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CO_2 laser-photoacoustic analysis of smoke emitted during minimal invasive electro-knife surgery

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Abstract. Smoke samples produced by colorectral laparoscopic operations have been studied with a $^{13}CO_2$ laser-based photoacoustic spectrometer. The most difficult problem was the existence of almost 100% CO_2 present in the sample. The PA measurements were complemented with broad range FTIR spectra. An important result is the striking difference between sample spectra taken from different operations and patients. Apart from dominating CO_2, a first spectral analysis revealed the existence of ∼100 ppm water vapor and of unknown compounds that could not yet be identified but that are not identical with compounds found in related studies.

1 Introduction

Surgery performed with tools such as lasers, ultrasonic (harmonic) scalpels, and electro-knives produces smoke during tissue dissection [1]. This smoke is potentially dangerous for both the medical staff in the operating room and the patient [2,3]. The danger for the patient occurs mainly during laparoscopic procedures, where the smoke is concentrated in the peritoneal cavity. Hence, detailed knowledge of the chemical and biological composition of surgical smoke is highly desirable.

In a previous study we investigated the smoke produced during reduction mammaplasty with an electro-knife with the aid of a CO_2-laser photoacoustic system [4]. In a most recent study we investigated samples from laparoscopic surgery. In this case, the produced smoke differs in composition from open surgery for two reasons: firstly, laparoscopic procedures are usually performed in a CO_2 atmosphere and secondly, the smoke is generated inside the patient and the smoke-containing gas sample is evacuated periodically.

2 Experimental set-up and methods

We examined smoke samples produced with bipolar scissors (LigaSure^{TM}). This is a bipolar vessel sealing system: the tissue is grasped with the jaws and by applying pressure and heat, blood vessels up to a diameter of 7 mm are sealed. The tissue can then be dissected with the same tool resulting in only little bleeding. A feedback system controls the amount of energy applied and stops the power delivery when the seal – formed by partially denatured proteins – is completed. As mentioned we collected samples produced during laparoscopic colorectal surgery. Since the abdominal cavity of the patient is filled with CO_2 for these operations, the smoke is produced in a CO_2 atmosphere. At irregular time intervals during the operation, the gas was released into plastic bags (Linde, Plastigas) whose internal surface is treated to minimize adsorption and

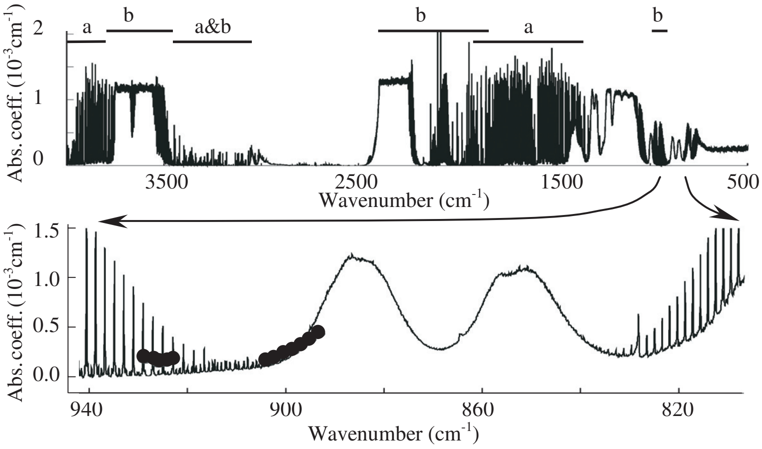

Fig. 1. FTIR overview spectra of smoke sample. The PA data taken with the $^{13}CO_2$ laser PA spectrometer are shown as dots (λ). The letters **a** and **b** denote H_2O vapor and CO_2 absorption, respectively. The origin of the two broad peaks between 840 and 900 cm^{-1} is still unknown.

desorption effets. The bags were filled to slightly above ambient pressure, holding ca. 5.5 l and were then brought to our laboratory for analysis. We employed our CO_2 laser photoacoustic (PA) spectrometer with the multi-pass acoustically resonant PA cell with a 16-microphone array described in detail previously [5]. In order to take the expected high absorptions into account the cell was not operated at its full potential but instead a stable configuration was used with 16 (instead of 36) beam passes. To reduce interferences with CO_2 present in the smoke sample (almost 100%), the measurements were performed with a cw sealed-off $^{13}CO_2$ laser in the wavelength range between 10.7 μm and 11.3 μm. The sealed laser tube was rather old resulting in a comparatively low laser power of a few 100 mW for the strongest lines at the beginning of the study and only 150 mW towards the end. As a consequence the laser could only be operated on = 20 lines compared to the usual 60–80 lines. Samples were taken from three different patients during operations on different days. PA spectra were recorded at different times after the sample was taken in order to study effects of adsorption and desorption or chemical changes during transport and storage in the bag. In addition, extended IR spectra were recorded with a commercial FTIR spectrometer (Bomem, DA8) to complement PA spectra.

3 Results and discussion

Our first results demonstrated the excellent stability of the sample with respect to storage time in the bag: Even a spectrum taken 25 h after the first spectrum coincides with the spectrum recorded soon after sampling. Furthermore, although the samples contained mainly CO_2, distinct differences were found between sample spectra taken during different operations and background spectra recorded from samples of CO_2 taken from the CO_2 gas bottle. Figure 1 shows an overview FTIR spectrum between 820 cm^{-1} and 1020 cm^{-1} with a resolution of 0.1 cm^{-1} of a typical smoke sample.

As expected the IR spectrum is dominated by CO_2 and H_2O vapor absorption but there are also some additional features, e.g. two absorption bands between 840 and 900 cm^{-1} plotted in more detail on the bottom of the figure. These 20 cm^{-1} broad peaks with no substructure resolved at the given spectral resolution of the FTIR instrument indicate the presence of large molecules. The measurements taken with the CO_2 laser spectrometer are denoted as single dots. The individual PA data agree well with the FTIR spectrum around 900 cm^{-1} ($^{13}CO_2$ 10P laser branch), but not for the wavelengths between 920 and 930 cm^{-1} with dominant CO_2 absorption, of course not coincident with the $^{13}CO_2$ laser lines.

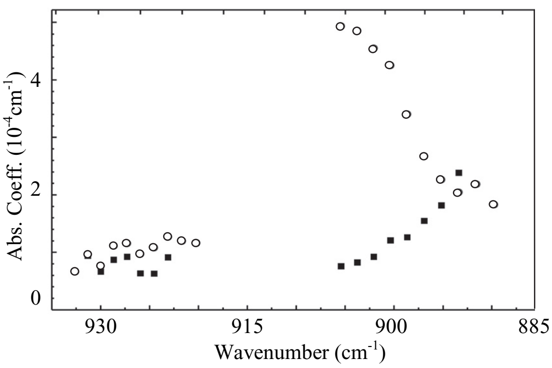

Fig. 2. PA spectra of smoke samples (○ and ■) taken during electro-knife laparoscopic colonrectal surgery during operations on two different patients.

The FTIR and PA spectra were carefully analyzed on the basis of compounds found in two previous studies. In an *in vitro* study conducted on porcine liver 21 chemical compounds like hydrocarbons, nitriles, amines and aldehydes were identified by gas chromatography–mass spectrometry (GC-MS) [6]. We found 17 of those IR spectra in the NIST database [7] though with a poor resolution of only $4\,cm^{-1}$, but none of them could be identified neither in our FTIR spectra nor in the PA spectra. Furthermore, none of the 15 compounds that we had determined in our previous *in vivo* study [4] could be found in the current samples. Hitherto, only ∼100 ppm of H_2O vapor in a background of almost 100 % CO_2 could unequivocally be identified in the present smoke samples. It should be noted that PAS – depending on the laser source employed – can offer both higher sensitivity and spectral resolution than FTIR on the cost, however, of limited spectral range. Furthermore, a laser-PAS spectrometer can be much more compact and cheaper than a high-resolution FTIR instrument.

A most interesting result is depicted in Fig. 2. It shows the spectra of two smoke samples taken from different operations on different patients. While similar spectra resulted in the 10R branch of the $^{13}CO_2$ laser emission, drastically different spectra were obtained for the 10P branch corresponding to wavelengths between 890 and $905\,cm^{-1}$. Whereas the lower spectrum shows a similar behaviour as the one shown in the FTIR/PA spectra of Fig. 1 (which originates from still another operation and patient), the upper spectrum around $900\,cm^{-1}$ ($^{13}CO_2$ laser 10 P branch) appears completely different.

Several reasons could explain the fact that certain compounds found in other related studies could not be identified in this study: i) the smoke production in our previous study on reduction mammaplasty [4] was much heavier and the operation was performed in air, ii) the overall detection sensitivity in the current study was limited to a minimum detectable absorption coefficient of about 10^{-5} cm^{-1} due to deteriorating laser performance, and iii) the other cited study [6] was performed *in vitro* and on animal tissue. A direct comparison is thus at least questionable. It should also be noted that the almost 100% abundancy of CO_2 in the samples was problematic although a $^{13}CO_2$ laser was employed for the measurements. In further studies, the problem of limited spectral range and coverage could easily be overcome by using other tunable laser sources, e.g. difference frequency generation or quantum cascade lasers. The striking difference between smoke samples taken from similar operations on different patients definitely needs further investigations before conclusions on the reasons can be drawn.

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