Less Smoke and Minimal Tissue Carbonization Using a Thulium Laser for Laparoscopic Partial Nephrectomy Without Hilar Clamping in a Porcine Model

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ABSTRACT

Purpose: We evaluated the utility of a thulium laser and a novel implementation of its use for laparoscopic partial nephrectomy to achieve precise, smokeless, and hemostatic dissection without hilar clamping and with minimal charring in a porcine model.

Materials and Methods: Laparoscopic transperitoneal lower-pole partial nephrectomy was performed in five Yorkshire farm pigs without clamping of the renal hilum. All animals were kept alive for 1 week. Using a 365-μm laser fiber, a 30 W thulium laser was used to produce full-thickness cortical excisions of the lower-pole renal cortex. The laser fiber was delivered through the working channel of a 16F flexible cystoscope inserted through a 10-mm laparoscopic port. The laser incision was directed by manual deflection of the cystoscope along with low-pressure saline irrigation through the cystoscope.

Results: Laparoscopic partial nephrectomy was completed in all cases without perioperative complications and with an estimated blood loss of <50 mL. The thulium laser was able to cut tissue and simultaneously to coagulate vessels as large as 1.6 mm. The flexible cystoscope with concurrent saline irrigation permitted precise laser control for dissection with minimal tissue charring and no smoke to obscure visibility. At 1 week, the cut edge of the tissue showed minimal necrosis with preservation of histologic architecture.

Conclusions: Laparoscopic partial nephrectomy with the thulium laser provides precise dissection and hemostasis without hilar clamping. Minimal tissue charring and no smoke generation improve visibility.

INTRODUCTION

PARTIAL NEPHRECTOMY is the treatment of choice for small localized renal masses, for solitary kidneys, or for patients with renal insufficiency. The oncologic efficacy of partial nephrectomy is equivalent to that obtained with radical nephrectomy. Although the benefits of laparoscopy have been clearly demonstrated in terms of less postoperative pain and faster convalescence, widespread application of laparoscopic partial nephrectomy (LPN) has been limited by concerns about hemostasis, prolonged warm ischemia, and the inherent technical difficulties of intracorporeal suturing.

Available approaches to achieve hemostasis during LPN include topical hemostatic agents, radiofrequency pretreatment, hilar clamping with bulldog or Satinsky clamps, the argon-beam coagulator, electrocautery, the Harmonic Scalpel, fibrin glue, ultrasonic dissection and TissueLink™, microwave tissue coagulation, and cable ties. Hemostasis by hilar occlusion risks prolonged warm ischemia time and potential renal-artery damage from the necessary dissection. In contrast, hemostasis without hilar clamping averts renal ischemia and the possible hazards of hilar manipulation. We evaluated the utility of the novel Food and Drug Administration-approved continuous-wave Revolix™ laser for LPN without hilar clamping in a porcine model. This thulium-based laser has a λ = 2 μm wavelength, delivers power through a silica fiber, and concurrently cuts and coagulates with shallow penetration.

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MATERIALS AND METHODS

Animals

Five female farm pigs weighing between 50 and 75 kg were approved for this study by the Animal Research Committee at our institution. Animals were anesthetized using sodium pentobarbital (35 mg/kg) and maintained on ventilation during all procedures. In a pilot study, a single animal was used to determine the optimum parameters for the laser. For survival procedures, veterinary staff monitored the animals before and after each procedure in accordance with the National Research Council 1996 Guide for the Care and Use of Laboratory Animals. Animals were euthanized 1 week after surgery with an overdose of pentobarbital (100 mg/kg).

Surgical technique

Pneumoperitoneum was established through a Veress needle. Three 10-mm transperitoneal ports were placed lateral to the rectus muscle at the level of the xyphoid, at the umbilicus, and equidistant between the xyphoid and the umbilicus. A fourth 10-mm trocar was placed at the umbilicus for the suction/irrigation device. The lower pole of the left kidney was mobilized, and the ureter was dissected free from the renal surface and the psoas muscle.

A 50 W Revolix laser unit (AllMed Systems, Inc., Pleasanton, CA), set at 30 W total power, was used in conjunction with a 365-μm end-fire silica fiber delivered through the working channel of a 16F flexible cystoscope (Karl Storz Endoscopy-America Inc, Culver City, CA). The shaft of the cystoscope was stiffened with a modified polycarbonate tube that did not affect deflection of the distal end and was able to fit through a 10-mm laparoscopic port. Manual deflection of the flexible cystoscope allows the fiber tip to arc from -90° to +90°. Low-pressure saline irrigation was infused through the working channel of the cystoscope for improved visibility and to eliminate smoke. A full-thickness cortical excision of the lower pole was initiated by deflecting the fiber tip across the tissue. Blunt-tip forceps were used to separate the cut edges and expose the line of excision. Then the groove was deepened until the lower pole was excised completely. The laser was defocused as necessary to coagulate small areas of bleeding.

After complete resection, one ampoule of indigo carmine was administered intravenously, and the cut surface was inspected for entry into the collecting system and urinary extravasation. Fibrin glue was administered to the exposed parenchyma. The specimen was removed intact using an entrapment sack via an extension of a trocar site. All laparoscopic port sites were sutured closed in the standard fashion. Each pig was allowed to recover and monitored daily for 1 week.

After 1 week, the pig was euthanized, the left kidney was harvested, and a retrograde ureteral infusion was performed ex vivo with a solution of indigo carmine to evaluate collecting-system integrity.

Histopathologic examination

All histologic examinations were completed and confirmed by two pathologists (DG and JS). At necropsy, both the acute and the survival kidneys were evaluated grossly and histologically to assess the effect of the laser on the kidney tissue. Kidney slices were incubated at 37°C for 30 minutes in 2% 2,3,5-triphenyl-2H-tetrazolium chloride (TTC). Infarcted areas can be identified as an area of unstained tissue, whereas viable tissue stains red (see Fig. 2B below). Routine hematoxylin and eosin staining was completed on paraffin-embedded sections containing the edge of the kidney and neighboring renal parenchyma. Grossly, the maximum depth of laser penetration into the renal parenchyma was measured.

RESULTS

Laparoscopic partial nephrectomy was successful in all cases without the need for hilar clamping. The flexible cystoscope (Fig. 1A) permitted curvature of the laser fiber for optimum contact with the tissue for precise cuts. The low-pressure continuous saline irrigation along the path of the laser fiber ensured clear visibility of the cut edges (Fig. 1B) by minimizing the generation of smoke and tissue carbonization (Fig. 1C). The maximum amount of irrigation fluid required to complete the resection did not exceed 500 mL. The laser was able to cut tissue and coagulate small vessels simultaneously. Defocusing the laser by drawing the fiber tip away from the tissue allowed coagulation of larger vessels and achieved absolute hemostasis of the resection bed (Fig. 1D). The largest vessel coagulated was 1.6 mm in diameter (Table 1).

No intraoperative or postoperative complications occurred. The estimated intraoperative blood loss was <50 mL for all cases. The mean operative time required for excision of the cortex and complete hemostasis was 15 minutes (range 12–17 minutes; Table 1). The mean total operative time was 42 minutes (range 35–60 minutes). All the pigs in the survival group made a full recovery without observable postoperative morbidity. In all cases, intraoperative intravenous infusion of indigo carmine did not show any urinary extravasation. The kidney was harvested 1 week postoperatively. No urinoma was observed in any case. Furthermore, ex-vivo retrograde injection of indigo carmine into the ureter did not reveal extravasation.

A full-thickness cortical excision of the lower pole was achieved in all cases (Fig. 2A). The mean specimen weight was 12 g (Table 1). The TTC viability stain showed that the shallow penetration of the laser caused minimal ischemic injury to the remaining parenchyma (Fig. 2B). Similarly, histologic analysis of the cut edge of the tissue revealed no evidence of charring or necrosis, with complete preservation of histologic architecture (Fig. 2C). After 1 week, a well-defined scar had formed with thicknesses ranging from 0.2 to 0.6 cm (Fig. 2D). Again, the histologic architecture beneath the scar was well preserved without extensive tissue necrosis or inflammation.

DISCUSSION

With the widespread routine use of CT and abdominal ultrasonography, the indications for nephron-sparing surgery have been expanded to include an increasing number of asymptomatic, incidentally diagnosed, mass lesions in the kidney. Laparoscopic partial nephrectomy achieves cancer control equivalent to that of open partial nephrectomy but with
THULIUM LASER FOR LPN

FIG. 1. (A) The laser fiber is delivered through the working channel of a flexible cystoscope that allowed the fiber to arc from −90° to 90°. (B) Continuous low pressure saline irrigation through the working channel of the cystoscope in the direction of the laser fiber allows for clearer visibility of bleeding vessels. (C) Laser incision concurrent with saline irrigation eliminates smoke for clearer visibility of tissue margins. (D) Defocusing the laser by withdrawing the fiber tip away from the tissue allows coagulation of larger vessels and achieved absolute hemostasis of the resection bed.

lower perioperative morbidity. Howewr, despite its feasibility, widespread application of LPN has been protracted, primarily because of concerns about warm ischemia and parenchymal hemorrhage. Perioperative hemorrhage is seen in as many as 9.5% of patients, necessitating open conversion or aggressive blood transfusions. In addition, prolonged warm ischemia risks renal deterioration and dysfunction, although recent studies suggest that warm ischemia time as long as 55 minutes does not significantly influence long-term renal function after LPN.

To obtain hemostasis and avoid warm ischemia during LPN for small cortical tumors, several investigators have evaluated the utility of surgical lasers without the need for hilar clamping. Excisional partial nephrectomy affords cleaner pathologic analysis and confirmation of negative margins in contrast to ablative techniques such as cryosurgery or radiofrequency ablation. Laser partial nephrectomy has been described for CO2, Nd:YAG, diode, holmium, and KTP lasers. The shallow penetration of the CO2 laser did not provide adequate hemostasis. The Nd:YAG laser (1064 nm) provided a deeper thermal penetration with efficient hemostasis but did not have adequate tissue-cutting properties. The diode laser (980 nm) has a tissue absorption coefficient and depth of penetration similar to those of the Nd:YAG laser, but both lasers produce poor tissue ablation and cause severe carbonization. Although the holmium laser provides better tissue cutting and coagulation for hemostasis, it generates significant smoke and causes excessive blood splattering, both of which limit visibility and therefore its clinical application. A recent report of KTP laser partial nephrectomy in a calf model demonstrated negligible backscatter, but the procedure generated considerable smoke, thereby limiting visibility.

The 2-μm Revolix laser has ablative and coagulative properties similar to those of the holmium laser, but the energy is

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<th>Table 1. Operative and Histologic Data</th>
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<td><strong>Mean (range)</strong></td>
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<td>Total resection time (min)</td>
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<td>Total operative time (min)</td>
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<td>Laser energy (kJ)</td>
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<td>Fibrous scar depth (μm)</td>
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<td>No. with urinary leak or urinoma</td>
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FIG. 2. (A) A full thickness cortical excision of the lower pole was achieved in all cases. (B) TTC viability stain showed that the shallow penetration of the laser had minimal ischemic injury to the remaining parenchyma. (C) Histological analysis of the cut edge of the tissue specimen showed no evidence of tissue charring or necrosis with complete preservation of histological architecture. Original magnification ×20. (D) After 1 week, a well-defined scar has formed with thickness ranging from 0.2–0.6 cm. The histological architecture beneath the scar is well-preserved without extensive tissue necrosis and inflammation. Original magnification ×10.

delivered as a continuous wave. Therefore, there is no blood splattering during the efficient tissue cutting. When used in a dry environment, there was excessive generation of smoke and tissue charring. However, the optimum condition for use of this laser is submergence in a low flow of saline or water, which virtually eliminates smoke, minimizes carbonization, and affords clear visibility of the tissue. Less than 500 mL of irrigant was required to complete the resection and was easily evacuated. Passage of the laser fiber through the working channel of a flexible cystoscope allowed convenient simultaneous irrigation along the fiber path to better see the blood vessels. Furthermore, manual deflection of the flexible cystoscope, a technique well known to most urologists, permitted precise control of the laser fiber for tissue incision. Defocusing the laser by withdrawing it from contact with the tissue allowed coagulation of vessels as large as 1.6 mm in diameter. Other commercial laparoscopic instruments for intracorporeal laser use require continuous saline infusion through another port.

There are several limitations to our study. First, we treated only the renal cortex. Although the thulium laser can cut tissue and coagulate cortical vessels reliably, in the non-survival pig study with the current fiber size and power setting, the laser did not reliably seal the larger blood vessels near the hilum (data not shown). Deeper and medullary incisions likely would require additional agents such as fibrin glue to help seal larger vessels and collecting-system openings. In addition, the interaction of the laser with highly vascularized tumor tissue, as well as its effects on tumor histopathology, should be determined. Further studies will be required to address these issues. Another limitation of this study was that our porcine model may not represent the utility of the laser in humans. The renal vessels in a developing farm pig may not correspond to the vessels in a human subject. Maneuvers to make the pig hypertensive during the laser incision may more closely mimic the physiology of humans. Clinical evaluation in humans is clearly indicated to validate the laser’s true utility.

CONCLUSION

Laparoscopic partial nephrectomy is a developing modality well accepted for its oncologic efficacy. However, LPN poses
significant challenges in obtaining hemostasis while minimizing warm ischemia. The ability to perform precise tumor excisions without hilar clamping in a hemostatic environment will undoubtedly expand the role of LPN in urologic surgery. Surgical lasers thus far have had limited clinical utility for LPN. However, the thulium laser holds significant promise in providing both efficient tissue-cutting properties and concomitant coagulation. For use in humans, this laser would be well suited for laparoscopic excision of exophytic lesions limited to the renal cortex.

REFERENCES

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ABBREVIATIONS USED

CT = computed tomography; LPN = laparoscopic partial nephrectomy; TTC = 2,3,5-triphenyl-2H-tetrazolium chloride.