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A new type of CO_2 laser avoids power density loss due to absorption and the blooming effect by the CO_2 gas environment

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The aim of this study was to compare the acute tissue effects of a standard CO_2 laser (Ultrapulse 5000) with a new design (Ultrapulse 5000L) that utilizes a different carbon isotope (C_{13}) in the rat uterine horn model. Following laparotomy, measured laser injuries were effected with the Ultrapulse 5000 or Ultrapulse 5000L lasers via a laparoscope using CO_2 or air for insufflation. Serial sections of the lesions were, thereafter, obtained to evaluate depth and width of total injury, width of defect and thermal damage zone. When CO_2 was used as the insufflating gas, Ultrapulse 5000L laser was associated with significantly deeper lesions compared to the Ultrapulse 5000 system for the two tested pulsed energy levels ($P < 0.0001$). The width of total injury and thermal damage zone were significantly less with the former laser compared to the latter. The width of the defect was, however, significantly larger with the Ultrapulse 5000L laser for the 200 millijoule pulsed energy level, whereas it was comparable for the 75 millijoule level. When air was used as the insufflation gas, all four parameters of tissue injury were comparable between the two types of laser ($P > 0.05$). The adverse effects on the CO_2 laser beam and the resultant altered tissue effects that occur in a regular CO_2 environment are avoided by the use of the Ultrapulse 5000L or an air environment.

Key words: blooming effect/CO_2 gas/CO_2 laser/power density

Introduction

The carbon dioxide (CO_2) laser is commonly used during laparoscopic gynaecological procedures. Endometriosis and fertility-promoting procedures, including adhesiolysis, fimbrioplasty and salpingoneostomy are the most common applications of the CO_2 laser in gynaecological laparoscopy. Precise cutting with minimal adjacent thermal damage are the main advantages of this energy modality. The limitations of the CO_2 laser include high cost and similar results with respect to healing process (Filmar *et al.*, 1989; Luciano *et al.*, 1991) and postoperative adhesion formation (Luciano *et al.*, 1991) or reformation (Tulandi, 1987) when compared to the use of other surgical modalities.

Several factors have a direct effect on the relation between the power output of the CO_2 laser and the power density delivered to the tissue via laparoscopy. These include the diameter of the laser beam, coupler optics, lumen size of the delivery probe or channel and absorption of the laser energy by the insufflating gas (Reich *et al.*, 1991). Although CO_2 laser has been traditionally considered to be very precise, one or more of these factors may compromise the expected tissue effects and precision of the CO_2 laser (Reich *et al.*, 1991). When a CO_2 laser is activated in a CO_2 gas environment, the CO_2 molecules in the beam path absorb the laser energy and move to a higher energy level. This results in a reduction of the CO_2 molecules in the centre of the beam path. Such changes in the density of CO_2 gas molecules in the insufflation medium may defocus the CO_2 laser and enlarge the spot size called the blooming effect (Reich *et al.*, 1991). This blooming effect adversely affects the power density and the precision expected from the CO_2 laser.

The aim of this study was to compare the acute tissue effects of a standard CO_2 laser with a new design that utilizes a different carbon isotope (^{13}C).

Materials and methods

Eight female Wistar rats weighing 200–220 g were used as animal model to compare the acute tissue effects of a standard CO_2 laser (Ultrapulse 5000, Coherent, Inc., Palo Alto, CA) with a new CO_2 laser that used a different carbon isotope (Ultrapulse 5000L, Coherent, Inc., Palo Alto, CA, USA).

Operations were performed under general inhalation anaesthesia using Halothane (Fluothane; Ayerst Laboratories, Montreal, Canada), oxygen and nitrous oxide. Following laparotomy via a 2 cm vertical mid-line incision, measured laser injuries were effected on one uterine horn utilizing the Ultrapulse 5000 laser and on the other with the Ultrapulse 5000L. A direct coupler was used to connect the laser to the 30 cm laser laparoscope with a 5 mm operating channel. The acute tissue effects of pulsed wave forms using identical pulse energy levels were compared between the two types of laser.

Lesions were created at a typical superpulse setting (75 millijoule/pulse) and at a typical ultrapulse setting (200 millijoule/pulse) with each laser. The total energy delivered to tissue was controlled and fixed at 4 joule per lesion deposited in 0.1 s. This was equivalent to 53 pulses at 75 millijoule/pulse and 20 pulses at 200 millijoule/pulse.

Lesions were created either insufflating CO_2 or air, at a flow rate of 0.5 l/min through the operating channel of the laparoscope which is traversed by the laser beam. This was done to evaluate the effect of the type of medium on the acute tissue effects of both types of laser.

Eight rats (16 uterine horns) were randomized to three groups

Table I. The characteristics of the laser beam and insufflation medium used

Group	Number of rats	Laser type	Number of injuries	Wave type	Pulse energy (millijoules)	Power (watts)	Exposure time (s)	Insufflation gas
1	3							
		5000	21	Pulsed	200	40	0.1	CO_2
		5000L	25	Pulsed	200	40	0.1	CO_2
2	3							
		5000	21	Pulsed	75	40	0.1	CO_2
		5000L	26	Pulsed	75	40	0.1	CO_2
3	2							
		5000	13	Pulsed	75	40	0.1	Air
		5000L	15	Pulsed	75	40	0.1	Air

Table II. The acute tissue effects of the two different types of CO_2 laser. Values are mean ± SD

Group	Laser type	Depth of injury (mm)	Width of total injury (mm)	Average thermal damage zone (mm)	Defect width (mm)
1					
	5000	0.38 ± 0.07^{a}	2.33 ± 0.52^{c}	0.67 ± 0.30^{j}	0.99 ± 0.17^{m}
	5000L	0.55 ± 0.16^{a}	1.78 ± 0.18^{c}	0.28 ± 0.12^{l}	1.22 ± 0.13^{m}
2					
	5000	$0.35 \pm 0.07^{b,d,e}$	$2.21 \pm 0.57^{f,g,h}$	$0.53 \pm 0.26^{j,k,l}$	1.15 ± 0.17
	5000L	0.59 ± 0.16^{b}	1.79 ± 0.27^{h}	0.31 ± 0.19^{j}	1.17 ± 0.29
3					
	5000	0.51 ± 0.13^{d}	1.66 ± 0.19^{f}	0.16 ± 0.13^{k}	1.33 ± 0.21
	5000L	0.51 ± 0.08^{e}	1.73 ± 0.27^{g}	0.27 ± 0.12^{l}	1.20 ± 0.24

$^{a,b,c}P < 0.0001$; $^{d,e,f,g,k,l}P < 0.05$; $^{h}P = 0.002$; $^{i}P = 0.0001$; $^{j}P = 0.003$; $^{m}P < 0.001$.

(Table I). In all groups, regardless of the type of laser used, power output was set at 40 watts, and exposure time 0.1 s. Twelve to 26 injuries were effected on the anti-mesouterine surface of the uterine horns with one or the other type of laser. The uterine horns were immediately removed after the completion of the procedure and the animals killed. The removed horns were fixed in labelled jars in 10% formalin. Multiple segments were cut from areas of injury and processed for histological examination. Serial sections of the lesions were obtained and examined histologically by a pathologist unaware of the laser characteristics. Four parameters of tissue injury were measured: depth of injury, total width of injury, width of thermal damage zone and width of defect (width of the crater). The depth and total width of injury were measured manually using a micrometer on the microscope. The width of defect was measured on Quantimet Q520 Image Analysis system. The width of thermal damage zone was calculated by the following formula = (Total width of injury – width of defect)/2.

The results were expressed as mean ± standard deviation (SD). Student's *t*-test and one-way analysis of variance (ANOVA) with Tukey as a post-hoc test were used for statistical analysis of the results.

Results

The mean ± SD of the depth of injury, total width of injury, width of thermal damage zone and width of defect for the four groups of laser injury are presented in Table II.

In groups 1 and 2, Ultrapulse 5000L laser was associated with significantly deeper lesions compared to the Ultrapulse 5000 laser ($P < 0.0001$ in both groups). In addition, the mean width of total injury was significantly less with the 5000L compared to the 5000 ($P < 0.0001$ in group 1; $P = 0.002$ in group 2). Similarly, the width of thermal damage zone was significantly less with the Ultrapulse 5000L laser ($P = 0.0001$ in group 1; $P = 0.003$ in group 2). The width of the defect was significantly larger with the Ultrapulse 5000L laser in group 1 ($P < 0001$) but similar for the two types of laser in group 2 (Table II).

In group 3 where air was used as the insufflation gas, all four parameters of tissue injury were comparable between the two types of laser ($P > 0.05$).

Tissue effects with the Ultrapulse 5000L laser through a CO_2 environment were comparable to those obtained with the same laser and the Ultrapulse 5000 unit through an air environment ($P > 0.05$).

Discussion

The term laser is an acronym for Light Amplification by the Stimulated Emission of Radiation. Understanding how the laser generates its beam of light is essential for effective and safe use of this energy modality (Sinai, 1994; Munro, 1995). To emit energy, a molecule must be aroused to an excited energy level above its ground state. This excitement of the CO_2 molecules is achieved by an electrical discharge in the CO_2 laser. A natural tendency of the excited molecules to dispose of surplus energy results in the emission of light wave pockets, called photons. Emission of light may be spontaneous or stimulated. Stimulated emission forms the basis of laser physics creating monochromatic coherent wave of photons. The distinct and precisely determined excited (surplus) energy levels of each particular molecule result in the emission of photons of different energies and hence wavelengths. Carbon

dioxide laser emits a directed beam of light with a monochromatic wave length of 10.6 μm. The radiation is highly collimated and coherent, producing a laser beam in which all the waves are parallel and in phase. The lens system allows the beam to be focused to a very small diameter.

Loss of power density has been noted when a CO_2 laser is used in a CO_2 gas environment, such as at laparoscopy (Daniell and Brown, 1982; Reich *et al.*, 1991). CO_2 molecules in the path of the laser beam absorb the laser energy and move to a higher energy level. This absorption has a two-fold impact on the laser beam. Firstly, energy transmission by the laser is reduced to some extent secondary to absorption. Secondly, the density of the CO_2 gas molecules in the insufflation medium becomes no longer homogeneous. The density of CO_2 becomes less in the centre of the beam path, where energy levels are the highest. Such decreased density of CO_2 gas through the beam path acts like a concave lens where the thickness is the least in the middle (gas lensing) (Reich *et al.*, 1991). Gas lensing effectively defocuses and disperses the laser beam. Furthermore, it enlarges the spot size at the original focal point distance (blooming effect). Obviously, blooming effect reduces the power density significantly. The detrimental effect of the CO_2 gas on the transmission of the CO_2 laser beam has been previously reported (Daniell and Brown, 1982; Reich *et al.*, 1991). Daniell and Brown (1982) noted that passage of the beam through CO_2 significantly reduced the power of the laser. They reported that at 5–10 watts on continuous mode, the laser beam produced no visual effect on the tissues. Reich *et al.* (1991) reported the enlargement or blooming of the laser beam with the addition of CO_2 gas. They noted that the blooming effect of the CO_2 gas on the transmitted beam was greatest at the higher power settings. They concluded that absorption of the laser beam by CO_2 gas not only reduced energy transmission by as much as 30%, but also created gas lensing which increased the spot size and thus reduced power density.

We compared the acute tissue effects of a standard CO_2 laser (Ultrapulse 5000) with a new type of CO_2 laser (Ultrapulse 5000L) that has a different isotope of the carbon particle (^{13}C) in its CO_2. When used in an air environment, the tissue effects of the two lasers were similar. This indicates that the air medium does not affect the characteristics of the laser beam. In other words, the blooming effect does not occur in an air environment.

The tissue effects were markedly different with the two types of CO_2 lasers tested, when they were used in a CO_2 environment. In comparison with the 5000, the 5000L produced significantly greater depth of injury associated with a smaller diameter of total injury and lesser thermal damage. These result from the ability of the 5000L (which uses a ^{13}C isotope) to maintain the spot size and thus power density of the beam by avoiding the blooming effect noted in a CO_2 environment with conventional CO_2 lasers. The lack of the blooming effect with the 5000L laser in a CO_2 gas environment may be explained by the different excited (surplus) energy levels of ^{12}C and ^{13}C isotopes of the CO_2 molecule. In other words, the emitted wavelength of the 5000L laser utilizing the ^{13}C isotope does not correspond to the surplus energy level of the ^{12}C isotope within the CO_2 insufflation medium. This difference results in avoidance of efficient absorption of the laser beam and hence the blooming effect by the regular CO_2 gas environment.

The blooming effect with the conventional laser observed in our study is underestimated, since the laser was on for only 0.1 s per injury. However, in practice, the laser is used for a much longer period of time, causing more thermal heating of the CO_2 gas medium and thus a greater blooming effect resulting in a larger spot size. These changes in the characteristics of the CO_2 laser beam and the resultant altered tissue effects that occur in a normal CO_2 environment may be avoided by using a CO_2 laser with a different carbon isotope or an air environment as is the case in gasless laparoscopy.

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