The Carbon Dioxide Laser for the Surgical Management of Endometriosis- A Treasure in the Armamentarium of the Gynecological Surgeon

Ceana Nezhat MD, Nisha Lakhi MD

Case Introduction

The use of laser technology in gynecology became widespread since the carbon dioxide (CO_2) laser was first utilized by Kaplan and his colleagues in 1973 for the treatment of cervical erosions [1]. Over the next ten years, the CO_2 laser was used during basic laparoscopic procedures [2], and from the early 1980's to 1990's, the Nezhat Brothrs in USA had optimized its use for laparoscopic treatment of extensive endometriosis involving multiple organs [3-8].

The CO_2 laser has several features that make it suitable for performing multiple surgical functions. It can be used for both excision and vaporization with homeostatic capability on small vessels. There are several advantages in utilizing the CO_2 laser in gynecological procedures. High precision and capacity for simultaneous coagulation allows for controlled and virtually bloodless ablation of endometrial implants. Compared with all available energy sources, such as electrosurgical instruments and other types of lasers, the CO_2 laser is precise, has minimal depth of tissue penetration (0.1 mm), can coagulate small blood vessels, and produces the least thermal spread [9-14].

In addition to its precise cutting characteristics, this laser is used in a non-contact mode, thus does not touch the target lesion, allowing continuous visualization of the section plane between healthy and diseased tissue [15]. Finally, the low thermal impact of CO_2 lasers minimizes adverse healing responses and adhesion formation [15].

Despite the advantages of the CO_2 laser, in the past, ergonomic challenges associated with the free beam CO_2 laser delivery mode, which requires significant training and above average eye-hand coordination, as well as the ability to handle complex assembly and operation, made its use available to only limited number of experts from around the world. However, many new innovations have occurred since the CO_2 laser was first introduced, that maximize precision, safety, ease of use, and delivery to target tissue. Also, the new generation of surgeons is well versed in operative endoscopy with ample ambidexterity and eye-hand coordination. This paper reviews the CO_2 laser as an energy source, discusses the new developments in laser technology as well as highlights its applications for minimally invasive gynecological surgery in comparison with alternative energy sources.

Physics of the CO_2 Laser making it suitable for gynecological endoscopic surgery

The CO_2 laser has a long wavelength (10.6 μm) that is able to produce excitation and rotational energy in the tissue, resulting in vaporization of cell contents [16, 17]. The depth of penetration of the CO_2 laser is limited to a precise area less than 0.1 mm [16, 17]. This high energy impact produces steam that explodes the intracellular water within a cell. The resulting cellular debris is carried off as plume. Depending on the power density, the CO_2 laser can be used for vaporization, excision, or incision of tissue. Bleeding is limited with the use of the CO_2 laser because its coagulation ability seals small vessels as it cuts.

Tissue Selectivity

In order for laser energy to be effective, it must be absorbed by chromophores in the tissue. Human tissue contains three useful chromophores (water, melanin, and oxyhemoglobin) that selectively reflect, transmit, absorb, or scatter specific wavelengths in the electromagnetic spectrum. The absorption coefficients of these chromophores, and their distribution in a specific tissue determines how a particular laser wavelength will affect the tissue [16, 17]. If the tissue surface either reflects laser energy or transmits the laser energy through the tissue, there will be little to no effect on the target tissue. However, if the tissue chromophore has a high affinity for a specific wavelength (high absorption coefficient), the laser energy can be confined to that particular tissue, thereby minimizing effects on adjacent tissue making the operation as precise and targeted as needed to achieve the optimal clinical effects [16, 17].

CO_2 lasers emit light at a wavelength of 10,600 nm that is absorbed strongly by water. Thus water is the primary chromophore for the CO_2 laser. Conversion of radiant energy to heat at the point of absorption instantly raises the temperature of tissue water to more than 100°C, so the water in the tissue is vaporized. This property makes the CO_2 laser ideal for use on soft tissue where water is ubiquitous. In contrast, the argon laser, potassium-titanyl-phosphate (KTP) laser, and the neodymium yttrium-aluminum-garnet (Nd:YAG) laser energy, are preferentially absorbed by oxyhemoglobin and/or melanin, thus making them good choices for vascular applications and aesthetic surgical procedures (Table 1) [18].

Table 1: Types of lasers and their properties

Type of Laser	Wavelength (nm)	Region	Chromophore	Depth of Penetration (mm)
Argon	488-512	Visible	Melanin, Hemoglobin	0.5-0.8
KTP	532	Visible	Melanin, Hemoglobin	1-2
Nd:YAG	1064	Infrared	Melanin	3-4
CO_2	10,600	Far Infrared	Water	0.1

Limited Depth of Penetration and Lateral Spread

An important factor in tissue-laser interactions is the depth of laser energy penetration. Laser energy will penetrate tissue to different extents depending on several variables. These factors include: wavelength of the laser, the absorption coefficient, the composition of the receiving tissue, the power density of the beam, and the application method (e.g., non-contact, light contact, or contact with firm pressure) [18]. Since the CO_2 laser is not pigment seeking (i.e. oxyhemoglobin, melanin), its depth of penetration is strictly limited, and is virtually independent of tissue type. Due to preferential absorption by water, 90% of CO_2 laser energy is superficially absorbed by an approximate 0.1 mm layer of soft tissue. The KTP laser has a wavelength of 532 nm and penetrates deep into tissue until it is absorbed by melanin or by oxyhemoglobin in blood vessels [19]. Similarly, diode lasers with varied wavelengths (λ = 830 nm, 940 nm, 980 nm) penetrate several millimeters into tissue and produce diffuse coagulative effects. Nd:YAG laser energy scatters in tissue and thermal effects can spread several millimeters beneath the tissue surface. Therefore, the risk of unintended thermal damage produced by non-visible deeper necrosis caused by light scattering and/or deep penetration of energy from potassium-titanyl-phosphate (KTP), diode, and Nd:YAG lasers makes them less suitable than CO_2 lasers for highly selective ablation of endometrial implants [18,19].

Laser-Tissue Interaction

The CO_2 laser has three main functions. It can be used as a cutting or excisional instrument, as a vaporizing or ablating instrument, or as a coagulating instrument. The laser-tissue interaction is determined by the amount of energy that is delivered to the tissue. The three factors that influence the tissue effect are energy, time, and spot diameter. For most gynecologic procedures using the CO_2 laser, the average power is 20–30 W, which is used primarily for excision purposes [19]. The second factor is laser exposure time. The longer the laser remains focused on one spot, the more energy is applied to that area. To limit amount of time the tissue is exposed to laser, one can simply move the beam back and forth, or select an intermittent time-pulse mode. The third factor is the spot diameter. As the instrument is moved closer to the target area, the spot size is made smaller, power density (fluence) is increased, and a more intense effect is produced. When the instrument is retracted away from the tissue, the spot diameter enlarges, which decreases the power density. Power density is inversely proportional to the area of the spot size. Therefore, doubling the beam diameter reduces the power density to one fourth. The versatility of the laser is demonstrated via the fact that the higher the power density is, the greater the laser's ability to cut or vaporize, and at a lower power density, the laser functions as a coagulation instrument [19].

Lasing Power Modes of the CO_2 Laser

CO_2 lasers have two main modes of operation: continuous wave (CW) and pulsatile. In the CW mode, the laser energy can be delivered in a continuous uninterrupted manner as long as the foot pedal is being deployed. In the pulsatile mode, there are several variations which allow for energy to be discharged in either single or multiple pulses with adjusted frequencies. In the single-pulsed mode, the operating system discharges a single burst of energy over a fixed time interval (0.05-0.5 second) each time the pedal is depressed. The single-pulsed mode allows for a controlled precise penetration of the laser beam. This mode is useful to ablate superficial endometriosis over bowel or the pelvic side wall without damaging underlying structures or perforating the bowel [20].

In the AcuPulse family of lasers (Lumenis surgical), both the Pulser mode and the SuperPulse mode release several intermittent bursts of laser energy at a specified time. Due to the intermittent release of energy in these pulsatile settings, the power density can be increased compared to the CW mode. This is because during the refractory period between the pulses, heat will dissipate, thereby minimizing damage to the surrounding tissue. The SuperPulse mode releases rapid bursts of super high peak power pulses at very short intervals. This allows for extremely precise vaporization with decreased tissue desiccation, thermal spread and coagulative effects [20]. This precise Pulsed mode can be useful for ablating endometriosis on delicate structures such as the ovary or fallopian tube where tissue damage, coagulation effect, and thermal spread should be limited [20]. The CW mode is more suitable when a coagulation effect is desired [20].

The efficacy of the superpulsed laser in gynecologic laparoscopic surgery is limited when the CO_2 laser is used through the operating channel of a laparoscope, due to the "blooming effect", an effect that defocuses, enlarges, and distorts the laser beam [20]. This occurs when the CO_2 laser energy is absorbed by the CO_2 insufflation gas in the channel, causing the CO_2 molecules to move to a higher energy level, resulting in a reduction of CO_2 molecules in the center of the beam path. This "blooming effect", enlarges the spot diameter and subsequently decreases the transmitted power density by 30 to 60%. The larger spot size also decreases precision and increases tissue desiccation, carbonization and thermal spread.

With the UltraPulse family of lasers, the surgeon is able to specify the amount of energy delivered in each pulse and the pulse shape is "top hat", four to five times more energy is delivered as compared to superpulsed lasers per pulse [15]. This enhances the precision, incising ability, and decreases damage to surrounding tissue. The UltraPulse® CO_2 laser (Lumenis Surgical), is an advanced computer-controlled CO_2 pulsed laser platform. It is based on a patented CO_2 laser tube providing up to 60 Watts of average power and pulse energies up to 225mJ. The system can generate a continuous series of short-period, high-peak-power pulses, and the laser energy is delivered very rapidly resulting in vaporization of the targeted tissue without the creation of collateral injury. The lasing modes (UltraPulse and Continuous Wave) and the energy per pulse selection can be alternated according to the desired tissue interaction depending on whether greater precision or level of hemostasis is desired, while the three exposure modes (Repeat, Single & Constant) allow for comprehensive timed-controlled energy delivery. The new member in this family, the UltraPulse DUO system is designed to deliver the UltraPulse CO_2 laser energy with all of the above advantages via an articulated arm or through the FiberLase CO_2 laser fiber (Lumenis surgical). Having the two delivery modalities on one platform, with the ability to seamlessly alternate between the two lasing modalities will provide more flexibility in achieving desired tissue interaction and access to surgical site. The versatility of the Dual system allows the surgeon to use the free beam or fiber with conventional laparoscopy and fiber laser with robotically assisted laparoscopy.

Delivery Modes

Historically, CO_2 lasers used to be fixed to rigid instruments lending to ergonomic difficulties, thus limiting their use. However, newer technologies have allowed for a flexible fiber delivery systems for the CO_2 laser in gynecology. These systems feature several characteristics that have the potential to foster the adoption of this energy form by the wider community of gynecologic surgeons. Flexible CO_2 laser fibers, such as the FiberLase Flexible CO_2 Laser Fiber (Lumenis Surgical) utilized either on the AcuPulse DUO, or UltraPulse DUO systems, overcame past ergonomic challenges by providing flexibility, durability, and ease of use. The hollow fibers feature controlled beam divergence, and intuitive method which allows the surgeon to control the area of laser-tissue interaction simply by moving the beam slightly away from the tissue. A smaller area concentrates the energy to produce a cutting effect, while a larger area allows for broad deposition of energy contributing to hemostasis or superficial ablation. The addition of the aiming beam is a significant contributor to the ease of use and the ability to target the desired tissue. Flexible delivery systems can easily be introduced through a side port, an operative channel of the laparoscope, or used in robotic assisted laparoscopic surgery (RALS).

Other Energy Sources

Electrosurgical Techniques

Before the advent of laser, the only method available for the endoscopic removal of endometriosis was by laparoscopic scissors, heating the endometrial implants with an endocoagulator.

Monopolar and bipolar electrosurgical instruments utilize high-frequency radio waves to provide electric current. With monopolar instruments, heat is generated in tissue. This occurs by transmission of the electron flow through a conductive medium (electric cable) that passes through the patient and exits via a grounding pad. The conductance or resistance of the tissue determines the flow of current towards the ground to complete the circuit. [19] With sufficient voltage (at least 200 volts), electrosurgical instruments cut or vaporize tissue via an electric arc [19]. Alternately, contact between the electrode and tissue reduces current density and tissue is heated more slowly, leading to desiccation and coagulation at the surgical site.

Bipolar electrosurgery uses two small electrodes of the same size; one is active and the other serves as a return electrode. With bipolar instruments, the flow of current is restricted to the tissue between the two poles rather than through the patient, making it safer for the patient than monopolar electrosurgery.

Standard bipolar instruments deliver a lower power than monopolar devices and are typically reserved for coagulation and removal of superficial endometrial lesions [19].

Although there is certainly a place for these techniques, monopolar is rather hemorrhagic and bipolar is rather imprecise. Laparoscopic electrosurgery is an established treatment, however it is important to realize that it has little proven efficacy in the treatment of endometriosis and is potentially dangerous. The potential for collateral thermal damage is greatest with monopolar surgical instruments because of higher depth of penetration, electricity can arc to non-target tissue, and insulation failure. Direct coupling or capacitive coupling can cause electrical burns to surrounding organs that may go unnoticed during surgery [20].
With bipolar surgical devices, the incidence of thermal injury to surrounding tissue and hemorrhage is reduced. However, the use of the bipolar device is limited in endometriosis surgery because it lacks the precision necessary to excise lesions in delicate areas that are in close proximity to the major vessels, bladder, ureter and bowel. The same holds true for monopolar techniques, as depth of tissue penetration and lateral spread of current cannot be precisely controlled.

Because of the large thermal spread, electrosurgical instruments must be used with extreme caution to limit common complications. With alternatives such as argon beam coagulator, there is a lower depth of tissue penetration then with monopolar current; however the high-flow infusion of argon gas can cause a rise in intra-abdominal pressure and potentially predispose the patient to life-threatening gas embolism [21].

Ultrasonic Instruments

Ultrasonic devices operate by converting electrical energy into mechanical vibrational energy, thereby disrupting hydrogen bonds and forming a coagulum [16]. The frequency, 55.5 kilohertz (kHz), is in a range that will denature collagen molecules, vaporize cells, and provide both coagulation and cutting capabilities [16]. These instruments operate in a lower temperature range than electrosurgical tools and cause less lateral thermal damage than the monopolar or bipolar electrosurgical instruments [16]. Nevertheless, they can still cause significant tissue damage, particularly if the instrument tip is used for tissue handling while still hot [22].

Ultrasonic energy devices are well suited for dividing and sealing small to medium sized blood vessels and tissue during certain gynecological procedures, such as laparoscopic hysterectomy [23]. Ultrasonic devices lack the fine precision of the CO_2 laser, and are not able to vaporize superficial tissue implants with limited depth of penetration. These properties are of importance when attempting to vaporize or excise endometriosis tissue near delicate structures. In addition, there is no data with respect to safety, efficacy, recurrence, and future fertility rates that support the use of ultrasonic devices over other techniques for the surgical management of endometriosis.

A recent study [24] has compared flexible CO_2 laser fiber with ultrasonic harmonic scalpel during robotic myomectomy and demonstrated similar mean operative times and blood loss with both instruments. However, the CO_2 laser group had 87% reduced odds of staying in hospital for more than 1 day compared with those who underwent the same operation with the ultrasonic scalpel [19]. More specifically, 45% of patients in the ultrasonic scalpel group were admitted for more than 1 day as opposed to only 14.2% of those in the CO_2 laser group, a statistically significant difference [24]. As complication rates were similar between groups, the authors attributed this difference to decreased post-operative pain in the CO_2 laser group. In live animal as well as in human cadaver studies, the CO_2 laser has been shown to cause less thermal tissue damage in comparison to the harmonic scalpel [14,25], also a superior wound-healing effect on the uterus compared with electrosurgical instruments. [26]

CO_2 Laser for Treatment of Endometriosis

Laparoscopy has been shown to be the gold standard in the management of endometriosis. Removal or destruction of lesions, enucleation or vaporization of cyst, lysis of adhesions, and dissection around critical structures such as the ureter and bowel are among the more common laparoscopic procedures applied as surgical treatment. The CO_2 laser has been shown to be a well-suited instrument for reproductive surgeons with several benefits for patient, including precision of application, minimal destruction of surrounding normal tissue, minimal bleeding, as well as minimal scar formation.

The CO_2 laser is more precise and causes less thermal injury compared to other electrosurgical or ultrasonic instruments. The cutting action of the CO_2 laser is analogous to what occurs when increased mechanical energy is applied to a cold scalpel blade. This means any increase in laser energy power will result in a greater incision depth but not greater width (lateral spread) [27]. A comparative study assessed the gross and histologic effects of bipolar cautery, monopolar cautery, ultrasonic scalpel, and the CO_2 laser on porcine ureter, bladder, and rectum demonstrated CO_2 laser energy was associated with the lowest incidence (0/12 specimens) of urothelial or epithelial damage [14]. In contrast, 9/12 specimens from all three organs showed urothelial or epithelial damage (presenting as coagulative denaturation of collagen bundles, resulting in eosinophilic homogenization of tissue) when either monopolar or bipolar cautery was used for surgery; as did 5/12 ureter and rectum specimens when an ultrasonic scalpel was used. Monopolar caused the most lateral spread of thermal energy. The CO_2 laser caused the least deep-tissue injury of all the energy sources tested. Similarly, another animal study by Bailey et al. showed monopolar electrosurgery, in both cut and coagulation modes, damaged uterine tissue significantly more than the CO_2 laser delivered via fiber [27].

Clinical Benefits to CO_2 Laser Laparoscopy for Endometriosis

Pain Control

Use of the CO_2 laser for the treatment of endometriosis has shown good pain control and resolution of symptoms in endometriosis patients. In a prospective, randomized, double-blind, controlled trial of laser laparoscopy in the treatment of pelvic pain associated with minimal, mild, and moderate endometriosis, Sutton et al. demonstrated improved pain related outcomes in patients treated with CO_2 laser laparoscopy [28]. In this study, use of CO_2 laser laparoscopy resulted in statistically significant pain relief compared with expectant management at 6 months after surgery, with 62.5% of the patients in the CO_2 reporting improvement or resolution of symptoms compared with 22.6% in the expectant group [28]. This is supported by data from a prospective study by Cibula et al. that showed pain reduction in 40% of patients 18 months post CO_2 laser ablation of peritoneal Stage I-III endometriosis [29].

Fertility Outcomes

The use of the CO_2 laser for ablation of ovarian endometriomas is associated with good reproductive outcomes. Wyns and Donnez measured IVF stimulation parameters (number of gonadotrophin ampoules, number of follicles and mature oocytes, maximum estradiol concentrations) in a group of 85 patients with an ovarian endometrioma treated by CO_2 laser vaporization of the internal wall [30]. Ovarian stimulation parameters were not significantly different in patients managed by CO_2 laser vaporization compared to control patients with tubal infertility (no ovarian procedure). The authors concluded that the theoretical risk of loss of ovarian cortex when treating endometriotic cysts can be eliminated by the technique of vaporization. In a separate study, Donnez and colleagues assessed IVF outcomes after laser vaporization of endometriomas in comparison to controls with tubal infertility [31]. IVF outcome was not compromised by laser vaporization of the internal cyst wall. The clinical pregnancy rate was 37.4% and 34.6% in the endometriosis group and the control group, respectively [31].

In addition to vaporization of ovarian endometriomas, there are other applications of the CO_2 laser that positively impact fertility. In a study of 108 infertile patients with endometriosis diagnosed at laparoscopy, 64 patients had pelvic endometriosis and/or adhesions vaporized with a CO2 laser and were prospectively compared with a control group of 44 patients who had conventional laparoscopy [32]. The 6- and 12-month estimated cumulative pregnancy rates were higher in the vaporization group, as was monthly fecundity rate (6.7% vaporization group versus 4.5% control group) [32]. In another study, 167 women with early stage pelvic endometriosis were divided into four treatment groups: 49 patients underwent operative laparoscopy with CO_2 laser vaporization and/or resection; 45 were treated by operative laparoscopy with simple monopolar electrocoagulation; 43 had only diagnostic laparoscopy and did not receive any treatment; and 39 women received danazol 800 mg/day for 3 months after diagnostic laparoscopy [33]. Estimated cumulative pregnancy rates using life table analysis were indicators of treatment of success and compared among the treatment groups. Pregnancy rates in the CO_2 laser laparoscopy group were significantly higher than in the other three groups [33].

Deeply Infiltrating Endometriosis and Colorectal Endometriosis

There are three distinct types of endometriosis: superficial endometriosis, ovarian endometriomas, and deeply infiltrating endometriosis (DIE) [3]. DIE is characterized by endometriotic implants that penetrate more than 5 mm into the affected tissue and are responsible for painful symptoms whose severity is strongly correlated with the depth of the DIE lesions [3]. With the CO_2 laser, the surgeon can "shave" (vaporize) deep infiltrating endometriosis tissue, layer-by-layer, while the appearance of remaining tissue is unchanged. This feature makes the CO_2 laser especially suited for precise work around the bowel, ureters and other critical structures. In late 1980s, the Nezhats described safe laser excision and vaporization of endometriosis [34] and in subsequent years reported shaving technique, disk excision and segmental resection for bowel endometriosis [35-38].

Recently, Donnez et al. reported a prospective controlled study of 500 patients with deep rectovaginal endometriotic nodules using the shaving technique with a CO_2 laser and no rectal resection [39]. This surgical approach resulted in high postoperative pregnancy rates (84% of patients who wished to conceive, over a median of 3.1 years follow-up) and low complication and recurrence (7.8%) rates [39]. Due to safety concerns and device limitations, a rectal shaving technique is of limited utility when using electrosurgical or ultrasonic instruments.

In addition to its ablative capabilities, the CO_2 laser can also be used for more complex endometriosis cases requiring segmental bowel resection. Meuleman et al. reported clinical outcomes from one prospective [40] and two retrospective [41,42] studies in subjects with recurrent deep infiltrating endometriosis, with or without colorectal wall invasion, in which all visible endometriosis lesions were removed by laparoscopic radical excision with CO_2 laser. Surgery was performed with or without segmental bowel resection and reanastomosis. Median follow-up in the 3 studies ranged from 1.7 to 2.4 years. Results showed low postoperative complication rates (0-5%), cumulative re-intervention (5-11%) and recurrence rates (4-7%); high fertility rates (46-51%); and significantly improved quality of life with use of the CO_2 laser [40-42].

Myths Associated With the CO_2 Laser

Ergonomic Disadvantage

The early generation of CO_2 lasers posed certain problems that have since been overcome. Early CO_2 lasers were rigid. The long wavelength of the CO_2 laser prevented transmission via the flexible fiber optic cables used by other types of lasers. In addition, bulky articulating arms with mirrors were required to transmit sufficient energy in a direct line to the surgical site, restricting freedom of movement [43]. Today, contemporary CO_2 lasers transmit light using a hollow optical fiber lined with an interior omnidirectional dielectric mirror making them more flexible, and therefore removing this ergonomic barrier. These hollow fibers feature beam divergence, which allows the surgeon to increase the area of laser-tissue interaction simply by pulling the beam away or towards the tissue, thereby controlling the tissue effect [44]. This new generation of CO_2 lasers can be used both for conventional video laparoscopy and robotic assisted laparoscopic surgery (RALS).

In addition, use of the CO_2 laser by advanced surgeons has inherent ergonomic advantages. The CO_2 laser can be easily coupled to an operating laparoscope. This allows the operating surgeon to control both the camera and the the laser beam as an operating instrument with one hand, while freeing the other hand for utilizing additional auxiliary instruments. This advantage also affords the ability to minimize the number of port-sites required, therefore improving cosmetic outcome.

Increased Cost

The expense of the CO_2 laser has been suggested to be a disadvantage. Although it is more costly than electrosurgical instruments, CO_2 laser technology has the potential to reduce the long term cost of endometriosis treatment. A cost saving benefit may be inherent given the improved outcome and reduced risk of collateral thermal injury compared with other surgical tools, and lower rates of recurrence and re-intervention. Improved IVF outcomes, fecundity, and pregnancy rates may impart a cost-saving advantage that warrants further assessment. Thus, the costs associated with the CO_2 laser may be justified by the direct benefits provided to the patient through their use [45].

In addition, as demonstrated in the study described earlier by Choussein et al. [24], patients undergoing myomectomy with a CO_2 laser have a significantly lower chance of being admitted to the hospital overnight after surgery compared to those in whom an ultrasonic scalpel was used. Because overnight hospital admission is associated with an increased cost and toll on the healthcare system, this factor may also be associated with a cost saving advantage. Certainly further prospective studies are needed to assess cost impact with use of the CO_2 fiber laser in these areas.

Conclusion

The CO_2 laser is appropriate for use on all types of endometriotic lesions including superficial endometriosis, ovarian endometriomas, and deeply infiltrative lesions. Of the various lasers available, the CO_2 laser is the most versatile and is extremely easy to use due to its limited depth of penetration (0.1 mm) and lateral thermal damage (20-100 micron). This allows for use of the CO_2 laser in delicate areas where electrosurgery would be unsafe, such as the bladder, lateral side wall near the ureter, nerves, major vessels, and bowel serosa. Besides vaporization, the CO_2 laser can be used for coagulation, excision or incision by variation of its power density. In the hands of an experienced surgeon, the CO_2 laser is safer compared to monopolar or bipolar electrosurgical instruments as well as ultrasonic instruments. In endometriosis patients, clinical data has demonstrated good pain control, improved quality of life, peri-operative outcome and fertility rates with use of the CO_2 laser. Modern systems of the CO2 laser, enabling also the use of flexible fiber have overcome ergonomic difficulties, the blooming effect, and other challenges associated with older generation CO_2 lasers.
The CO_2 laser is a valuable instrument in the armamentarium of the gynecological surgeon.

References

1. Kaplan I, Goldman J, Ger R, The treatment of erosions of the uterine cervix by means of the CO_2 laser. Obstet Gynecol, 41 (5), 795-6, 1973
2. Nezhat C, Nezhat F. Laparoscopic surgery with a new tuned high-energy pulsed CO_2 laser. Journal of gynecologic surgery, 8(4):251-255, 1992
3. Nezhat C, Nezhat F, Pennington E. Laparoscopic treatment of infiltrative rectosigmoid colon and rectovaginal septum endometriosis by the technique of videolaparoscopy and the CO_2 laser. Br J Obstet Gynaecol, 99(8):664-667, 1992
4. Nezhat C, Crowgey SR, Garrison CP, Surgical treatment of endometriosis via laser laparoscopy. Fertil Steril, 45(6):778-83, 1986
5. Nezhat C, Nezhat F, Evaluation of safety of videolaseroscopic treatment of bowel endometriosis, Scientific Paper, 44th Annual Meeting of the American Fertility Society, Atlanta, Georgia, October 8-13, 1988
6. Nezhat C1, Hood J, Winer W, Nexhat F, Crowgey SR, Garrison CP, Videolaseroscopy and laser laparoscopy in gynecology. Br J Hosp Med, 38(3), 219-224, 1987
7. Nezhat C, Videolaseroscopy: a new modality for the treatment of diseases of the reproductive organs. Colposc Gynecol Laser Surg ,2: 221-224, 1986
8. Nezhat, C, Nezhat F, Nezhat C, Operative laparoscopy (minimally invasive surgery)-State of the art, J Gynecol Surg, 8:111–141,1992
9. Chang FH, Chou HH, Soong YK, Chang MY, Lee CL, Lai YM. Efficacy of isotopic 13 CO_2 laser laparoscopic evaporation in the treatment of infertile patients with minimal and mild endometriosis: a life table cumulative pregnancy rates study. J Am Assoc Gynecol Laparosc, 4(2):219-23, 1997
10. DeRiese C, Yandell R. Laser/light applications in gynecology. London: Springer-Verlag, 2011
11. Sutton C, Hill D. Laser laparoscopy in the treatment of endometriosis: A 5-year study. Br J Obstet Gynaecol, 97(2):181-5, 1990
12. Nezhat C, Hajhosseini B, King LP. Robotic-assisted laparoscopic treatment of bowel, bladder, and ureteral endometriosis. JSLS, 15(3):387-92, 2011
13. Nezhat C, Lewis M, Kotikela S, Veeraswamy A, Saadat L, Hajhosseini B, Nezhat C, Robotic versus standard laparoscopy for the treatment of endometriosis. Fertil Steril, 94(7):2758-60, 2010
14. Tulikangas PK, Smith T, Falcone T, Boparai N, Walters MD, Gross and histologic characteristics of laparoscopic injuries with four different energy sources. Fertil Steril, 75(4):806-810, 2001
15. Adamson GD, Nelson HP, Surgical treatment of endometriosis. Obstet Gynecol Clin North Am, ,24(2):375-409, 1997
16. Harrell AG, Kercher KW, Heniford BT, Energy sources in laparoscopy, Semin Laparosc Surg, 11(3):201-209, 2004
17. Sutton C, Abbott J, History of power sources in endoscopic surgery. J Minim Invasive Gynecol, 20(3):271-278, 2013
18. Te AE, The Next Generation in Laser Treatments and the Role of the GreenLight High-Performance System Laser Rev Urol, 8 Suppl 3:S24-30, 2006
19. Brill AI, Energy systems for operative laparoscopy. J Am Assoc Gynecol Laparosc. ,5(4):333-45; quiz 347-9, 1998
20. Nezhat C, Siegler A, Nezhat FR, Nezhat C, Seidman D, Luciano A, Operative Gynecologic Laparoscopy, Principles and Techniques. p. 65-67, 2nd Edition, McGraw Hill, New York, 2000
21. Kochhar P, Ghosh P, A comparative study of the use of different energy sources in laparoscopic management of endometriosis-associated infertility. World J Laparoscop Surg, 4(2):89-95, 2011
22. Law KS, Lyons SD, Comparative studies of energy sources in gynecologic laparoscopy. J Minim Invasive Gynecol, 20(3):308-318, 2013
23. Nezhat F, Mahdavi A, Nagarsheth NP, Total laparoscopic radical hysterectomy and pelvic lymphadenectomy using harmonic shears. J Minim Invasive Gynecol, 13(1):20-5, 2006

24. Choussein S, Srouji SS, Farland LV, Gargiulo AR, Flexible Carbon Dioxide Laser Fiber Versus Ultrasonic Scalpel in Robot-Assisted Laparoscopic Myomectomy. J Minim Invasive Gynecol, 22(7):1183-90, 2015

25. Hanby DF, Gremillion G, Zieske AW, Loehn B, Whitworth R, Wolf T, Kakade AC, Walvekar RR, Harmonic scalpel versus flexible CO_2 laser for tongue resection: a histopathological analysis of thermal damage in human cadavers. World J Surg Oncol, 1;9:83, 2011

26. Montgomery TC, Sharp JB, Bellina JH, Ross LF. Comparative gross and histological study of the effects of scalpel, electric knife, and carbon dioxide laser on skin and uterine incisions in dogs. Lasers Surg Med, 3(1):9-22, 1983

27. Bailey AP, Lancerotto L, Gridley C, Orgill DP, Nguyen H, Pescarini E, Lago G, Gargiulo AR, Greater surgical precision of a flexible carbon dioxide laser fiber compared to monopolar electrosurgery in porcine myometrium. J Minim Invasive Gynecol,21(6):1103-9, 2014

28. Sutton CJ, Ewen SP, Whitelaw N, Haines P. Prospective, randomized, double-blind, controlled trial of laser laparoscopy in the treatment of pelvic pain associated with minimal, mild, and moderate endometriosis. Fertil Steril, 62(4):696-700, 1994

29. Cibula D, Kuzel D, Fucíková Z, Hill M, Fanta M, Toth D, Jurovich P, Hrusková H, Zivný J, Long-term follow-up after complete treatment of peritoneal endometriosis with the CO_2 laser. Ceska Gynekol, 68(2):63-8, 2003

30. Wyns C, Donnez J. Laser vaporization of ovarian endometriomas: the impact on the response to gonadotrophin stimulation. Gynecol Obstet Fertil, 31(4):337-42, 2003

31. Donnez J, Wyns C, Nisolle M. Does ovarian surgery for endometriomas impair the ovarian response to gonadotropin? Fertil Steril, 76(4):662-5, 2001

32. Adamson GD, Lu J, Subak LL. Laparoscopic CO_2 laser vaporization of endometriosis compared with traditional treatments. Fertil Steril, 50(5):704-10, 1988

33. Chang FH, Chou HH, Soong YK, Chang MY, Lee CL, Lai YM. Efficacy of isotopic 13 CO_2 laser laparoscopic evaporation in the treatment of infertile patients with minimal and mild endometriosis: a life table cumulative pregnancy rates study. J Am Assoc Gynecol Laparosc. 4(2):219-23, 1997

34. Nezhat CR, Nezhat FR, Safe laser excision and vaporization of endometriosis. Fertil Steril, P 52(1): 149 – 151, 1989

35. Nezhat C, Pennington E, Nezhat F, Silfen SL, Laparoscopically assisted anterior rectal wall resection and reanastomosis for deeply infiltrating endometriosis. Surg Laparosc Endosc, 1(2): 106-108, 1991

36. Nezhat F, Nezhat C, Pennington E. Laparoscopic proctectomy for infiltrating endometriosis of the rectum, Fertil Steril, 57(5): 1129-1132, 1992

37. Nezhat F, Nezhat C, Pennington E, Ambroze W Jr., Laparoscopic segmental resection for infiltrating endometriosis of the recto sigmoid colon: a preliminary report. Surg Laparosc Endosc, 2:212–216, 1992

38. Nezhat C, Nezhat F, Pennington E, Laparoscopic treatment of lower colorectal and infiltrating rectovaginal septum endometriosis by the technique of videolaseroscopy. Br J Obstet Gynaecol, 99:664–667, 1992

39. Donnez J, Squifflet J, Complications, pregnancy and recurrence in a prospective series of 500 patients operated on by the shaving technique for deep rectovaginal endometriotic nodules, Hum Reprod, 25(8):1949-1958, 2010

40. Meuleman C1, Tomassetti C, Wolthuis A, Van Cleynenbreugel B, Laenen A, Penninckx F, Vergote I, D'Hoore A, D'Hooghe T, Clinical outcome after radical excision of moderate-severe endometriosis with or without bowel resection and reanastomosis: A Prospective Cohort Study, Ann Surg, 259(3):522-31, 2014

41. Meuleman C, Tomassetti C, D'Hoore A, Buyens A, Van Cleynenbreugel B, Fieuws S, Penninckx F, Vergote I, D'Hooghe T, Clinical outcome after CO(2) laser laparoscopic radical excision of endometriosis with colorectal wall invasion combined with laparoscopic segmental bowel resection and reanastomosis. Hum Reprod, 26(9):2336-2343, 2011

42. Meuleman C, D'Hoore A, Van Cleynenbreugel B, Beks N, D'Hooghe T. Outcome after multidisciplinary CO_2 laser laparoscopic excision of deep infiltrating colorectal endometriosis. Reprod Biomed Online,18(2):282-289, 2009

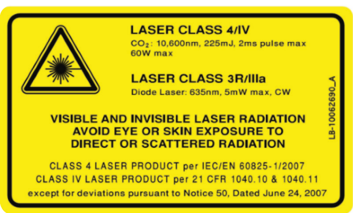
43. Munro MG, Economics and energy sources. J Minim Invasive Gynecol, 20(3):319-27, 2013

44. Gargiulo AR, Bailey AP, Nimble laser devices for minimally invasive gynecologic surgery. Contemporary OBGYN, October 2015. http://contemporaryobgyn.modernmedicine.com/contemporary-obgyn/news/nimble-laser-devices-minimally-invasive-gynecologic-surgery

45. Nnoaham KE, Hummelshoj L, Webster P, d'Hooghe T, de Cicco Nardone F, de Cicco Nardone C, Jenkinson C, Kennedy SH, Zondervan KT, World Endometriosis Research Foundation Global Study of Women's Health consortium, Impact of endometriosis on quality of life and work productivity: a multicenter study across ten countries. Fertility and sterility, 96(2):366-373 e368, 2011

Risk Information

CO_2 lasers (10.6 µm wavelength) are intended solely for use by trained physicians. Incorrect treatment settings or misuse of the technology can present risk of serious injury to patient and operating personnel.
The use of Lumenis CO_2 laser is contraindicated where a clinical procedure is limited by anesthesia requirements, site access, or other general operative considerations. Risks may include excessive thermal injury and infection. Read and understand the CO_2 systems and accessories operator manuals for a complete list of intended use, contraindications and risks.



Lumenis Ltd.
Yokneam Industrial Park,
6 Hakidma Street
P.O.B. 240,
Yokneam 2069204, Israel
Tel: +972-4-959-9000

EC REP **Lumenis (Germany) GmbH**
Heinrich-Hertz-Str 3
D-63303
Dreieich-Dreieichenhain
GERMANY
Tel: +49 (0) 6103 8335 0

0483

Lumenis® Energy to Healthcare

http://www.lumenis.com/Surgical