

Laparoscopic Partial Nephrectomy Using a Flexible CO₂ Laser Fiber

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ABSTRACT

Background and Objectives: Laparoscopic partial nephrectomy (LPN) is a challenging surgery that requires precise tissue cutting and meticulous hemostasis under warm ischemia conditions. In this study, we tested the feasibility of performing LPN using CO₂ laser energy transmitted through a specialized flexible mirror optical fiber.

Methods: General anesthesia and pneumoperitoneum were induced in 7 farm pigs. Various portions of a kidney, either a pole or a midportion of the kidney, were removed using a novel flexible fiber to transmit CO₂ laser energy set at a power of 45W and energy per pulse of 100mJ. The collecting system was approximated with a suture or 2, but no hemostatic measures were taken besides applying a few pulses of the laser to bleeding points. The pigs were sacrificed 3 wk later.

Results: Average renal mass removed was 18% of the total kidney weight. All pigs tolerated surgery well. Sharp renal cutting was accomplished in a single continuous incision, with minimal tissue charring and minimal blood loss (<10cc) in all animals. Necropsy revealed no peritoneal or retroperitoneal abnormalities. Histologic examination of the cut surface showed a thin sector of up to 100 μm of coagulation necrosis.

Conclusions: We report on the first LPN done using a CO₂ laser transmitted through a flexible fiber in an animal model. This novel application of the CO₂ laser produced excellent parenchymal incision and hemosta-

sis along with minimal damage to adjacent renal tissue, thus, potentially shortening ischemia time and kidney function loss. Further studies comparing this laser to standard technique are necessary to verify its usefulness for partial nephrectomy.

Key Words: Partial nephrectomy, CO₂ laser, Flexible fiber, Laparoscopy.

INTRODUCTION

Partial nephrectomy (PN) provides oncologic efficiency similar to radical surgery and is currently the advised treatment for most T1 and some T2 renal tumors.¹ The major benefit of PN is preservation of functioning renal tissue. This is dependent in turn on the magnitude and location of the tumor that dictate the extent of renal parenchyma loss and on length of renal ischemia. Renal ischemia is the most important and often the only modifiable surgical risk factor for decreased renal function after PN.² Irreversible diffusely distributed renal damage is typical when warm ischemic time exceeds 25 min, but when analyzing cases of patients who underwent PN for solitary kidney, it was found that when the renal hilum is clamped, every minute counts.³⁻⁵ Decreasing ischemia time is, therefore, a major challenge in PN.⁴ Any technology that can potentially decrease ischemia time is of interest.

The CO₂ laser is one of the first gas-based lasers. It produces a highly efficient, powerful midinfrared light that is well absorbed in water. The CO₂ laser cuts sharply and seals blood vessels but has a very shallow tissue penetration. It is used extensively by dermatologists and plastic surgeons for removal of superficial skin lesions and is commonly used in laryngeal surgery. Until recently, the implementation of CO₂ laser in laparoscopy has been limited due to a technical difficulty in transmitting this wavelength in a flexible optical fiber. Recently, a newly developed optical fiber (hollow waveguide), enables the transmission of carbon dioxide laser energy through a flexible instrument and is used already for transoral surgery.⁶

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In this study, we examined the safety and feasibility of using the CO₂ laser transmitted through a novel flexible fiber for laparoscopic partial nephrectomy (LPN).

MATERIALS AND METHODS

The Flexible CO₂ Laser Waveguide

The CO₂ laser waveguide is a hollow, semirigid, light-conducting tube designed to transmit laser energy at the midinfrared wavelength (**Figure 1a**). The CO₂ laser energy is transmitted through the hollow core of the waveguide, which is coated such that it acts as a mirror according to the principle of total internal reflection. In addition, the novel waveguide used in this study is capable of transmitting a red aiming beam at a wavelength of 0.65 μm, which adds to the safety of the surgical procedure. The aiming beam is generated by a low-power diode laser. Laser energy entering the waveguide travels down the tube by multiple bounces off the inner reflective surface and is delivered to the tissue at its distal end. The fiber's outer diameter is 1040 μm, and the inner diameter is 500 μm. It is capable of transmitting up to 60W at either continuous wave or pulsed mode. Transmission is proportionally attenuated in relation to fiber length or degree of bending. "Cutting" with the CO₂ laser is actually vaporizing a thin tissue sector. The vaporization zone is surrounded by rims of carbonized and coagulated tissues (**Figure 1b**). Additionally, to avoid the thermal blooming effect, e.g., defocusing and dispersing of energy, when using the CO₂ laser in a CO₂-filled cavity, a C13 isotope was used for the CO₂ laser. For convenience of use, the laser fiber is manipulated using a pencil-like instrument. It can be manipulated, however, by any other instrument or by hand.

Surgical Technique

The experiment was performed by surgery residents under the supervision of an attending physician and a veterinarian and after being approved by the local ethics committee. Anesthesia was induced in 7 farm pigs (mean weight, 50 kg; range, 34 to 68) by propofol after premedication with ketamine and xylazine. The animals were intubated and given isoflurane in a concentration of 1.5% to 2%. Heart rate, oxygen saturation level, and ETCO₂ were monitored throughout surgery. Pneumoperitoneum was obtained with a Veress needle and maintained at 15 mm Hg. Three trocars were inserted intraperitoneally. The renal hilum was isolated. Gerota's fascia was peeled off a single kidney pole (either a lower or upper pole of a kidney or a midportion simulating the random spread of kidney tumors). The renal hilum was clamped using a bulldog clamp. LPN was accomplished using the CO₂ laser set at a power of 45W and an energy per pulse of 100mJ transmitted through a 5-mm prototype instrument (**Figure 2a**). After complete transection, 1 or 2 sutures were applied to approximate the collecting system in all animals (**Figure 2b**). No other hemostatic measures were taken besides applying a few pulses of the CO₂ laser to bleeding points after unclamping the renal hilum. The specimen was removed intact using an endobag via an extension of a trocar site, and all laparoscopic port sites were sutured closed in the standard fashion. The resected pole was measured and weighed. Following surgery, the animals recovered, returned to their cages, and were given oral analgesia with tramadol for 3 d.

Follow-up

Daily temperature, weight, and overall animal health were recorded. Data on kidney function tests and blood count were collected daily for 5 d in 3 animals.

At 3 wk, the animals were scarified. The abdominal cavity was inspected; the operated kidneys were removed. In 4 renal units, retrograde pyelogram was performed ex vivo

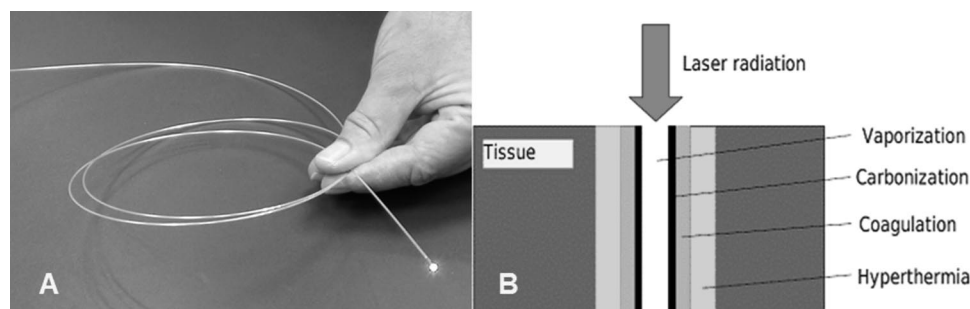


Figure 1. (a) The waveguide mirror fiber. **(b)** Schematic presentation of a tissue cut by the laser. Vaporization zone is surrounded by rims of carbonized and coagulated tissues.

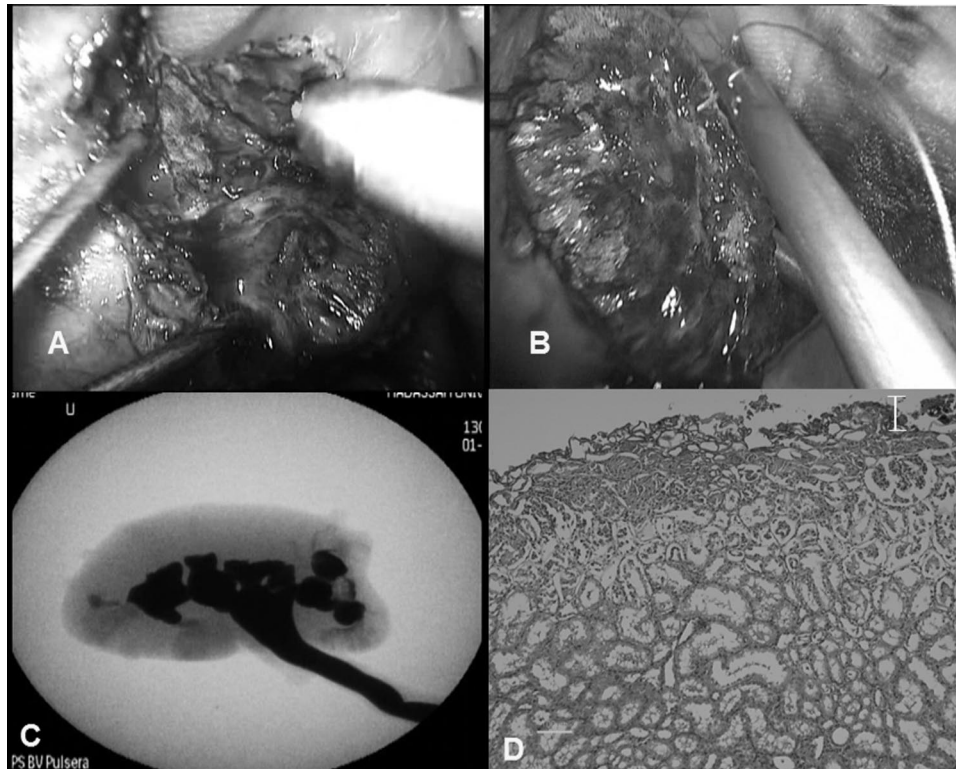


Figure 2. (a) Intraoperative photos of partial nephrectomy using a flexible CO₂ fiber. (b) Closing of the collecting system. (c) Retrograde pyelogram performed ex vivo showing contained collecting system. (d) Histologic examination (Hematoxylin and eosin, X 100) of the cut kidney surface. A thin sector (yellow bar) of about 100 μm of coagulation necrosis is seen.

to evaluate collecting system integrity. The kidneys were then fixed in formalin, stained with hematoxylin and eosin, and examined microscopically.

RESULTS

Using a novel flexible waveguide to transmit the CO₂ laser energy for LPN resulted in a smooth single incision with minimal tissue charring in all 7 renal units. Mean warm ischemia time was 17.4 min (SD 6.9), and the mean laser cutting time was 4.7 min (SD 0.85). Adequate hemostasis was attained in all animals by applying a few pulses of the laser on bleeding points. Blood loss was minimal (<10cc) in all animals. Average kidney mass removed was 22g (SD 8.2g). At necropsy, average kidney mass was 98g (SD 18g); therefore, an average of 18% of kidney mass removed at surgery (SD 31%).

All pigs tolerated surgery well and gained weight postoperatively. No significant changes in blood count were noticed. Creatinine rose from a preoperative level of 1.18 mg% (SD 0.15 mg%) to a maximal level of 1.67 mg% (SD 0.08 mg%) at postoperative day 3 and dropped to 0.99

mg% (SD 0.04 mg%) on postoperative day 5. Necropsy performed 3 wk after surgery revealed no peritoneal or retroperitoneal abnormalities. Ex vivo retrograde pyelograms performed in 4 renal units showed a contained urinary system (Figure 2c). Histologic examinations of the cut surface showed a thin sector of about 100 μm of coagulation necrosis (Figure 2d).

DISCUSSION

Lasers have become an established tool in the urologic armamentarium since Mulvaney⁷ first used a ruby laser to fragment urinary calculi in 1968. The application of lasers in urology has broadened to include lithotripsy, transurethral resection of the prostate, ablation of bladder tumors, photodynamic therapy, and partial nephrectomy.⁸ Open and laparoscopic laser PN has been described using multiple lasers including KTP, thulium, Green Light (532nm), and holmium YAG.⁹⁻¹²

The CO₂ laser at a wavelength of 10.6 μm is a highly efficient, powerful laser and well absorbed in water that provides sharp cutting with minimal tissue penetration.

The CO₂ laser is most useful for treating epidermal and dermal lesions in dermatology. The precise cutting with hemostasis provided by the CO₂ laser stimulated investigators to test it in partial nephrectomy. Meiraz and associates¹³ were the first to use a CO₂ laser with an output of 10W for PN in mongrel cats and demonstrated that the remaining kidney sustained minimal tissue destruction. By 2 wk postoperatively, the necrotic zone at the cut edge was only 5 mm.¹³ PN using the CO₂ laser as a knife was reported in 4 patients by Barzilay et al.¹⁴ in 1982. A 20W laser was available in the 1990s and was often used in combination with the Nd:YAG laser for PN.¹⁵

In the current study, we used a CO₂ laser with an output of 45W, which enables a far better precision and rapidity over previous low-output instruments, thus providing a fast PN with minimal blood loss. Additionally, the use of the CO₂ laser in laparoscopy was limited thus far by the technical difficulty of transmitting the CO₂ laser through a flexible fiber optic. The recently developed mirror fiber waveguide enables this and has already been approved for excision of laryngeal tumors.⁶

Another feature of the current laser is the use of the C13 isotope to avoid a blooming effect in a CO₂ filled cavity. This effect reduces energy transmission by as much as 35% to 61% and creates gas lensing that increased the spot size, thus reducing power density.¹⁶ All these features make this laser suitable for laparoscopy.

The 2 most challenging parts of PN are excision of the lesion and bleeding control. These portions of surgery determine the oncological and functional outcome of surgery and are usually done under warm ischemia conditions. In the current animal experiment, both incision and bleeding control were performed using the CO₂ laser. Parenchymal cutting (removing an average of 18% of total kidney weight) was accomplished by a single, continuous incision and with minimal tissue loss (**Figure 2d**). Hemostasis was accomplished by applying a few pulses of the laser to bleeding points after unclamping.

CONCLUSION

The CO₂ laser transmitted through the flexible waveguide fiber was used for the first time for LPN. Parenchymal incision was accomplished in a single precise cut, and blood vessel sealing was obtained by applying a few pulses of the laser. Thus, the CO₂ laser has a potential of reducing warm ischemia time. Further studies comparing this laser to standard technique are necessary to verify its usefulness for partial nephrectomy.

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