U M E N

La aplicación de las tecnologías avanzadas a la medicina ha supuesto el incremento de algunos factores de riesgo en el personal sanitario. Uno de ellos podría ser el humo quirúrgico producido por instrumentos electroquirúrgicos, ultrasonidos o láser. La voz de alarma acerca de un posible perjuicio para la salud de los trabajadores de quirófano se basa fundamentalmente en los componentes detectados hasta la fecha y los experimentos realizados en el laboratorio. No obstante, hay que tener precaución al extrapolar los resultados de los estudios in vitro a la práctica clínica diaria y, hasta la fecha, no hay evidencias suficientes del efecto perjudicial de la exposición crónica a éste en los estudios poblacionales publicados.

Los organismos responsables de velar por la salud de los trabajadores en distintos países no han emitido todavía normas para el tratamiento y la evacuación del humo quirúrgico

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generado en intervenciones tanto por laparotomía como por laparoscopia. En este artículo pretendemos ofrecer una visión de las consecuencias que el humo quirúrgico tiene para la salud y las medidas preventivas que se pueden adoptar.

Introduction

The application of advanced technologies in medicine has led to the appearance of new risk factors for health personnel. One of these could be surgical smoke, which is a collection of particles suspended in the air emanating from the thermal destruction of bones or tissue.[1,2]

In medical publications, the term surgical smoke and aerosol or smoke plume are used indistinctively, although the difference between them lies in the size of the particles. Smoke plume is described as a suspension of particles in a gas, resulting from the use of ultrasound and laser instruments and it contains the larger sized particles, which hold the main interest as far as biological damage is concerned. The smoke originates from the use of electro-surgical instruments and it contains smaller particles than the smoke plume, considered hazardous concerning chemical damage.[3]

The development of endoscopic surgery has added new concerns. Thus, in laparoscopic interventions, the surgical smoke and smoke plume generated cannot be absorbed by the patient's peritoneum, event that reduces visibility during the surgical intervention and requires its extraction. The aerosolised particles hinder vision as they are placed over the laparoscopic lenses or suspended between the laparoscope and the surgical object. Therefore, to re-establish visibility in the surgical field, cleaning of the particle layers on the laparoscope lenses is required, as well as the expulsion or aspiration of the gas and the aerosolised particles. It seems that monopole-based instruments cause the greatest deterioration of visibility, while bipolar and ultrasound instruments affect it to a lesser degree.[2] In any case, the person undertaking the aerosol or smoke plume extraction suffers its consequences the most. With regard to the latter, we should not forget that when the trocar valve is opened to evacuate the smoke or to introduce any surgical instrument through it, the team members could receive a direct mouthful of CO_2 and suspended particles in the face. In addition, exposure of the surgeons is more intense and concentrated than the rest of the surgical staff because they are the ones closest to the destruction of tissue, which is the source of the smoke.[3]

Impact on health

The physical and chemical composition of surgical smoke has not yet been established with precision, the substances and microorganisms identified to date should be a good reason to consider it as potentially hazardous. Laser, ultrasound, and electric-based surgical equipment can nebulise the operating room air with virus and viable cells, small particles, mutagens, carcinogens, and other toxic substances. Chemical analysis has proven that it contains 95% water vapour and 5% is composed of chemical products and cell remains.[1]

Although patients can suffer adverse effects due to exposure to surgical smoke, particularly during laparoscopic procedures, the greatest risk of chronic illness and damage to health is for the operating room staff members, who repeatedly inhale it.[4] It has been published that brief patient exposure to surgical smoke generated by laser during minimally invasive surgery produces changes in the biochemical structure of their haemoglobin and, therefore, we should also be concerned about the chronic exposure of operating room staff to it.[5] Furthermore, some authors consider that during the laparoscopic procedures high concentrations of carbon monoxide are created that could lead to a slight increase in carboxyhaemoglobin.[2]

Different-sized particles

Surgical smoke is composed of 2 types of particle populations: small and large. The smallest particles are spherical, they contain sodium, potassium, magnesium, calcium, and iron and are caused by the uniform evaporation of liquids, giving way to gas flow (nucleation). The large particles are irregular; they contain carbon and oxygen and result from the explosion of a fragment of tissue, which means, from the dragging of secondary tissue to mechanical aspects.[2]

It has been proven that there are particles measuring 0.07 to 25 µm in the trail of the CO_2 laser and in the electrocautery smoke.[6-8] Those measuring 0.5 to 5 µm are considered as "powder harmful to the lung" because it can penetrate in its deepest areas. In experiments carried out on laboratory animals (rats), it was observed that the inhalation of surgical smoke caused a gamut of damage from inflammatory interstitial pneumonia to extensive emphysema and that the changes proportionally increased with extended exposure.[3,9-11] However, the level of exposure was higher than what it would be in practical experience.[1] It has been pointed out that the histological changes found in laboratory animals (blood vessel hypertrophy, alveolar congestion, and emphysematous changes) were less when the surgical smoke was filtered,[3] which led the way to new types of protection. It

seems more probable that the smoke should increase the risk of chronic lung diseases (with asthma or pneumonia) than of lung cancer, due to the presence of small particles.[4]

Chemical components

Odour is an indication of the content of the chemical products in the smoke, secondary to the combustion of the proteins and lipids.[12,13] Basically, they cause migraines, irritation and pain in eyes, nose, and throat.[12,14] Some, such as benzene and butadiene are known carcinogens; others can be cardio-toxic, such as hydrogen cyanide and some are even nephrotoxic. In vitro studies[1] have identified 80 chemical components, some of which are included in Table.

One of the factors influencing the concentration of chemical products produced seems to be the type of tissue destroyed. Thus, for example, breakdown of the adipose tissue produces a larger quantity of aldehyde and less toluene; while ablation of the epidermal tissue produces larger concentrations of toluene, ethylbenzene and xylene.[15]

In an in vitro study, it was estimated that the smoke produced during laser irradiation or electrocauterization of 1 g of tissue was equivalent to the mutagenic potential of 3-6 cigarettes. Other laboratory studies have proven that electrocautery smoke and surgical laser is mutagenic for certain strains of *Salmonella tiphimurinum*.[4] Some researchers have observed that the extracted particles were unstable and lost their mutagenic potential 2 h after collection. Furthermore, a recent study has pointed out that the low concentration of volatile products, although minimal, poses a certain health risk to the operating room staff, comparable to that of passive smokers.[3]

To conclude, although laboratory studies and studies on animals have displayed the possibility that repeated exposure to surgical smoke can cause health problems in humans, no population-based studies have been published and there is no significant evidence of long term effects.[4]

Table – Some of the chemical products identified in surgical smoke

Acrolein	Palmitic acid
Acetonitrile	Hydrogen cyanide
Acrylonitrile	Indole
Acetylene	Isobutene
Alkylbenzenes	Methanol
Benzaldehydes	6-Methylindole
Benzene	2-Methylpropanol
Benzonitrile	3-Methylbutanal
Butadiene	2-Methylfuran
Butane	4-Methylphenol
3-Butenenitrile	Methylpyrazine
Carbon disulfide	Phenol
Carbon monoxide	Aromatic hydrocarbons
Cresols	Propene
1-Decene	Propylene
2,3-Dihydroindole	2-Propylene nitrile
Ethane	Pyridine
Ethene	Pyrrole
Ethylbenzene	Styrene
Ethylene	Toluene
Ethylbenzene	1-Undecene
Formaldehyde	Xylene

Viable cells

It has been established that viable cells and blood components can be aerosolised by laser and electric scalpels.[9,16-19] The liberation of cells during a laparoscopic procedure has been considered as the cause of tumour growth in the places of pneumoperitoneum leak around the trocars, far from the area of cancerous tissue removal (port site metastases).[1,9-11,20-25]

The study of surgical smoke produced in the process of exeresis of different abdominal cancers highlighted the presence of morphologically intact cells, most of which were mesothelial and blood cells.[1] In 1999, Fletcher et al[17] observed that only some of the cells present in surgical smoke immediately after collection were viable and that their survival in culture was limited to 5-7 days after extraction. Risk to operating room staff of the inhalation of viable tumour remains cannot be discarded despite that it has been proven that they have only been able to grow in culture and not in the human respiratory tract.[3]

Viable viruses

Some studies have detected nucleic acids from the human papillomavirus (HPV) alone or with viral particles and even with viable human immunodeficiency virus (HIV) in surgical smoke, although the latter cannot be cultivated for more than a fortnight in laboratory conditions, possibly due to thermal damage.[1,26]

There is no evidence that HIV infection can be transmitted to humans through this route, although a high incidence of nasopharyngeal warts in surgeons working with CO_2 laser has been reported. Furthermore, it has been proven in surgeons using Neodymium-Yag laser that the laryngeal papillomatosis they presented had been contracted after treating similar lesions with this laser in patients.[1,3,7,27-29]

With the use of both electric scalpel and laser, viral HPV particles can be volatilised able to generate lesions similar to those treated. Garden et al,[27] in 2002; published a study in which they recommended the use of smoke aspirators and the treatment of viral lesions with other therapeutic modalities for some situations, although it only referred to laser use.

Preventive measures

In Spain, current prevention norms are limited to control measures of the environmental quality in hospitals (operating rooms and critical areas), published in specialised texts.[30] Thus, operating rooms should have at least 15-20 air renewals per hour and the pressure should be positive in comparison to its surrounding area, which is obtained with air impulsion rates of 15% over the extraction rates. This measure contributes to the elimination of anaesthetic gases

and other products that can accumulate in the operating room. However, correct air renewal is not enough for the treatment of smoke resulting from both laparoscopic and laparotomy operations, making it necessary to combine other preventive measures to minimise exposure, such as the use of personal protective equipment, aspirators and surgical smoke filtration systems.[3,4]

Personal protective equipment (PPE)

Hygienic surgical masks protect the patient from exhaled microorganisms and particles from the nose or mouth of the practitioner and also reduce the risk of infection through blood splatters and other potentially infectious liquids from the patient. They have a filtering efficiency of ≥90% with particles measuring 0.5 µm and can be 1 of 3 types: hygienic dust mask, hygienic/surgical mask, and mask with shield. Despite having a very high resistance to fluids from the inside out, they should not be considered as complete personal protective equipment because the facial adjustment is not very effective. It is regulated by Spanish Royal Decree 414/96 for Grade I hazards.[31,32]

The so-called respirators with particle filters, as opposed to the previous ones, are aimed at protecting the practitioner from the inhalation of environmental contaminants, which means, they work from the outside in. They have a filtering efficiency of ≥95% for particles smaller than 1 µm and allow a facial adjustment of ≥90%. The use of these PPEs is regulated by the European norm for breathing auto-filtering protection against particles (UNE-EN 149, 2001) for Grade III hazards. Those professionals who work directly in the surgical field with patients and that require aerial isolation should use surgical masks with FFP3 respirators, which are of maximum efficiency.[32,33]

Thus, to protect the staff members' breathing, respirators with particle filters and exhalation valve (FFP3) could be used, and to protect the surgical field, a surgical mask should be used over the respirator. The inconvenience lies in the discomfort respirator use causes, together with the environmental conditions of the operating room and the duration of the interventions. These factors make its use low on a daily practical basis. To protect the eyes, face shields, masks or goggles with protective sides should be added.

Aspirators and surgical smoke filtration systems

The type of smoke extraction device and the position of the smoke evacuator can influence the level of exposure.[4] In the United Kingdom, the bodies responsible for workers' health and safety have not published any recommendation due to a lack of information of the exact risks involved. In the United States, the US National Institute for Occupational Safety and Health (NIOSH) recommends the use of smoke evacuators during surgical procedures in which surgical smoke or smoke plume is produced to minimize exposure, with a high suction capture speed (at least 31–46 m/s), non-standard, mounted on a wall, together with high efficiency particle filters.[28,29] However, some authors do not recommend wall aspirators for the evacuation of smoke due to its dubious efficiency and because a filtering of its piping is necessary to avoid the obstruction of the system. The NIOSH points out that local surgical smoke capturing devices should be within 5 cm of the surgical field and the aspirator should be connected at all times while surgical smoke is produced. Garden et al[27] found that at a distance of 1 cm, its efficiency was of 98% and over 2 cm the efficiency of smoke extraction dropped to 50%.

A number of studies have dealt with the subject,[3] and have informed that the histological changes of laboratory animals' lungs were less for those who breathed in surgical smoke subject to a simple or double filtration than those breathing unfiltered smoke. One of the conclusions was that, although there is not sufficient evidence of the harmful effects of surgical smoke to health, systems for its evacuation should be used, since they reduce exposure.[3]

The American National Standards Institute (ANSI) has developed norms related to the evacuation of smoke plume produced by laser ablation. Laser smoke plume evacuators have been widely accepted and used since the start of laser surgery. Recent research shows that there is a small difference between the smoke generated by electrocautery, harmonic scalpel and laser, which gives them similar hazard profiles.[1,3]

For laparoscopic interventions, it should be taken into account that a variable amount of CO_2 (15 to 150 L, according to duration, complexity, and incidences) is used. It is introduced into the patient's abdominal cavity, mixed with the surgical smoke produced by the electro-surgical, ultrasound or laser instruments and is released into the air breathed in by the operating room staff, with no norm regulating this in Spain, besides the control measures for environmental air quality. Although diluted, the components found in this mix should be sufficient reason to include the use of filtering systems connected to one of the trocars in laparoscopic interventions. This would avoid inhalation by the surgical team of viable cells, small particles, mutagens, carcinogens, and other toxic substances. Systematic aspiration with filter units can also be used, but never with an abrupt liberation of intra-abdominal gas. There are such systems on the market, like the LaparoShield® (Pall, Portsmouth, England) filter for trocar valve connection. With regards to laparotomy interventions, an aspirator with filtration systems placed close to the area of surgical smoke production should be used systematically, at least during the periods when it is in greater abundance. There are electro-scalpel and synchronised aspirator systems such as the OptiMumm® Smoke Evacuator/AccuVac® (Valleylab, Covidien, Colorado, United States).

With regard to the filters, it should be noted that they are contaminated with hazardous biological material and, therefore, they should be eliminated in the same way as products contaminated with blood and organic fluids. When the filters are replaced by operating room staff or biomedical technicians, gloves, eye protection and a mask should be used, because these connections are impregnated with the smoke and when freed, can release contaminated material into the air.[34]

Conclusions

Caution must be used when extrapolating laboratory study results to clinical practice because the conditions are not the same. In addition, in the clinical studies, the level of proof is low (type IV), based on documents or expert opinions or isolated clinical experiences; therefore, the different grades of recommendation are not categorical. In spite of doubts about the harmful effects of long term exposure to surgical smoke, caution should be applied and existing preventive measures within our reach should be applied: use of individual protection equipment, aspirators and surgical smoke filtration systems. Furthermore, norms for the control of environmental air quality should be complied with in hospitals (operating rooms and critical areas).

Current concern is based on the nature of the components of the surgical smoke identified to date, some are clearly harmful and which a null degree of exposure for workers has been requested, as in the case of benzene. The voluntary nature of regular physical examinations for operating room staff takes on a special meaning: performing them is not only needed to identify the state of health at any given time, but also for a correct follow-up and identification of new risk factors to workers' health, including surgical smoke. This is more evidence of the important role occupational medicine has in current society and, more specifically, in the hospital and healthcare domain.

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