"THERE IS NO SMOKE WITHOUT A FIRE" – SURGICAL SMOKE AND THE RISK CONNECTED WITH IT

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Starting from October 1-st, 1926, when Dr. Harvey Cushing was the first to apply electrocoagulation, the pioneer invention of William Bovie (1), surgical smoke has become an integral component of the atmosphere of the operating room. Thanks to technological progress in the twentieth century it was possible to use a laser or harmonic knife in the field of surgery. Undoubtedly, this facilitated the performance of selected procedures, but also exposed the operating room personnel to the effects of novel gases.

In recent years, numerous investigations were undertaken, aimed at determining whether there was any risk associated with the exposure of patients and medical personnel to surgical smoke. Some of these studies showed the presence of elevated levels of potentially harmful substances, while others the transmission of an infection. It would seem that these facts should be alarming, considering that surgical smoke is far from being indifferent. What really speaks to ones imagination is the very common in literature data comparison of surgical smoke inhalation resulting from the cauterization of 1 g of tissue and smoking of 6 cigarettes (2, 3). Nevertheless, many doctors are not aware of the potential threat, considering smoke to be totally harmless (4). They argue for the above-mentioned with the lack of disease symptoms, despite many years of exposure.

The aim of this study was to present the proven and theoretical risk posed by surgical smoke, as well as discuss methods which minimize this exposure.

General information and classical surgery

Electrocoagulation, laser and the harmonic knife create smoke of different properties. The average dimensions of particles differ, depending on the method used. Electrocoagulation creates the smallest particles in size- 0.07 μm (5), laser ablation-0.31 μm (6), while the harmonic knife, particles ranging between 0.35 and 6.6 μm in size (7). It is worth mentioning that the average size of a virus is a few nanometers, while that of a bacteria several micrometers. Therefore, smaller particles affect the organism through chemical reactions, while in case of larger particles biological factors plays an important role. In addition, there is a simple relationship between the size of the particle and its aerodynamic properties. The smaller the particle the greater the distance covered, since its development. Moreover, particles greater than 2.5 μm are trapped in the airways and removed from the body by means of the mucous-ciliary transport. Particles smaller than 2.5 μm penetrate directly into the alveoli, and if insoluble in water the only method to eliminate them, is by phagocytosis (macrophages). This can lead to a local inflammatory response, activation of prothrombotic factors, and development of atherosclerosis and cardiovascular diseases. This is all the more important, since inhalation is the major
route of smoke impact on operating room personnel (8).

The amount and content of surgical smoke produced may vary, depending on the type of electrocautery and procedure, cauterized tissue, or quantity of energy used (9, 10). Considering the composition of surgical smoke many substances have been identified, including numerous harmful (11).

One of them is acrylonitryl – a colorless, volatile fluid, easily absorbed by the skin and respiratory system. Under the influence of water (moisture) it releases hydrogen cyanide, an even stronger toxin. Acrylonitryl is probably carcinogenic. The Occupational Safety and Health Administration (OSHA) established an upper concentration limit at 2 ppm. In the operating room the above-mentioned concentration ranged between 1.0-1.6 ppm, just below the acceptable level (12).

On the other hand, high concentrations of benzene exceeding the accepted limits were detected near the diathermy electrode during colorectal surgery (13). It is worth mentioning, that this substance has proven to be highly carcinogenic. Furthermore, other harmful compound levels were found to be elevated: formaldehyde, methane, ethane, and carbon monoxide (2, 14).

We also showed that the vaporization of 3 g of tissue using a laser generates a sufficient amount of acrolein or polycyclic hydrocarbons that exceeded standards established by OSHA (11). Animal studies have shown that components of surgical smoke might irritate the respiratory system leading to the development of lung parenchymal changes, such as alveoli congestion, vascular hypertrophy, and focal emphysema (15, 16).

Not without significance is the fact that exposure to smoke in case of operating room personnel is chronic. Unfortunately, there are no studies on whether or what health consequences are connected with prolonged exposure to these toxic and mutagenic agents, especially when levels are at the limit of acceptability. The only epidemiological study thus far undertaken concerned 121 700 American nurses, and tried to find a relationship between exposure to surgical smoke and incidence of lung cancer. The epidemiological models applied showed no significant correlation between the duration of exposure and incidence of cancer. Moreover, in the group with the longest exposure time the incidence rate was significantly low. The Authors of the publication found no reasonable explanation for the above-mentioned (17).

Another significant threat posed by smoke during classical surgical procedures is its potential infectiousness. Many authors demonstrated the presence of living cells within the plume of the laser or diathermy smoke, which suggested its role as a potential vector of infection (18). This theory was further reinforced by the isolation of the human papilloma virus (19). These reports confirmed the clinical observations. HPV transmission was confirmed in case of a surgeon treating condylomas of the anus by means of laser therapy. The physician became sick with laryngeal papillomatosis and the viral serotypes were similar to those isolated from the operated patient. Other possible routes of infection were ruled out (20).

In another report, four physicians from the Mayo Clinic were diagnosed with flat warts, although in an atypical location (nasopharynx), which suggested the possibility of infection by smoke inhalation (21). If such transmission is possible a greater problem might be connected with the hypothetical possibility of HIV or HCV infections. Baggish et al. exposed the cell cultures infected with the immunodeficiency virus to laser therapy. The resulting smoke was collected and dissolved in culture medium. In such an environment the healthy cells were incubated. After 7 and 14 days of culture, viral protein p-24 presence was confirmed, and the PCR examination showed HIV DNA. However, after 28 days no markers of infection were observed. The authors explained the above-mentioned by the fact that laser therapy could compromise the integrity of the virus, so that long-term replication was impossible (22).

Laparoscopy

The impact of smoke on the patient and the operating team during laparoscopic procedures is multi-level, and may be responsible for unusual effects during classical surgery. Its main reason is that the peritoneal cavity is a closed space with a relatively small volume, as compared to the capacity of the operating room. Thus, the accumulation of smoke is much greater.

First of all, this might significantly reduce visibility during the surgical procedures. Weld
et al. demonstrated that the electrocautery instrument used is not without significance. The above-mentioned authors proved that monopolar electrocoagulation, due to the largest particle concentration interferes with the visibility to the greatest extent. In comparison, the relative visibility considering their experimental model amounted to 80% in case of the harmonic knife, and 2% in case of diathermy (23).

Secondly, due to the large surface of the peritoneum one may observe easy transfer of all substances to the patients' bloodstream, and their impact on tissues and organs. It is worth noting that carbon dioxide is the gas used for insufflation during laparoscopy. Therefore, cauterization occurs in an oxygen-free atmosphere, thus, combustion is incomplete which further increases exposure to hazardous compounds. Additionally, the vasodilatatory properties of carbon dioxide and positive pressure of peritoneal pneumothorax are factors that might influence absorption. For example, the CO level observed inside the peritoneal cavity ranged between 100 and 2200 ppm (24, 25). There are no established limits for intraperitoneal carbon monoxide concentrations. However, the Environmental Protection Agency (EPA) set a maximum level of 35 ppm for CO during the one-hour exposure (26), while OSHA- 400 ppm during 15 minutes of exposure (27). As one may observe the obtained concentrations during laparoscopy significantly exceed these limits.

Carbon monoxide easily penetrates into the systemic circulation. Its affinity to hemoglobin (Hb) is approximately 200-250 times greater, as compared to the affinity towards oxygen. The level of carboxyhemoglobin (COHb) in non-smokers amounts to less than 2%, and usually does not reach even 1%. It has been proven that slightly higher values (between 2-4%) are connected with a greater probability of an angina attack (28), in patients with coronary heart disease, or cognitive disturbances (29). Investigations concerning the content of COHb after laparoscopic procedures are inconclusive. Ott et al. observed elevated levels ranging between 2.8% and 18.5% (mean-10.5%). In case of patients with the highest values they observed headaches, dizziness, nausea, and general weakness. As suggested by the authors the above-mentioned could have been connected not only to the effect of anesthetic drugs, but also to carbon monoxide poisoning symptoms. Espert et al. (30) demonstrated a statistically significant average increase of the carboxyhemoglobin level from 0.7 to 1.2% during laparoscopic cholecystectomy. Beebe et al. (24) and Wu et al. (12), observed no such differences, and found no correlation between the postoperative symptoms.

Another pathological form of hemoglobin is methemoglobin (MetHb). It is created from the activity of substances oxidizing iron in the hem molecule, thus, becoming trivalent with the protein losing the ability to bind oxygen. Proper MetHb values account for 0.2-1% of hemoglobin. Similarly to CoHb, investigations concerning MetHb are inconsistent. Ott et al. observed increased MetHb values (2-3%) after laparoscopic procedures (31). Investigators from St. Louise, considering an experimental animal model observed no MetHb changes during the pre- and postoperative period (12).

Research conducted on other substances, such as hydrogen cyanide (prussic acid) or acrylonitrile demonstrated their elevated concentrations in the smoke from the peritoneal cavity, but they did not reach toxic levels. The already mentioned mutagenic benzene was not detected (12).

Researchers from the University of Dundee under the leadership of Alfred Cuscheri performed an experiment, which was aimed at determining the cytotoxic properties of laparoscopic smoke. They demonstrated a 30% decrease in cell survival after 15 minutes of exposure to substances contained in the surgical smoke (32). A similar sublethal effect might occur in vivo, and the substances contained in the surgical smoke can affect peritoneal cells of the immunological system leading to its suppression, which might prove to be very important when fighting an infection or cancer.

The third theoretical risk posed by smoke during laparoscopic procedures is the potential impact on the development of neoplastic metastases, especially port site metastases (33, 34). As previously mentioned, the presence of living cells has been experimentally proven (18). What's more, under the influence of the gaseous environment cells may undergo aerosolization, and thanks to the pressure gradient created between the peritoneal pneumothorax and gas leakage surrounding the trocars (the so-called chimney effect), one may observe
their implantation in the cannula tissues (34, 35, 36). This hypothesis, as the two previously mentioned has not received universal approval. Many research studies question cellular aerosolization as a significant etiologic mechanism of the above-mentioned phenomenon (36, 37). The effect of other factors, such as experience (38), surgical technique (39, 40), peritoneal epithelial damage (41), or type of gas required to produce the pneumothoax (42) is also postulated. The only undisputable fact is that further studies are needed, in order to determine the pathogenesis, and thus, elaborate an effective method preventing the development of port site metastases.

It is worth mentioning, that the problem of smoke resulting from tissue cauterization also concerns other endoscopic techniques, used in case of thoracosurgery and urology. As in case of the peritoneal cavity, the pleural cavity is a closed space with a relatively large surface allowing easy absorption of potentially harmful substances, or the direct impact of toxic compounds on surrounding tissues. Similarly, studies on the composition of gas created during transurethral resection of the prostate gland demonstrated its similarity to that generated during laparoscopy (43, 44).

How to minimize the risk?

There are several ways to reduce exposure to the harmful effects of surgical smoke. To move away from the direct streak or avoid inhalation seems to be a truism. Secondly, it is possible to use appropriate ventilation exhausts or HEPA filters, which effectively purify the air in the operating room (14, 45).

Moreover, there exist high-filtration surgical masks, which are not permeable to particles exceeding 0.1 μm. Unfortunately, despite the undeniable protection they provide, and the fact that they hinder normal breathing, they are not very popular amongst the personnel. It is worth mentioning that classical surgical masks do not provide such security, since they retain particles exceeding 5μm (46). In order to protect the personnel against microbial constituents of surgical smoke, masks coated with nanoparticles were created. Experimental studies demonstrated that the use of silver and titanium compounds provides effective antibacterial and antiviral protection (47).

Another method consists in the use of smoke evacuators. Currently, a number of different systems are available on the market, considering both conventional and laparoscopic surgery. They are usually placed in the proximity of smoke production leading towards its aspiration. Their effectiveness has been repeatedly demonstrated. However, these devices have been criticized, mainly for their price and loudness, being unwieldy (14, 45, 48).

CONCLUSIONS

In light of these figures it seems difficult to assess the harmful effect of surgical gasses. In vivo and experimental animal model investigations, as well as the toxicological analysis of the composition of smoke demonstrate the potential danger. Chronic exposure to surgical smoke, considering operating room personnel seems important. However, the only epidemiological investigation did not confirm the above-mentioned. Moreover, in connection with the widespread exposure to surgical smoke, and in the absence of immediate and typical results, the issue is constantly underestimated. Many authors point to the lack of sufficient information concerning the subject (49, 50, 51). An important issue concerns the steps to be undertaken in the given situation. Is it appropriate to stand still awaiting for further epidemiological investigations, which will eventually resolve the issue or initiate cost- and time-consuming steps to minimize the potential risk?

REFERENCES


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