The visualisation of surgical smoke produced by energy delivery devices: significance and effectiveness of evacuation systems

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ABSTRACT

Devices delivering energy to biological tissues (eg lasers, RF and ultrasound) can induce surgical smoke consisting of particles, vapor, gasses and aerosols. Besides interfering with the view of the surgeon, the smoke is a risk for the health of both the users and patients. In literature, it has been shown that surgical smoke can contain carcinogenic and harmful biological agents. However, the impact on health of the users and patients is widely debated. The use of smoke evacuation systems in the OR is usually governed by economical reason instead of safety issues.
A special image enhancement technique is used to study the behavior of smoke and aerosols and the effectiveness of smoke evacuation systems.
A back scatter illumination technique using 1 µs light flashes at video rate was applied to image the smoke production of various surgical devices without and with smoke evacuation while ablating biological tissues. The effectiveness of various smoke evacuation devices and strategies were compared.
The ablative thermal devices produced smoke but also aerosols. If the thermal energy was delivered in high peak pulses, the presence of aerosols was more significant. Ultrasound based devices produce mainly aerosols. The distance to the target, the opening of the evacuation nozzle and the dimension of aerosols were leading for the effectiveness of the smoke evacuation.
The smoke visualization technique has proven an effective tool for study the effectiveness of smoke and aerosols evacuation. The results can contribute to the necessity to use evacuation systems in the OR.

Keywords: surgical smoke, aerosols, energy delivering devices, OR, visualization techniques

1. INTRODUCTION

In many places in and around the house smoke is produced. In our kitchen, we produce smoke by cooking and in our living room we produce smoke with our fireplaces. In all these situations smoke is evacuated successfully either by suction hoods or chimneys. Smoking tobacco is prohibited in many public places and the government spends money on campaigns warning people not to smoke because of the danger involved concerning health. In every OR energy delivery devices are used. Especially, electro surgery devices are commonly used in every OR. Besides electro surgery equipment other systems are used that are capable of producing smoke as a result of dissecting and coagulating tissue. Lasers are also used for coagulating and dissecting tissue and these systems also have the capability of producing smoke especially when used on tissue in high power settings. Ultrasound equipment that is also used for dissecting tissue is capable of producing large clouds of aerosols. In these systems, water is used in order to facilitate an environment for cavitation effects and therefore an aerosol cloud is easily created. Smoke in the OR is generally underestimated. Some people think that surgical smoke is negligible. A reason for that could be that people are not aware of the danger involved in surgical smoke. Still there are people that think that smoke only consists of burnt particles, that smoke does not contain any vital components, that smoke produced by laser is more harmful than smoke produced by electro surgery equipment. The combination of the backscatter illumination technique and data from literature proofs that all these previous summarized presumptions are not true. The contents of smoke produced by energy delivering devices have been chemically analyzed and many mutagenic and carcinogenic agents have been found. Qualitative and quantitative studies have been performed as shown below. Still quantitative studies have to be performed at breathing level of the personnel in the operating room. The quantitative levels that have been analyzed were only performed at the source of the smoke producing delivery device.

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Substance	Formula	Concentration (ppm V)	OEL (ppm V)
1-Ethhyl-3-methyl-benzene	C_9H_{10}	12	NA
1,3-Butadiene	C_4H_6	1,5	5.0
Propanenitrile	C_3H_5N	18	NA
Toluene	C_7H_8	17	50
Thiocyanic acid methyl ester	CH_3SCN	22	NA
1-Heptene	C_7H_{14}	8,5	NA
Ethylene	C_2H_4	0.065	10000
Ammonia	NH_3	0.12	20
1-Decene	$C_{10}H_{20}$	190	NA
2-Furancarbox aldehyde	C_5HO_2	24	2
Methylpropene	C_4H_8	7.2	NA

Table 1. A list of mutagenic and carcinogenic agents that have been analyzed in surgical smoke. (Plast. Reconstr.Surg.114:458,2004)

In table 1 a list of identified gas components in electro surgical smoke is summarized. The concentration and the occupational exposure limit is shown in parts per million. The OEL is a maximum exposure limit that is allowed within 8 hours. Especially the concentration of 2-Furancarbox aldehyde (furfural) is alarming. These quantative measurements were obtained with carbon dioxide laser photoacoustic spectrometer. The samples were obtained from a reduction mammaplasty. The data described above were obtained 2 cm from the source of diathermia pencil.

The size of smoke particles compared to viruses and bacteria is very large. From these sizes it can be assumed that viruses and bacteria are able to travel through air and consequently are inhaled by the operating team. (j. Garden et al.,Paillomavirus in the vapour of carbon dioxide laser treated verrucae, J.A.M.A. 259: 1199,1988) There are cases known in which gynaecologists are infected with HPV by treating patients with condyloma accuminata. With the back scatter illumination technique it is not only possible to see smoke particles but also lager aerosols are clearly visible. It is not yet fully understood into which extend the travel of virus parts or bacteria can cause illness.

Type of particles	Measurement (micron)
Viruses	0,01 tot 0,3
HIV	0,18
HPV	0,045
Tobacco smoke	0,1 to 3,0
Surgical smoke	0,1 to 5,0
Bacteria	0,3 to 15,0
Lung-damaging smoke	0,5 to 5,0
Smallest visible particle	20

Table 2. Measurement of virus particles compared to smoke

Smoke evacuation systems have been developed for OR's and these systems can be very effective when used in the right way. Fluid evacuation systems that are used for evacuating blood and irrigation fluids are also used for evacuating smoke but these systems are not designed for smoke. Smoke evacuation systems require special filters and high airflow

The aim of this study is to show that smoke production of energy delivering devices can be substantial and that smoke evacuation can be very effective.

2. METHODS

A high speed backscatter illumination technique was applied to shows that smoke evacuation is necessary due to the large plumes that are produced by the various energy delivering devices. Video frames from a digital camera (frame rate up to 50 frames per second) were captured with a computer. In order to use a back scatter illumination, a stroboscope was used with a frequency at 50 Hz. We used chicken or porcine meat as model tissue for smoke production. Different energy delivery systems were applied on the tissue to create smoke. The stroboscope was placed behind the tissue towards the camera but not directly into the lens of the camera. In order to obtain the best effect the stroboscopic light had to "sheer" on the position of the energy delivery (fig.1)

We used a diathermia apparatus, a CO2 laser and an ultrasound dissector (CUSA) to deliver energy to tissue devices. For smoke evacuation we used a Buffalo smoke evacuation system.

For comparison, we also applied a liquid evacuator as normally being used in the OR for evacuating blood other fluids. In OR's, where no special smoke evacuation equipment is available, OR personnel tends to use these liquid evacuation systems to evacuate the smoke as good as possible. These systems, however, are not designed for evacuation of smoke. The vacuum system becomes contaminated with surgical smoke which should not be there.

Liquid evacuation tubing has a relatively small aperture and is not sufficient for removing large quantities of polluted air. Especially, when a small tube cannot reach the source effectively as performed with a liquid evacuation system. Special smoke evacuation tubing has a larger aperture en therefore smoke evacuation is more effective. Larger volumes of air can be transported that way. In our experimental setup we tested the difference between large and small tubing aperture. Nearly all smoke evacuation systems have diathermia pencil integrated tubing. We also tested these devices.

Different light settings were used to show the effectiveness of the backscatter illumination technique. In ambient light setting, smoke is visible. When the stroboscope light is applied the visibility changes dramatically in a positive way and surgical smoke becomes clearly visible. The surroundings of the experimental setup was covered with drapes to improve the contrast.

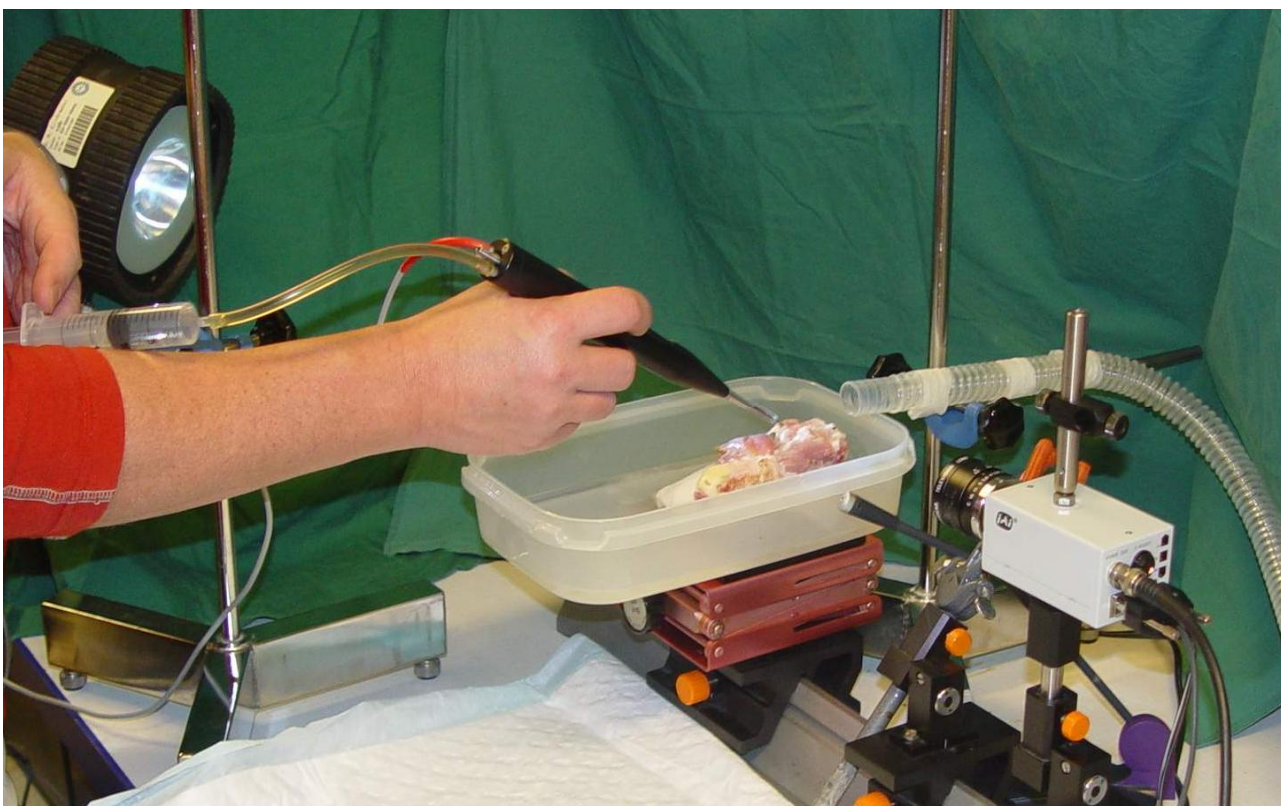

Figure 1. Experimental setup for imagingof surgical smoke

3. RESULTS

We imaged different energy delivery devices in different light settings. Two different settings are shown below:
Under 'normal' light conditions surgical smoke and aerosols are hardly visible. However, using our special illumination technique with backlight from a stroboscope, the contract is enhanced enormously in favour of smoke and aerosols.
The difference of applying smoke evacuation versus no smoke evacuation is also demonstrated for the three different energy delivering systems are tested: an electro surgery system, a CO_2 laser and and ultrasound dissector.
Besides under laboratory conditions our imaging technique was also applied in the operating room in live surgery during mammaplasty. It clearly proved the production of smoke by diathermia in a clinical situation and helped with the awareness for the OR personnel.

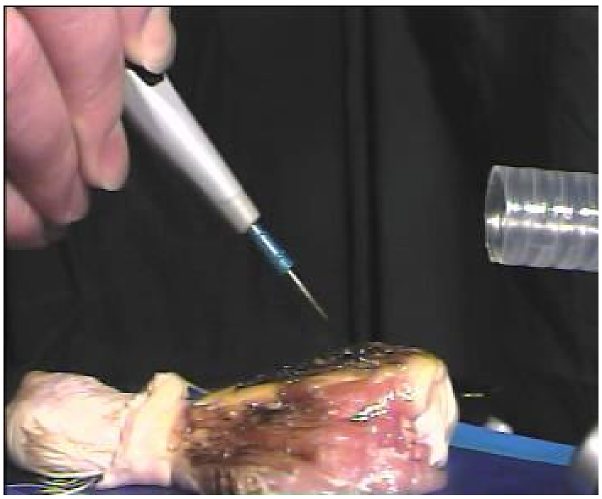

Figure 2. Electro surgical smoke can hardly been observed under normal light conditions

Figure 3. Using the backscatter technique the surgical smoke becomes clearly visible

Figure 4. The evacuation system for liquid is not effective for smoke removal and aerosols

Figure 5. An dedicated smoke evacuation system, however, removes the smoke effectively although aerosol might still be present.

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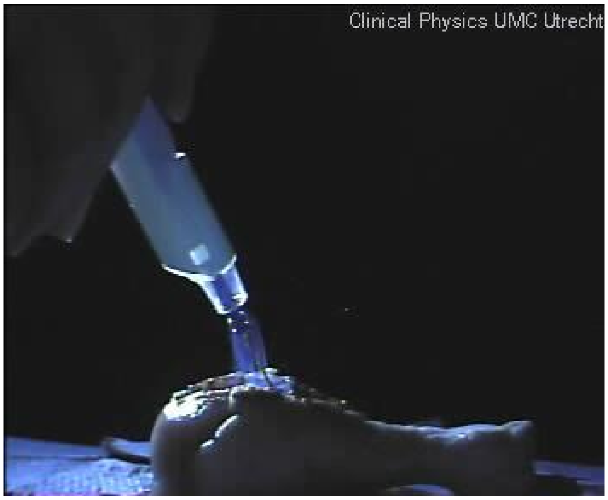

Figure 6. Electrosurgery companies have developed special smoke evacuation systems integrated in the diathermia pencil. This shows to be an effective way for smoke removal near the source.

Figure7. The pulsed CO_2 laser creates explosive smoke plumes and aerosol. The smoke is effectively removed. However, the aerosols are ejected at high speed from the source

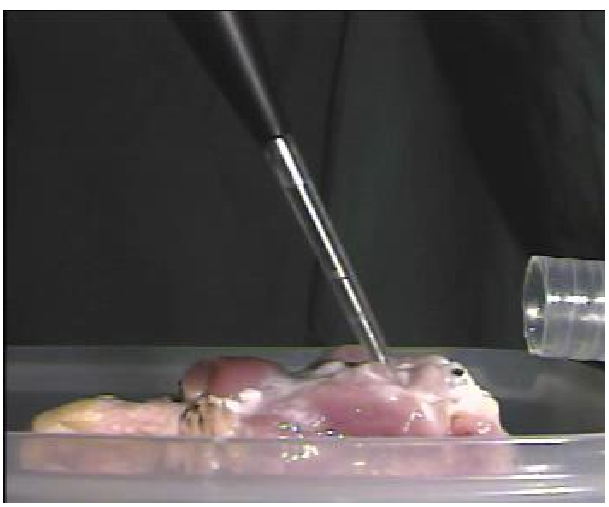

Figure 8. An ultrasonic resector is applied with a water coolant. Normal lighting conditions do not show any indication of aerosols or fumes.

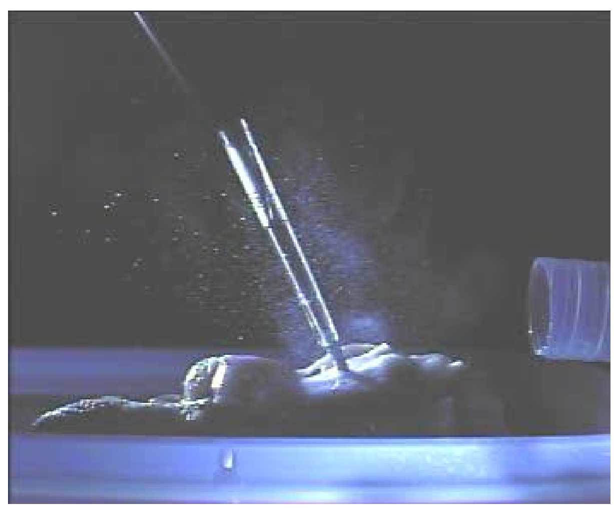

Figure 9. Using the special lighting technique, a spray of aerosols and cloud of water vapour becomes visible. Only the smaller droplets are removed by the evacuation system.

Figure 10. In the OR during a mamma reduction procedure using electrosurgery the smoke is hardly visible during normal light conditions. However, the OR personnel can smell it.

Figure 11. Using the special backlight illumination technique, the surgical smoke becomse visible and it shows to move along the face of the surgeon when no evacuation is used .

4. DISCUSSION

Using our backscatter illumination technique surgical smoke becomes clearly visible. It shows that surgical smoke does not only contain burnt particles but also aerosols and liquid droplets are formed and spread in air. Both the droplets and also smoke particles can contain mutagens and pathogens form a potential risk for infection through air.

A bigger tubing aperture is more effective compared to a smaller tubing aperture. However, when an integrated smoke evacuation system is built in a diathermia pencil, smoke evacuation can be very effective. Reducing the distance from tubing to source increases effectiveness of smoke evacuation Video clips made with backscatter illumination show that the use of smoke evacuation systems is very effective. By visualizing surgical smoke, people may realize that the contents can be dangerous. The presence of aerosols proof that surgical smoke does not contain of only burnt particles and therefore surgical smoke is not sterile. Pathogens travelling on smoke or aerosols can be vital. Therefore people should try to protect themselves with smoke evacuation systems and with special masks that filter out small particles. Ordinary face masks do not filter out any smoke at all. Therefore special masks with hepa filters are recommended.

We can also see that smoke produced by a pulsed CO_2 laser is spread slightly different compared to electro surgery equipment. The CO_2 laser in pulsed mode spreads the smoke in a more explosive way and reaches further. But when special smoke evacuation is used, all surgical smoke can be evacuated successfully. Bigger aerosols cannot be evacuated because they are too heavy to be transported by the airflow produced by the smoke evacuator. However, aerosols are heavier than smoke particles and will not be transported into the breathing area as much as smoke particles.

Still good quantification of inhaled air by the surgical team needs to be done. The backscatter illumination technique can only be used as a tool to let people realise how much smoke is produced. It is strange that in more and more countries tobacco smoke is prohibited in public areas and that smoke produced in the OR is acceptable. However in Denmark it is prohibited to use energy delivery devices without special smoke evacuation systems. Every source that creates smoke or aerosols can be visualized with this technique. We still want to visualize the presence of aerosols and particles in dentistry. We expect to see many aerosols in drilling and laser procedures.

Various publications have presented the contents of surgical smoke and there is debate going on about the actual concentrations of the mutagens and pathogens. In this study we wanted to stay out of this discussion but make people in the OR aware of the presence of smoke by visualization. Usually, the smoke can easily be detected just by the smell. We have used our images in training presentations for OR nurses. The response was enormous just by making the smoke visible, the potential hazards seem to come alive. Due to budgetary reasons, the investment in special evacuation systems for the OR by hospital administrators seems to have a low priority (in the Netherlands). Our imaging technique has already helped to convince some hospitals to buy evacuation equipment.

There are hardly any publications or data on OR personnel being infected by smoke of aerosols. It might be difficult to prove direct or indirect contamination. However, many OR nurses will confirm they have had irritation of their airways. Unofficially, surgeons will state they know of colleagues (e.g. gynaecologists) who developed infections diseases in the months or airways which they attribute their clinical practice.

Using radiation in the hospital, radiation protection and safety regulation make use of the ALARA (As Low As Reasonably Achievable) principle. Looking at the health risks involved this principle should also be used when surgical smoke is concerned.

5. CONCLUSIONS

The smoke visualization technique has proven an effective tool for study the effectiveness of smoke and aerosols evacuation. The results can contribute to the necessity to use evacuation systems in the OR.

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