Investigation of water spray to reduce collateral thermal damage during laser resection of soft tissue

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Abstract: To reduce unwanted collateral thermal damage to surrounding tissue and organs during laparoscopic laser dissection (cw, wavelength: 1.9µm) of porcine liver water spray was used. Size and amount of the produced water droplets of the water spray were photographed by short time imaging and analyzed by imaging software. At in vivo measurements on fresh porcine liver the depth of thermal damage was reduced by 85 % with water spray and the lateral size of thermal damage at the tissue surface could be reduced by 67%. This results show that especially for laparoscopic laser surgery water spray application might be a useful tool to avoid unwanted collateral thermal damage.

OCIS codes: 000.2170; 170.1610

1. Introduction

Using laser radiation (e.g., at a wavelength of 1.9 µm) to dissect soft tissues (liver, kidney, etc.) in open and even more so in laparoscopic surgery commercial quartz fibers are used for transmission of the laser radiation, [1, 2]. After dissection of the target tissue, the laser radiation continues to emit from the fiber tip and may damage organs located behind. To avoid this collateral thermal damage, a water spray in front of the distal end of the transmission fiber was produced in a way that the emitted laser radiation is partially absorbed. Since this water spray arises about 2-3 mm behind the nozzle, the ongoing dissection was not significantly affected, since the fiber tip is then in contact with the tissue. For the success of this technique, the parameters of the water spray including droplet size, density and size of the total cloud are crucial. Therefore short time imaging was used to determine size and density of the water droplets. The aim of this study was to investigate the dependence of the density and the size distribution of the water droplets in the water spray to reduce collateral thermal damage most effectively.

2. Material and Methods

In order to produce the water spray, a nozzle was connected to various constant flow rates of CO_2 gas (2, 3 and 5 l/min.) As liquid component water (Aqua ad iniectabilia, Braun Melsungen AG, Melsungen, Germany) was supplied from a reservoir. The nozzle was mounted vertically above a collecting container. To analyze the shape of the cloud as well as the size and density of the water droplets short time imaging was employed. Images of the water spray cloud were taken using a frequency-doubled Q-switched Nd:YAG laser system (MBB Medizintechnik GmbH, Ottobrun, Germany), emitting light at a wavelength of 532 nm with a pulse length of 13 ns (FWHM). Incorporating a cylindrical lens (f = 50mm) and a plano-convex lens (f = 400 mm) in the X-plane an illumination field of 2cm in height was achieved. In the Y-plane, a focus with a beam width of 100 microns was produced. This beam width is the depth of field of the image [3]. A digital camera "FinePix S1 Pro" with 3.4 million pixels (Fujifilm Europe GmbH, Dusseldorf, Germany) and a zoom lens with focal length 24-70 mm (Tamron Europe GmbH, Cologne, Germany) were used, see Figure 1.

Medical Laser Applications and Laser-Tissue Interactions VI, edited by Lothar D. Lilge, Ronald Sroka,
Proc. of OSA Biomedical Optics-SPIE Vol. 8803, 88030F · © 2013 OSA-SPIE
CCC code: 1605-7422/13/$18 · doi: 10.1117/12.2032384

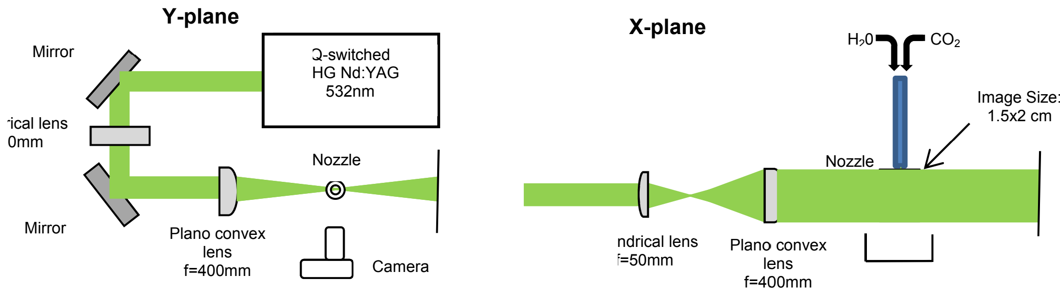

Fig. 1. Setup of the short time imaging in X- and Y-Plane. The Image size was 1.5 x 2 cm with a depth of field of 100 µm

For digital evaluation image processing software was used (ImageJ, v. 1.44, NIH, Maryland, USA) generating a list of the amount and the number of contiguous pixels. Thereby the amount and the size of the photographed water droplets were determined. The pixel size of the CCD array was 12.5 µm. As the water droplets were assumed to be circular, the square pixels were converted into idealized circles. Thus resolution of the smallest water droplet was 14.1 µm in diameter. In each case, 5 photos were evaluated at the same parameter setting.

In an in vivo study on porcine liver the thermal damage at the tissue surface was evaluated with and without water spray. A Laser prototype for soft tissue dissection (Medical Laser Centre Lübeck, Lübeck, Germany) emitting a wavelength of 1.9µm was used. A quartz fiber with core diameter of 365 µm and a NA of 0.22 was held 5cm above the tissue. Laser radiation was emitted for 5 s without moving the fiber tip. Two parameters of the thermal damage were measured:

1) Diameter of the circular whitening at the tissue surface
2) Maximum depth of the tissue coagulation in a cross-sectional cut

3. Results

Figure 2 shows the different water spray clouds produced by varying the CO_2 gas flow rate. The higher the gas flow rate the denser the cloud appears but also the water flow rate increases from 7 ml/min to 13 ml/min. Figure 3 shows the size distribution of the water droplets. By increasing the gas flow rate from 2 to 3 l/min the total amount of droplets increase by a factor of 5. At further increase of the gas flow rate from 3 to 5 l/min the amount of water droplets is doubled.

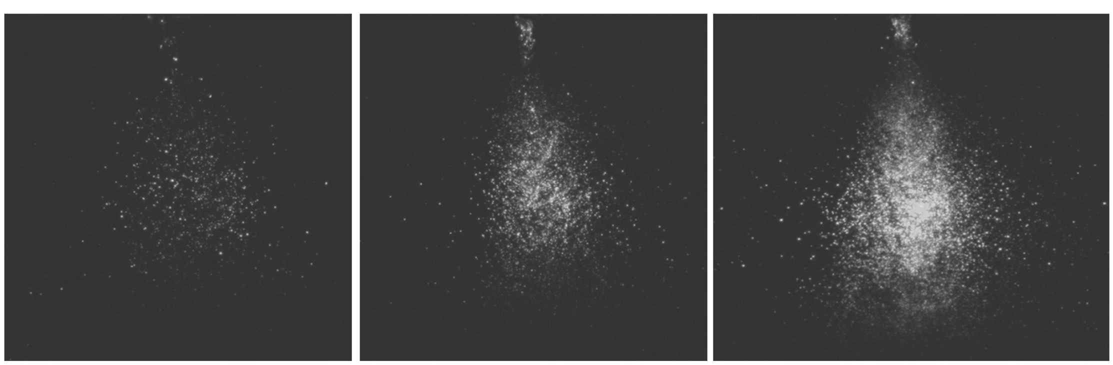

Fig. 2. Images of the water spray taken by short time imaging. CO_2 gas flow was 2 l/min (left); 3 l/min (center) and 5 l/min (right).

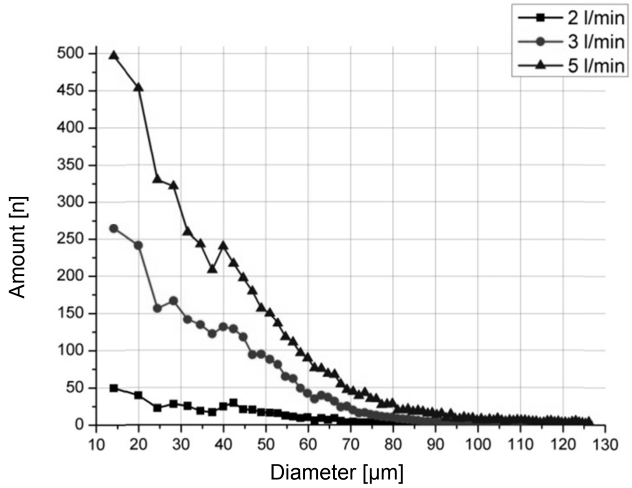

Fig. 3. Size distribution of water droplets generated by a constant CO_2 gas flow rate of 2 l/min (squares), 3 l/min (circles) and 5 l/min (triangles).

At a constant CO_2 gas flow rate of 2 l / min with a water consumption of 7 ml / min a very low dense water spray cloud was achieved. By increasing the CO_2 gas flow rate to 5 l / min and a water consumption of 13 ml / min a significantly denser water spray cloud was produced. To evaluate the reduction of thermal collateral damage a cw Thulium laser system emitting at a wavelength of 1.9 µm was used at power of 20 and 40 W. At a distance of 5cm from the emitting fiber tip to the tissue the depth of thermal damage was reduced by 85 % with water spray and the lateral size of thermal damage at the tissue surface could be reduced by 67%. The reduction in thermal collateral damage of tissue at a distance of 5 cm using water spray is shown in Figure 4.

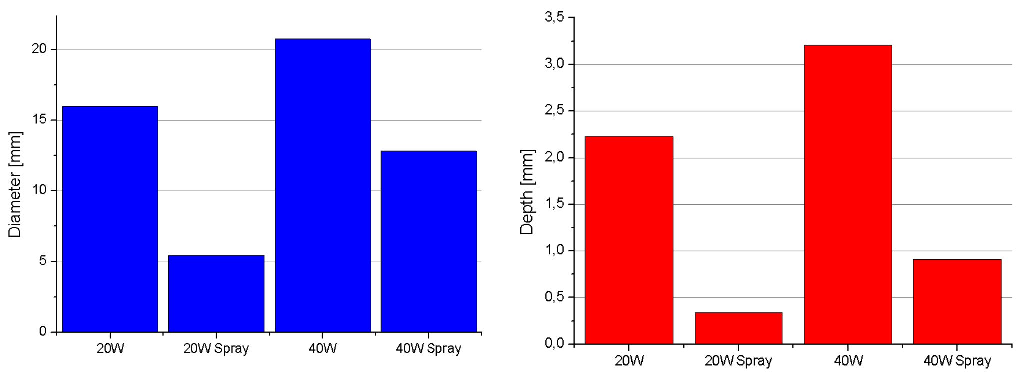

Fig. 4. Collateral thermal damage at porcine liver tissue by laser radiation at 1.9 µm transmitted via 365 µm fiber (NA 0.22) for 5 s. Distance fiber tip to tissue surface was 5cm.

4. Discussion

It was shown that short time imaging setup with a laser pulse length of 13 ns is sufficient to analyze the parameters of the water spray cloud with respect to the number and the size of the water droplets. At the focal plane in the X-plane, however, only a depth of field of about 100 µm was achieved. Therefore not all individual water droplets (especially in high density water spray clouds) could be resolved completely. However this photographic analysis method can be used to optimize the geometric construction of the nozzle for the desired effect.

Using a cw Thulium Laser system at power of 20 and 40 W for soft tissue dissection, it was shown in the animal study that the reduction of the thermal collateral damage was 85 % in depth and 67% in diameter respectively at 20 W laser power. At a higher power level of 40W the reduction decreased, only 72% in depth and 38% in diameter were achieved. To increase the efficiency of the water spray at a power level of 40 W the nozzle may have to be redesigned. Especially for laparoscopic laser surgery water spray application might be a useful tool to avoid unwanted collateral thermal damage.

5. Acknowledgement

This work was supported by a grant of the Central Innovation Program for SMEs (ZIM) of the Federal Ministry of Economics and Technology of Germany as a project of the Association of Industrial Research Consortia "Otto von Guerike" (AiF) (grant number KF2341202AK0).

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