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Evaluation of a Smoke Evacuator Used for Laser Surgery

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A preliminary study was conducted to determine the effectiveness of a smoke evacuation system used in laser surgery. A 30 W medical CO_2 continuous wave (CW) laser was used to make cuts in a pork chop to simulate smoke production during laser surgery. A commercially available smoke evacuation system was used to control the smoke from the simulated surgery. The smoke concentration was measured at 6 in and at 3 and 4 ft from site of laser interaction. The nozzle of the smoke evacuator was located at distances of 2, 6, and 12 in from the surgical site to measure the relative effectiveness of the control. Complete control of smoke was achieved when the nozzle was located at 2 in, but significant amounts of smoke escaped when the nozzle was located at 6 and 12 in. Suggestions for the use of the smoke evacuation system and areas for further study are given.

Key words: emission, control, ventilation, fume

INTRODUCTION

Laser surgical procedures allow more precise control of surgical parameters and can reduce patient recovery times. Unfortunately, one of the disadvantages in using lasers for surgical procedures is the production of smoke and fume. Proper control of smoke/fume emissions from laser surgery procedures is needed because of occupational health issues of hospital personnel, comfort of patient, restrictions of the surgeon's field of view, and the smell of the emissions [1]. One more recent health issue concerns the possible presence of HIV and hepatitis B virus in the smoke from surgery. Intact DNA from human papiloma virus (HPV) has, in fact, been observed in the smoke from laser surgery [2]. There are several smoke evacuation systems commercially available that attempt to capture emissions from these procedures. The systems are self-contained suction sources that draw fumes produced from the surgical process into an air cleaning unit. Typically, a hose fitted with a nozzle is attached to the suction source and the nozzle is located as close as possible to the site where the surgery is performed on the patient. One of many questions to be answered in controlling the emissions from these procedures, is, in fact, how close the nozzle should be located to this site. In this article, the results of a preliminary study to answer this question are reported.

MATERIALS AND METHODS

Experiments were performed to estimate the relative degree of emission control with a suction nozzle located at various distances from the laser interaction site. The experiments were performed in a closed room about 10 ft wide and 20 ft long. The room had general ventilation from the heating and cooling system, but no special ventilation other than the smoke evacuator. A 30 W contin-

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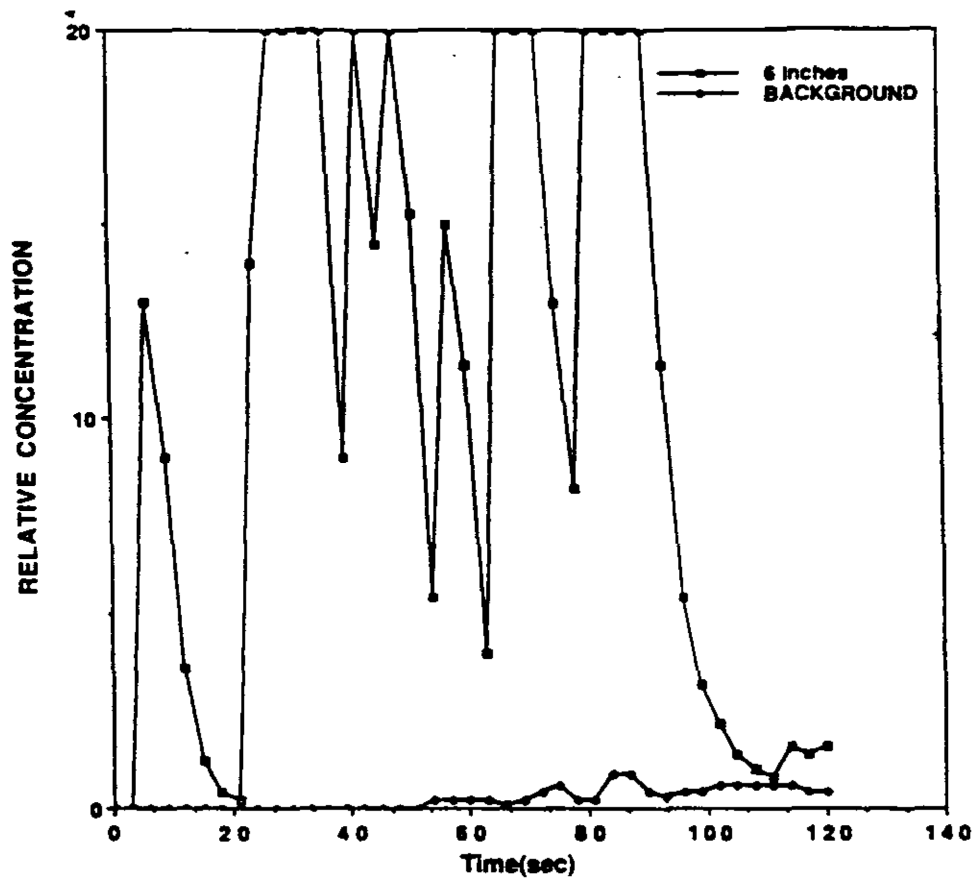

Fig. 1. Smoke concentrations in laser room without smoke evacuation system in operation. Laser in operation for entire period of measurement.

uous wave (CW) CO_2 medical laser system was used that had an articulated arm beam delivery system with a 125 mm focal length lens. The laser spot size ranged from 0.5 to 1.0 mm. The workpiece used to simulate a patient was a pork chop about 6 in long, 4 in wide, and 0.5 in thick. The pork chop was cut by the laser in a manner similar to a surgical event. Since laser surgical procedures can vary widely in the laser-patient configuration and the quantity of smoke produced, the simulation used does not represent any particular operating procedure. The smoke evacuation system used to contain the fumes was a Lase System II (Lase Inc., Cincinnati, OH) smoke evacuation system. This unit has a nominal flow rate of 50 cfm and has HEPA and odor elimination filters. The HEPA filters are rated at 99.97% capture for 0.3 μm particles. The fumes were drawn into the Lase System II through a 1.25 in OD hose with a manufacturer provided oblong shaped nozzle on one end. The nozzle at the end of the hose was mounted at distances of 2, 6, and 12 in from the laser interaction site in order to estimate the effect of distance on control of the fumes.

Three direct reading dust monitors were used to estimate the fume concentrations at various distances from the laser interaction site. A Hand-held Aerosol Monitor (ppm, Inc., Knoxville, TN) (HAM) was mounted 6 in above the laser interaction site to monitor the area where the surgeon and other personnel directly performing the surgery would be located. Air was drawn into the HAM at 1 liter per minute (LPM) with a portable sampling pump.

Two Real-time Aerosol Monitors (MIE, Inc., Bedford, MA) (RAM-1) were used to estimate fume concentrations at 3 and 4 ft from the laser interaction site and were located about 5 ft from the floor of the room. These were used to monitor areas where other personnel might be present in the operating room and were used to estimate background concentrations in various parts of the room. Data from the dust monitors were recorded using a strip chart recorder. The values for the

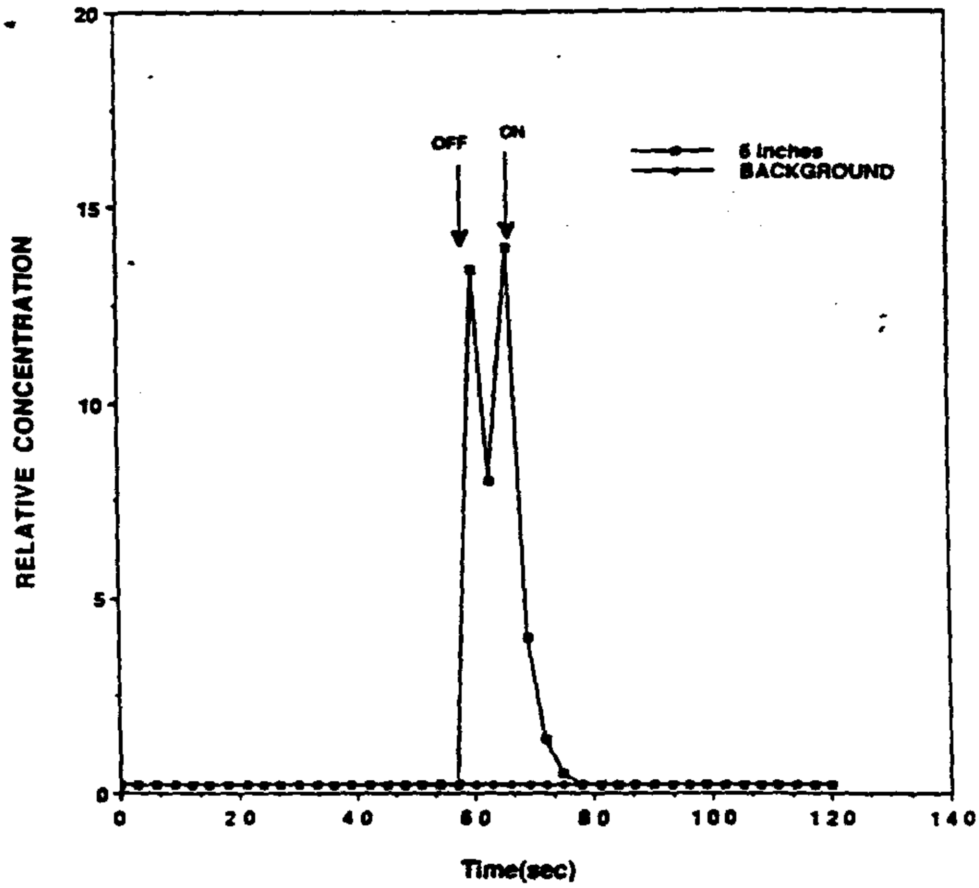

Fig. 2. Smoke concentrations in laser room with nozzle of smoke evacuation system positioned 2 in from laser worksite. Laser on for entire period of measurement but smoke evacuation system was turned off and on.

background concentration in Figures 1–3 are the average of the values given by the two RAM-1's.

It should be pointed out that both the HAM and RAM-1 respond preferentially to particles in the respirable size range (particles less than 3 μm) [3]. Their response also changes with the particle size of the aerosol being monitored. However, the particle size of the smoke should be constant so that relative changes in concentration can be monitored. Since the monitors were not calibrated for the smoke produced in the experiment, the plots produced are on a relative scale to show the level of control rather than absolute gravimetric concentrations.

RESULTS

Figures 1–3 show the effect of placing the smoke evacuation system nozzle at various distances from the laser interaction site.

Figure 1 shows the fume concentrations measured at 6 in from the laser interaction site as determined by the HAM and the room background concentration as determined by the two RAM's when the smoke evacuation system was not in operation. Concentrations near the interaction site could easily exceed 20 (the full-scale range for the monitors) for extended periods of time when the laser was operating. The background concentration in the room also increased from 0 to 1.4 during laser operation. The wide variation in concentration levels observed at 6 in during laser operation was due to two factors. First, as the laser beam came into contact with different parts of the target different amounts of smoke were produced since different parts of the target produce different smoke levels and beam interaction was not constant. Second, transport of the smoke to the HAM is not constant since it is dependent on the air currents in the room, which

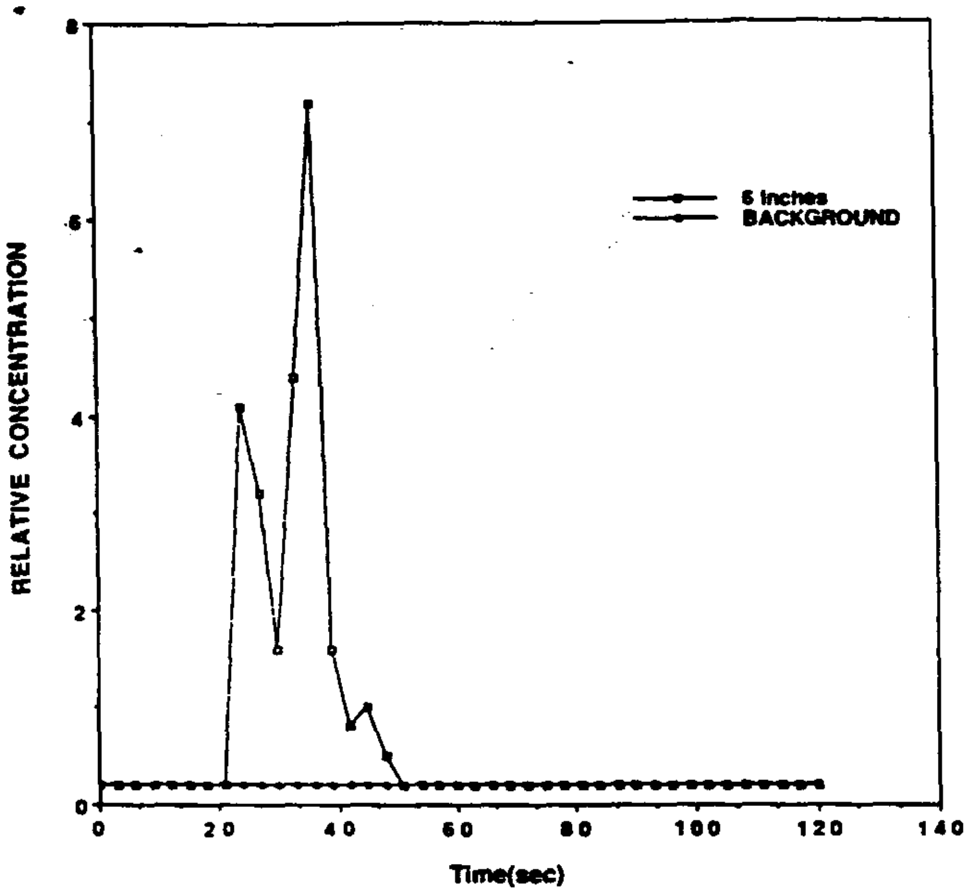

Fig. 3. Smoke concentrations in laser room with nozzle of smoke evacuation system positioned 6 in from laser worksite. Laser and smoke evacuation system left on for entire period of measurement.

are not constant, and this would result in concentration fluctuations. Figure 1 clearly indicates that there is a need to use a smoke evacuation system since high levels of smoke relative to background levels are produced.

The fume concentrations measured with the smoke evacuation system nozzle located 2 in from the laser interaction site is shown in Figure 2. The smoke evacuation system completely collected the fumes from the laser operation when the evacuator was operating. The concentration observed remained at the room background level both at the interaction site and in other areas of the room. When the smoke evacuation system was turned off for a brief period, the concentration at the interaction site increased rapidly to values above 10. However, as soon as the smoke evacuation system was turned on, the levels again decreased to those of the room background. Background levels in the room were not affected by briefly turning off the smoke evacuation system.

Figure 3 shows the fume concentrations observed with the nozzle located about 6 in from the laser interaction site. Collection of fumes was not complete and concentrations as high as 8 were observed 6 in from the laser interaction site. Concentrations of smoke as measured by the HAM fluctuated and decreased after 50 seconds due to variable transport of the smoke to the HAM by air currents in the room. It should be pointed out that both the laser and the smoke evacuation device were operating during the entire time that these measurements were made and still smoke collection was not complete. Background concentrations in the room did not increase measurably during operation of the laser.

The fume concentrations were also measured with the nozzle located 12 in from the laser interaction site. The results were qualitatively similar to those shown in Figure 3 except that concentrations higher than 20 were measured at 6 in from the laser interaction site. Background levels in the room also increased from about 0.4 to about 1 during the time the laser was in operation.

The results observed can be compared with those predicted by standard ventilation calculations. The formula for predicting flow rates around circular exhaust openings is $Q = V(10x^2 + A)$ [4], where Q is the volumetric flowrate, V is the air velocity at the center-line of the exhaust opening at a distance x from the opening, and A is the area of the opening. Although the nozzle is not completely circular in shape, this formula can give an approximate air velocity at various distances from the opening since shape will not affect it greatly. If we use $Q = 50$ ft^3/min (the nominal flow rate of the evacuator), $V = 150$ ft per minute (fpm) (a control velocity for conditions similar to those in an operating room), and A as the area for a 1.5 in round opening, we obtain $x = 2.1$ in. It should be noted than this formula is only an approximation and will not give a precise value of the velocity at any point. However, it is useful for giving an approximate idea of where adequate control can be maintained. These calculations show that the nozzle must be closer than about 2 in from the laser interaction site to obtain a control velocity of 150 fpm or greater. One hundred fifty feet per minute is a value used for control velocity under conditions similar to those in an operating room.

DISCUSSION

The smoke evacuation system studied is capable of providing what appears to be complete collection of fumes only if the nozzle is within a short distance of the laser interaction site. Positioning of the nozzle of the smoke evacuator at a distance of 2 in from the laser interaction site was found to be adequate. Other studies have also indicated that the nozzle of the evacuator must be close to the site of laser interaction [5,6] to obtain efficient collection. However, the smoke evacuation device should be turned on at the same time or before the laser and run during the entire time the laser is in operation. If the smoke evacuation system were turned off for even a short period, high concentrations could result. These could be controlled rapidly if the device were turned on but exposure could result in the meantime. Perhaps, permitting the smoke evacuation system to operate for 20–30 seconds after the laser was turned off is another possible control measure for situations where continuous operation of lasers is the rule.

Distances of greater than 2 in are likely to result in exposure to high concentrations for personnel working near the laser interaction site and in addition are likely to result in the background concentration in the room being increased. This was certainly found to be the case when the nozzle was at 12 in from the laser interaction site. If the simulated surgery had been carried on for periods of time greater than those used in this study, the background likely would have been increased with the nozzle held closer than 12 in. This would expose personnel located at greater distances from the laser interaction site. Surgical procedures that require the nozzle to be located at distances greater than 2 in may require other means of smoke control. It should be noted that using the smoke evacuation nozzle at distances of 2 in or less from the interaction site may also require adoption of resterilization techniques for the nozzle of the smoke evacuator since it will be close to the surgical site. Although the nozzle is sterile when it is received from the manufacturer, it may become contaminated as surgery proceeds.

Studies are needed to characterize further the controls for laser surgery. The chemical and biological content of the smoke should be determined to assess the hazards presented to personnel. From these results the efficiencies of air cleaners used in the evacuation systems can be determined. It has been determined that filters in smoke evacuators must be able to collect particles efficiently down to 0.1 µm [5]. Complete flow patterns around the nozzle of the smoke evacuation system need to be plotted, and further studies of various operating parameters such as laser power levels, different nozzle designs, and placement of the nozzle are needed. Presence of the surgeon may increase smoke concentration in his/her breathing zone, so this is another area that needs further study. Finally, the present systems are very noisy, another drawback to their use; therefore; other methods of emission control should be investigated.

REFERENCES

1. Baggish MS, Elbakry M. Effects of laser smoke on lungs of rats. Am J Obstet Gynecol 1987; 156:1260–1265.
2. Garden JM, O'Bannion MK, Shelnitz LS, Pinski KS, Bakus AD, Reichmann ME, Sandburg JP. Papillomavirus

in the vapor of carbon dioxide laser-treated verrucae. JAMA 1988: 259:1199–1202.
3. Smith JP. Baron PA. Murdock DJ. Response characteristics of scattered light aerosol sensors used for control monitoring. Am Ind Hyg Assoc J 1987: 48:219–229.
4. Committee on Industrial Ventillation. "Industrial Ventillation: A manual of recommended practice." 19th edition. Cincinnati: American Conference of Governmental Industrial Hygienists, 1986.
5. Baggish MS. Baltoyannis P. Sze E. Protection of rat lung for the harmful effects of laser smoke. Lasers Surg Med 1988: 8:248–253.
6. Mihashi S, Ueda S, Hirano M, Tomita Y, Hirohata T. Some problems about smoke condensates induced by CO_2 laser irradiation. Proceedings of the 4th Congress of the International Society for Laser Surgery, Tokyo, Japan. 1981:(2-25)-(2-27).