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Smoke From Laser Surgery: Is There a Health Hazard?

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The composition of plume produced during carbon dioxide laser endoscopic treatment for endometriosis was examined to determine whether it represented a hazard to the surgical staff. A total of 32 plume samples were collected from 17 women undergoing laser laparoscopic treatment for endometriosis and/or adhesions. The smoke was found to consist of particles having a median aerodynamic diameter of 0.31 μm with a range of 0.10–0.80 μm. The size range has two consequences: 1) using a human red blood cell as a model for all cells, it can be stated with greater than 99.9999% certainty that no cell-size particles, including cancer cells, are present in the plume; 2) particles in this size range are too small to be effectively filtered by currently available surgical masks.

Key words: gynecology, laparoscopy, endometriosis, carbon dioxide laser plume, respirable particles, particulate sampling, hazards

INTRODUCTION

Lasers, especially the carbon dioxide laser, are now widely used in surgery [Wright, 1982]. The principle advantage of the laser in surgery as compared to the electrocautery or a knife, is the ability to deliver a concentrated amount of power to a very precise area of tissue, allowing a delicacy of technique not otherwise available. Other advantages include a drier operative site owing to the coagulating effect of the laser on small blood vessels and a reduction of trauma to surrounding tissue leading to more rapid wound healing [Alberti, 1981; Daniell, 1984].

At the focal point of the carbon dioxide laser, the energy supplied is so great that the tissue is vaporized. Smoke is produced in this process, along with particulate debris, presumably from cells explosively disrupted near the focal point of the beam [Daniell, 1984; Wright, 1982]. The smoke is extremely malodorous and researchers have suggested that the smoke may act as a vector for disease [Alberti, 1981; Bellina et al, 1981, 1982; Daniell, 1983, 1984; Hoye, 1967; Lobraico, 1984; MacLachlan, 1983; Mihashi et al, 1974, 1986; Oosterhuis et al, 1982; Ossoff and Karlan, 1984; Voorhies et al, 1984; Walker et al, 1986; Wright, 1982]. Researchers have been particularly concerned about the possibility of cancer cells being inhaled by the surgical team [Bellina et al, 1981, 1982; Hoye, 1967; Lobraico, 1984; Mihashi et al, 1974; Oosterhuis et al, 1982; Voorhies et al, 1984].

The amount of smoke produced varies with the type of procedure, the type of disease, the amount of lasing performed, and the surgeon's technique. Presently, the surgeon may vent the smoke to the ambient air of the operating room or may attempt to control it either with a mechanical smoke evacuator system or with suction tubing connected to a wall suction system. These control systems are inconvenient and, when used, are often used ineffectively. As a consequence, operating room (OR) personnel may be repeatedly exposed to the malodorous smoke without knowing its impact.

This study was undertaken to examine the composition of the carbon dioxide smoke plume produced during laser laparoscopic treatment of endometriosis, in order to determine whether the OR team was at risk from the laser smoke.

MATERIALS AND METHODS

Women undergoing carbon dioxide laser laparoscopic treatment for endometriosis and/or adhesions were studied. Thirty-two plume samples were obtained from 17 female patients. Of the patients studied, 10 were between 21 and 30 years of age; 5 were between 31 and 40; and 2 were between 41 and 50. Of the 17, twelve patients presented with varying stages of endometriosis.

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Of the remaining 5 patients, 2 presented with adhesions, 1 with fibroids, 1 with polycystic ovaries, and 1 underwent a neurectomy.

When a carbon dioxide laser is used to treat endometriosis, the procedure is typically performed through a laparoscope. For this study, a carbon dioxide laser (Cooper 500Z, Cooper Lasersonics, Santa Clara, CA) was used through the operating channel of a Wolf laser laparoscope (Richard Wolf Medical Instruments Corp, Rosemont, IL). A Nezhat coupler (Cabot Medical, Langhorne, PA) was used to focus the beam. The procedures were performed under general endotracheal anesthesia with the patients placed in lithotomy position.

Following pneumoperitoneal induction, the operating laparoscope was inserted intraumbilically. A 5.5-mm second-puncture trocar was then inserted into the midline approximately 2–4 cm above the symphisis pubis. A Nezhat suction-irrigator probe (Cabot Medical, Langhorne, PA) was introduced through the second puncture site for irrigation and suction control of the smoke plume. An atraumatic alligator grasping forcep (Eder Instruments Co, Research Triangle, NC) was then introduced through the third-puncture site for manipulation as needed during surgery. The third-puncture trocar was inserted 5–8 cm from the second trocar.

A focused beam of 6,000–12,000 W/cm^2 (0.5-mm spot size, at a 15–30-W setting) was employed to vaporize endometrial implants from the ovaries, pelvic sidewall, cul-de-sac, tubes, uterosacral ligaments, bladder flap, and/or the peritoneum. Other structures vaporized during this study included pelvic adhesions, fibroids, and uterosacral nerve tissue. The laser was used in continuous mode for structural vaporization. For delicate dissections, the laser was used in pulse mode. The pulse mode was approximately 1.7/s with a shutter opening of 0.05–0.1 s.

Smoke accumulates in the abdomen during surgery, slowly obscuring the surgeon's vision. Management of the accumulated smoke is determined by the surgeon, depending on the amount of lasing and the need for clarity of vision. Dr. Nezhat has developed a unique method of smoke control. When the smoke in the abdominal cavity obscures his vision, the pelvic area is irrigated with 60–180 cc of a heparin solution (5,000 units heparin in 1 liter lactated Ringer's solution). The smoke appears to settle to the floor of the pelvic area, though the exact mechanism of particulate management by this method is unknown. The irrigation solution is then removed via a standard wall suction system containing a filter (Bemis Health Care, Sheboygan Falls, WI) to prevent the laser plume from clogging the suction system.

More commonly, smoke may be removed from the abdomen by venting it through either the distal opening of the laparoscope or through a second or third trocar puncture site, either continuously or intermittently depending on the amount of lasing done and the surgeon's need for clarity of vision.

For this study, smoke from the abdomen was collected by venting into in a specially designed sterilized plastic bag. The second-puncture trocar proved to be the most convenient site for venting the intraabdominal smoke into the collection bag. The bag was prepared by heat-sealing a folded sheet of 18×27-in 2-mil polypropylene film, impregnated with a conductive agent, along two sides. The bag was then turned inside out, and the remaining opening was heat-sealed at an angle to leave a 2-in opening. The opening was propped open with a rolled strip of paper. The finished bag was placed in a peelable pouch and ethylene oxide sterilized.

At the beginning of the procedure, one or more bags would be dispensed onto the back table. When sufficient smoke had collected within the abdomen, the scrub nurse would position the bag, pull the suction tube from the second trocar, and quickly cover the opening with the bag. When the bag had inflated with the mixture of smoke and carbon dioxide (from the insufflation of the abdomen), the nurse would seal the end of the bag with a clamp, such as a hemostat, remove the bag, reinsert the suction tube, and then hand off the filled bag.

The smoke in the bag was sampled by snipping off the small opening, inserting a Marple Personal Cascade Impactor (Sierra-Anderson, Atlanta, GA) inside the bag, piercing the opposite end of the bag with a filter tube, and then turning on a precalibrated air pump to draw the smoke through the cascade impactor for precisely 3 min.

The level of exposure of the surgeon and scrub nurse(s) to the laser plume was determined by drawing air from the surgical field through a 6-ft length of sterilized Tygon tubing (positioned by the scrub nurse) into another Marple Personal Cascade Impactor. The pump for this impactor was turned on when the first incision was made, and turned off when the last suture was tied. In general, no measureable quantity of laser smoke particulates were found from sampling the surgical field, indicating that the surgeon and scrub nurse(s) were not being heavily exposed to the plume. However, on certain occasions, such as when the seals in the laparoscope or trocars leaked, or when the patient had stage III or stage IV endometriosis (AFS classification [American Fertility Society, 1979]) and required a substantial amount of laser surgery, some amount of laser plume would be sampled from the surgical field. This happened in 4 of the 17 surgeries.

The overall level of exposure of all the staff to the laser plume was determined by placing another sampler on a utility table by the wall near the foot of the OR table. This sampler was turned on when the room was being set up in the morning, and was not turned off until

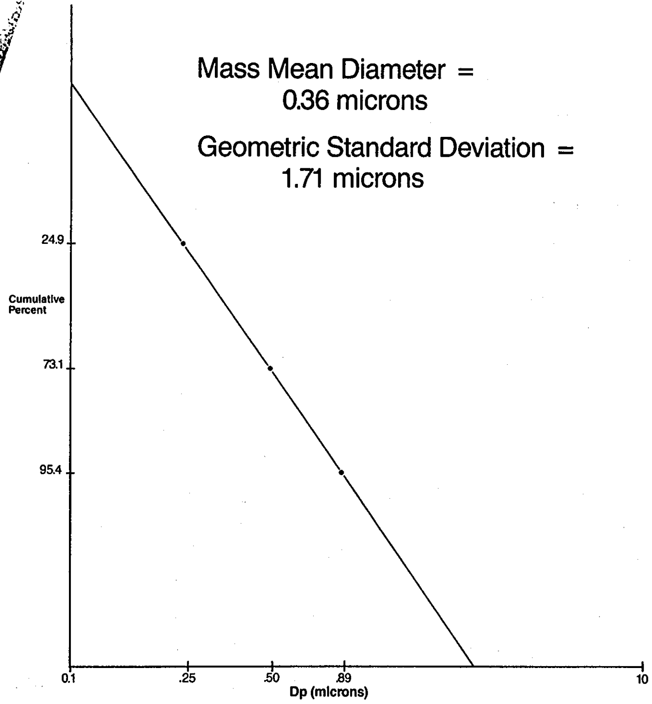

Fig. 2. A log-probability plot using the same data displayed in Figure 1. From this chart it is possible to determine the median mass diameter (MMD) and the geometric standard deviation. The geometric standard deviations showed a rather small range in this study, varying from 1.47 to 2.62 μm.

the particle distribution follows the theoretical log-normal distribution pattern, the plot will be a straight line. Figure 2 illustrates such a log-probability plot, using the same data displayed as a bar chart in Figure 1. From Figure 2, it is possible to determine the amount of material within any size range, the probability that particles of a certain size are present, and the size of particles at any point in the cumulative distribution. In particular, it is possible to determine the size corresponding to 50% (cumulative), which is the midpoint of the distribution, that size which exactly divides the mass. That size is known as the median mass diameter (MMD), and it has properties similar to that of an arithmetic average. The geometric standard deviation (G), a measure of the scatter in the distribution, can be determined by dividing the MMD by the size corresponding to 16% (cumulative), ie, 1 SD. The geometric standard deviations showed a rather small range in this study, varying from 1.47 to 2.62 μm (average of 1.84 μm).

Figure 3 is a summary of the MMD's for each of the 32 plume samples. The distribution is broad, possibly bimodal, which we believe is due to changes in the energy delivery to the focal point as the surgeon changed focus and altered power density. The median aerodynamic diameter of the 32 plume samples is 0.31 μm within a range of 0.1–0.8 μm. The arithmetic average of the distribution is 0.35 μm, with a standard deviation of 0.16 μm. Because the mean diameters of the individual plume samples are obviously not normally distributed,

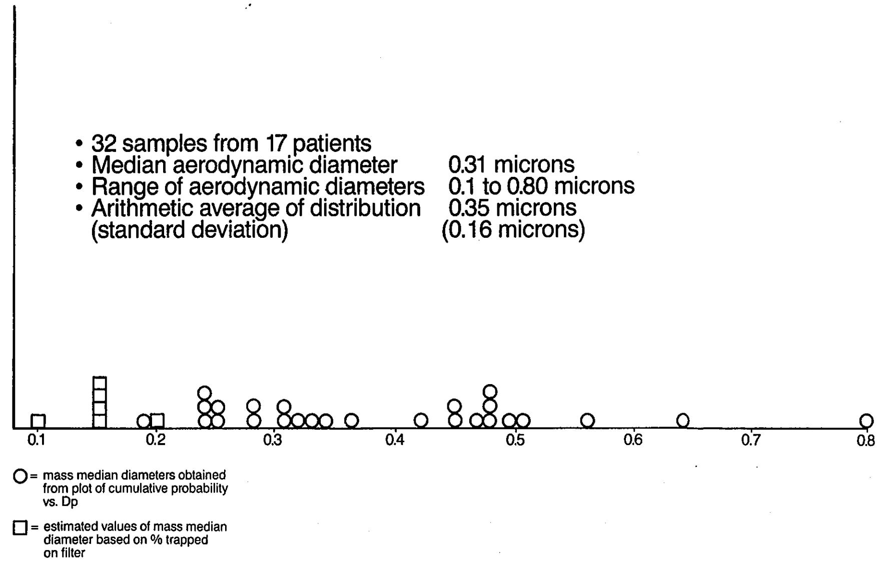

Fig. 3. A summary of the median mass diameters (MMD) for each of the 32 plume samples. The distribution is broad, possibly bimodal, which is believed to be due to changes in the energy delivery to the tissue as the surgeon changed focus and altered power density.

dioxide and neodymium:YAG laser irradiation of different types of animal tissue [Bellina et al, 1981, 1982; Hoye et al, 1967; Mihashi et al, 1974; Oosterhuis et al, 1982]. These differences are no doubt due to the substantial differences in methodology between this study and previous ones. In previous studies, collection was made with either settling plates or by suction through absolute filters positioned near the irradiated tissue. These techniques bias the collection toward large pieces, which may be propelled for short distances, but which may never become truly airborne. In such studies, the risk being evaluated is actually that of the patient, who will have cells from the tissue being lased dispersed within the surgical wound. In fact, in the study by Hoye et al [1967] in which the cancerous tumors of mice were irradiated with a neodymium:YAG laser, the mice subsequently showed severe metastasis into unexpected regions of their bodies, strongly suggesting that living cancer cells had been dispersed by the laser.

Our results in no way contradict these previous reports. Rather, we address the question of whether the cells and cell parts observed in previous studies are airborne in the smoke plume. By sampling laser smoke which had been allowed to accumulate inside the pelvic region during surgery, we biased our sample toward those particles which are truly airborne and which might actually be respired by the surgical staff, in keeping with our objective of evaluating whether there is or is not a hazard to the staff.

We had expected to find either a continuum of particles, from whole cell size to tiny fragments, or combustion debris, similar to cigarette smoke. We found neither. The log-normal plots of the data, of which Figure 2 is an example, show excellent straight lines with a steep slope and small geometric standard deviations. There is no possibility of a continuum of particles beginning with whole cells and ending with tiny fragments. Microscopic examination of the particles reveals no char, as would be expected from a combustion smoke; instead, the particles are homogeneous spheres. Microchemical analysis, which we hope will help reveal the source of the particles, is proceeding very slowly because of the difficulty of working with such small quantities (a typical collection totals 0.1 m, spread over four size ranges).

Since there seems no possibility that whole-cell sized particles, including cancer cells and most vegetative bacteria, are present in the laser plume, can we conclude that the smoke presents no hazard to the surgical staff? Unfortunately, there is at least one other possible hazard which cannot be ruled out by the results obtained in this study. Several researchers have raised the possibility of viral transfer from the laser plume [Oosterhuis et al, 1982; Walker et al, 1986]. Referring to the reference chart in Figure 4, we can see that viruses are much smaller than the laser smoke particles. It is therefore possible that a virus could "hitch a ride" on or within a particle in the laser plume. Without being able to identify more precisely how the particles in the laser plume arise, it is not possible to assess the probability that viruses are present in the plume. Nor is it possible to assess the probability that any viruses, if present, are still infectious after having been subjected to the plume-generating process.

Looking carefully at Figure 4, another potential hazard is revealed. The particles in the laser plume overlap the size range of "lung-damaging dust" (0.5–5.0 μm [Lapple, 1961]), ie, particles which, because of their size, can penetrate to the deepest regions of the lung [Alberti, 1981]. Other materials which fall into the "lung-damaging dust" category include coal, cotton, and grain dusts. Could a high exposure to laser plume over a long period of time cause a lung problem similar to "black lung"? We do not know. We do know, however, that the standard surgical mask is not meant to stop such small particles and that it will provide virtually no protection against whatever hazards, if any, that the laser plume presents [Orenstein, 1959].

Happily, our results for this particular series of operations, laser laparoscopy for the treatment of endometriosis, done by this particular surgeon, Camran Nezhat, all in the same facility, show that the surgical staff was in general exposed to only low levels of laser smoke. We have no reason to believe, however, that this result can be generalized to other hospitals, other surgeons, other procedures, etc.

CONCLUSIONS

Although there is no identifiable hazard from airborne cancer cells, a significant portion of the particles in the laser plume are in the size range which is classified as hazardous to breathe—0.5–5.0 μm. Furthermore, any of these particles are too small to be effectively filtered by the currently available surgical masks. Measurements of the plume concentration were made in the surgical suite and at no time during the sampling study was there any indication of concentrations of particles which could harm the staff. However, the amount of smoke in the air will depend on the surgeon, the disease, the procedure, the technique of plume evacuation, the hospital ventilation system, etc. In view of the findings of this study and the concerns of other researchers about the transmission of viable particles in the plume, it is appropriate to consider the use of a mechanical smoke evacuator system with a high-efficiency multistage filter during plume-generating laser vaporization procedures. In some cases respiratory protection for the staff might be desirable. Personal protective equipment is available, devised to protect workers who are routinely exposed to hazardous