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Energy Sources for Laparoscopic Partial Nephrectomy - Critical Appraisal

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ABSTRACT

Laparoscopic partial nephrectomy (LPN) has emerged as a viable alternative for the conventional open nephron-sparing surgery (NSS). So far, an adequate renal parenchymal cutting and hemostasis, as well as caliceal repair remains technically challenging. Numerous investigators have developed techniques using different energy sources to simplify the technically demanding LPN. Herein we review these energy sources, discussing perceived advantages and disadvantages of each technique.

***Key words**: laparoscopy; surgical procedures, minimally invasive; nephrectomy; energy sources*
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INTRODUCTION

The majority of renal tumors are now incidentally diagnosed and smaller than 4 cm (1). The treatment of choice for most small renal masses is the NSS. Fergany et al. have demonstrated similar results comparing partial and radical nephrectomy for 10 year follow-up (2).

Although some different techniques of LPN have been described (3-7), in the senior author institution (ISG), this technique include complete kidney exposure, hilar clamping, cold cut with laparoscopic scissors, precise collecting system closure, reconstruction of partial nephrectomy bed over surgical bolsters, and the use of biological haemostatic agent (Floseal®).

Widespread application of LPN has been limited given the challenges associated with intracorporeal suturing for hemostasis and collecting system closure. To simplify the procedure, several reports have been published using various energy modalities to replace the need for intracorporeal suturing (6-8).

In this review, we describe and evaluate several energy sources used to achieve cutting and hemostasis during LPN, as well as ablative tissue energies, outlining the advantages and disadvantages of each one.

LASERS: CUTTING AND HEMOSTATIC ENERGY

Several lasers have been developed specifically for surgical applications, being used to cut or vaporize tissue while leaving a coagulated field. Their efficacy to coagulate or excise tissue is regulated by specific wavelength, energy or power setting and mode of operation (continuous or pulsed) (8). Applications in urology include lithotripsy, ablation of bladder tumors, transurethral resection of prostate, and partial nephrectomy (9).

Several kinds of laser energy have been tested for parenchymal transection during LPN (8-11). The use of laser fibers with the specific application of tissue welding is based on delivering energy to the target lesion, with heat absorption resulting in thermocoagulation. This modality avoids needle trauma and suture reaction, may allow shorter operative time and less bleeding, although it presents thermal damage in tissue with indirect contact (12-15). The search for the ideal hemostatic method still continues since no single laser was proven to have ideal results.

Descriptions of open laser partial nephrectomy using the CO_2, Nd: YAG and holmium lasers have previously been published (10,16). Since this early experience, several authors have reported the use of lasers for LPN in animal model, as well as in the clinical field (Table-1). Lotan et al. (16) studied the use of holmium laser for partial nephrectomy in the porcine model. The authors performed transperitoneal lower pole laparoscopic partial nephrectomy in 5 pigs. Fibrin glue was applied to the nephrectomy bed to seal the collecting system. All cases were performed with adequate hemostasis and without the need of further hemostatic devices.

Lotan et al. (17) described the first clinical report of laser during LPN, using the holmium: YAG laser in three patients. Indications included complex cyst, nonfunctioning lower pole, and renal mass. There was minimal blood loss and no need for hilar clamping. Although the laser alone was hemostatic, the authors used fibrin glue in two cases and oxidized cellulose in one case to reinforce the tissue against delayed bleeding. There were no perioperative complications and the average hospitalization was 3 days. The authors in this study concluded that with high power settings (0.2J/pulse at 60 pulses/sec and 0.8J/pulse at 40 pulses/sec), the Ho: YAG laser can be used as an effective hemostatic tool in LPN.

The advantages of this laser are simplicity of use and relative low cost. The Ho: YAG laser is able to cut and coagulate tissues, with minimal damage to the adjacent renal parenchyma, preserving as much normal tissue as possible. The disadvantages include the smoke created and the splashing of blood on the camera, particularly when transecting larger vessels.

The use of Diode laser in LPN was reported by Ogan et al. (18). They performed transperitoneal lower pole laparoscopic partial nephrectomy in 5 pigs without the need for hilar occlusion using a 980-nm diode laser. The laser hemostasis was insufficient in 3 cases, requiring adjunctive measures, as hemostatic

***Table 1** – Use of laser during laparoscopic partial nephrectomy.*

Author/Year	Animal Model vs. Clinical (n)	Acute vs. Chronic	Open vs. Laparoscopic	Laser Employed	Hilar Clamping
Hughes (5), 1972	canine (n = 7)	chronic	open	CO_2	yes
Meiraz (7), 1977	feline (n = 20)	chronic	open	CO_2	yes
Benderev (49), 1985	canine (n = -)	chronic	open	Nd: YAG	yes
Landau (9), 1987	canine (n = 20)	acute	open	Nd: YAG	yes
Taari (10), 1994	porcine (n = 9)	acute	open	Nd: YAG	yes
Ogan (11), 2002	porcine (n = 5)	chronic	laparoscopic	Diode	no
Ogan (13), 2003	porcine (n = 5)	chronic	laparoscopic	Diode	yes
Moinzadeh (20), 2005	bovine (n = 6)	chronic	laparoscopic	KTP	no
Lotan (12), 2002	clinical (n = 3)	N/A	laparoscopic	Ho: YAG	no

**Adapted from Moinzadeh et al.: Potassium-titanyl-phosphate laser laparoscopic partial nephrectomy without hilar clamping in the survival calf model. J. Urol. 2005, 174: 1110-4.*

clips to stop bleeding. The mean operative time was 126 minutes, the mean blood loss was 150 mL (50-300 mL), and no urinary extravasation was observed on retrograde pyelogram at 2 weeks. The authors concluded that the diode laser is feasible on the porcine model and limited its use in humans to small periferic tumors. The limitation of this laser was observed in controlling large vessels. Fibrin glue was applied to all partial nephrectomies, resulting in selling of the collecting system in all cases. It was unknown if the selling occurred as result of the glue or the laser. Further studies are necessary to achieve success with this kind of energy in LPN.

The same group has utilized an 810-nm pulsed diode laser (20W) plus a 50% liquid albumin-indocyanine green solder in 5 pigs demonstrating the tissue welding qualities of lasers (19). All surgeries were performed without complications with mean operative time of 82 minutes. Average blood loss was 43.5 mL and mean warm ischemia time was 11.7 minutes. There was no evidence of urinoma formation or delayed hemorrhage in any of the animals. Histologic studies showed good preservation of renal parenchyma beneath the solder.

The main advantage of this soldering technique includes the ability to close the collecting system and control of bleeding during LPN, with short warm ischemia time (< 12 minutes). In this study, the laser was able to control large vessels, mimicking human LPN, and the violated collecting system was fixed with the solder without problems. Further studies are required to confirm this fact.

The KTP laser has been recently tested for LPN in the calf model (20). Using 6 calves, the authors successfully completed the operation without hilar clamping in 11/12 procedures. One animal required temporary occlusion of the hilum for hemorrhage not controlled with the laser. The histological analysis revealed minimal effect on the adjacent area to the excision. The unique feature of the KTP laser includes the 532-nm wavelength, with specific uptake by hemoglobin. The authors believed that this aspect yielded excellent hemostasis in the robust calf model. In addition, minimal blood splatter was noted given decreased bleeding and thermomechanical ejection when compared to the Ho:YAG laser.

HIDRO-JET DEVICE: MAINLY CUTTING ENERGY

Hydro-jet technology has been established for surgery of the liver and other parenchymatous organs, using the principle of high-pressure water flow to cut tissues (21,22). The delivery probe allows dissection with both water high pressure and blunt dissection. Coagulation is applied usually with a bipolar thermo-applicator if needed. The first report in the urologic field was done by Pentchev et al. for open renal surgery in the canine model (23).

Shekarriz et al. published the first experimental laparoscopic study in LPN. The authors performed the procedure with hilar clamping in the porcine model, using 5 animals (24). In this study, the mean warm ischemia time was 17 minutes. Moinzadeh et al. evaluated the feasibility of hydro-jet assisted LPN without renal hilar vascular control in the larger size and more robust calf model, to better reproduce the human kidney (25). The authors performed bilateral LPN using the Helix Hydro-Jet® (ERBE Tubingen, Germany) without hilar control in 10 survival calves. All procedures were completed successfully without open conversion, and the hilar clamping was not needed in 18 (90%) cases. The mean operative time was 173 minutes (60-240), kidney section time was 63 minutes (13-150), and estimated blood loss was 174 cc (20-750). Histological studies showed a thin (1 mm) layer of adherent coagulum beneath the resection area with minimal thermal artifact.

Clinically, Penchev et al. used the hydro-jet without hilar clamping in open partial nephrectomy for a low pole tumor (n = 1) and open anatrophic nephrotomy of a staghorn calculi (n = 1) (26). The hydro-jet dissection time was 25 and 12 minutes, with blood loss of 150 and 100 mL, respectively. The procedures were done without vascular clamping or local hypothermia (27).

Basting et al. reported the largest clinical experience with the hydro-jet device for a variety of open kidney procedures (26). A total of 24 patients underwent open surgery for nephrolithiasis, renal masses, and complicated cysts. Operative resection time was between 14 and 40 minutes with minimal intraoperative blood loss. They concluded that the water jet device was useful for renal parenchymal transection.

To date, no clinical report of hydro-jet LPN has been published, but the suitability of the LPN technique to improve hemostasis and dissection has been proven (Table-2). This use of kinetic energy has the advantage of dissect selective parenchyma while preserving vessels and the collecting system during the surgery. With this technology, the procedure may be easier, faster, avoiding the warm ischemia and the technically challenging intracorporeal suturing during LPN. Since there is no cautery tissue damage, the Hydro-jet device preserves the renal parenchyma. Limitations include the theoretical spread of cancer cells with the use of the high pressure saline flow. In addition, current rigid instruments lacking flexibility make the laparoscopic angles of dissection challenging.

BIPOLAR ELECTRICAL CURRENT: CUTTING AND HEMOSTATIC ENERGY

The bipolar needle electrode is composed of two 5 cm long needles, in parallel, that connects to a bipolar energy source. By electric current, it dissects and cauterizes the tissue that lies between the needles. This technique facilitates the procedure, creating a regional ischemia, without hilar occlusion. It is very efficient to coagulate deep parenchymal vessels before cutting out the renal tissue. Its linear shape can be a limitation to different tumors locations.

Barret et al. compared the efficacy and morbidity between three hemostatic techniques: high-frequency bipolar, high-frequency unipolar, and ultrasound during LPN in a porcine model without vascular control. In this study, the authors evaluated perioperative complications, blood loss, renal function, and histological findings in the parenchyma. There was a significantly decrease in blood loss when the ultrasound was employed (p = 0.0026). One pig developed hemorrhage in day 6. There was no difference in histological results (28).

In another porcine study, Ong et al. demonstrated the use of the bipolar needle device in LPN with comparable results to those reported by Barret et al. (28). In this series, the blood loss was decreased (29).

Janetschek et al. and Guillonneau et al. reported the use of bipolar hemostatic coagulation in LPN showing the clinical feasibility of this energy to achieve good hemostasis (30,31).

Some modifications in the future, including curved shape or articulating head may expand the use of this device for midpole and hilar renal masses. It seems that the damage to the remaining tissue is minimal. Nevertheless, more clinical studies are required to define the proper role in LPN.

FLOATING BALL: CUTTING AND HEMOSTATIC ENERGY

The TissueLink Floating Ball (Tissuelink Medical, Inc., Dover, NH) comprises a monopolar

***Table 2** – Use of water jet during laparoscopic partial nephrectomy.*

Author/Year	Animal Model vs. Clinical	Acute vs. Chronic	Open vs. Laparoscopic	Hilar Clamp	Hemostatic Method
Pentchev (7), 1993	dog model	chronic	open	no	suture ligation
Hubert (8), 1996	porcine model	acute	open	no	suture ligation
Shekarriz (10), 2000	porcine model	acute	laparoscopic	yes	electrocautery
Corvin (9), 2001	porcine model	acute	laparoscopic	no	electrocautery Endo-GIA
Moinzadeh (25), 2005	calf	acute and chronic	laparoscopic	no	Biclamp
Penchev (11), 1999	clinical	human	open	no	suture ligation
Basting (12), 2000	clinical	human	open	no	suture ligation coagulation

*** Adapted from Moinzadeh et al.: Water jet assisted laparoscopic partial nephrectomy without hilar clamping in the calf model. J. Urol. 2005, 174: 317-21* current that combines water-cooled with radio frequency for blunt dissection and coagulation purposes. The technology uses the radio frequency close to the instrument tip, sealing small blood vessels, achieving good hemostasis prior to parenchymal resection. The electrical energy is transmitted by the saline irrigation and converted into thermal energy on the target tissue. Scar formation is prevented by the saline since the coagulated area remains cool, maintaining the temperature at or bellow 100^o C (32).

Sundaram et al. first reported the feasibility of LPN with the Floating Ball without vascular control in 3 patients (33). The mean estimated blood loss was 275 mL and one patient had a urine leak that resolved spontaneously. Urena et al. retrospectively reviewed 10 LPN where this energy source was used to achieve hemostasis. Mean tumor size was 3.9 cm and mean blood was 352 mL. All margins were negative (32).

Stern et al. reported the largest series available (34). The authors performed 14 LPN using the Floating Ball. The mean operative time in this series was 124 minutes and mean blood loss was 168 mL. The argon-beam coagulator, Fibrilar^{tm} (Ethicon, Somerville, NJ) and fibrin glue were used for control minor bleeding.

The parenchymal resection is slower when performed without hilar control. To minimize the bleeding, the renal tissue can be coagulated prior to resection, and the scar produced does not affect the pathological analysis of tumor margin status. Vascular structures up to 3 mm can be sealed by the use of the floating ball device. The depth of tissue penetration is correlated to the type and duration of contact between the kidney surface and the device.

HARMONIC SCALPEL: CUTTING AND HEMOSTATIC ENERGY

The harmonic scalpel (LaparoSonic Coagulating Shears; Ethicon Endo-Surgery, Cincinati, OH) has the potential to vibrate its jaws at a rate of 55,000 Hz, generating heat in the range of 50^{o}C TO 100^{o}C, coagulating and cutting the tissue simultaneously. This device forms a protein coagulum between the jaws of the shear resulting in minimal spread of energy laterally (2 mm).

Jackman et al. showed the ability of the harmonic scalpel to perform LPN in a porcine model without control of the hilar vessels (35). Additional hemostatic measures were necessary in 25% of the cases when a polar nephrectomy was performed. The authors concluded that the use of harmonic scalpel in hemiphrectomies is not recommended because the high risk of substantial hemorrhage.

Harmon et al. reported the use of harmonic scalpel in 15 patients undergoing LPN (36). All procedures were completed without complications. The mean tumor size was 2.3 cm and mean blood loss was 368 mL. The renal bed hemostasis was accomplished by using oxidized cellulose and argon beam coagulator. All resection margins were negative at the pathology results.

Although this device may aid in dissection of small superficial renal tumors, it is not sufficient to perform LPN particularly for larger and centrally located tumors. Overall, the use of this technology has not shown good results when used without others hemostatic device/agents.

ELECTRICAL SNARE: CUTTING AND HEMOSTATIC ENERGY

This device was designed as a combination of an electrosurgical snare electrode (Cook Urological Inc., Spencer, IN) with an electrosurgical generator (ERBE USA, Inc., Marietta, GA), to produce renal transection and parenchymal hemostasis simultaneously.

Elashry et al. compared the effectiveness of this snare during LPN, comparing it to ultrasonic dissectors in the porcine model. The electrical snare was faster and produced less intraoperative bleeding than the ultrasonic dissectors (37).

In the study from Washington University reporting the use of the electrosurgical snare in LPN without occlusion of hilar vessels (38), the hemostasis was successfully achieved in all but one case, where it was necessary to use the argon-beam coagulator to stop the bleeding after parenchymal resection.

The limitations of this device include capability of using only for guillotine resections and it can not be safely used close the hilum because of risk of renal pelvis injury. Clinical trials are still being awaited to confirm its applicability in LPN.

RADIO FREQUENCY ABLATION: TISSUE HEMOSTATIC - ABLATIVE ENERGY

The Radio Frequency Ablation (RFA) creates a good parenchymal zone of coagulative necrosis usually visible after 24 to 48 hours post procedure. This treated tissue is finally replaced by inflamation and fibrosis (39). In animal studies, Gill et al. demonstrated the renal parenchyma trombosis and coagulation noted after RF ablation (40,41).

The first clinical report on RFA assisted LPN was published by Gettman et al. (42). The RFA was used in 10 patients mainly to coagulate the tumor, facilitating the tumor excision with minimal bleeding. The Texas University group published the initial series of RFA assisted LPN (43) with 13 patients undergoing surgery. A total of 5 tumors were completely excised and 7 tumors were left in situ after treatment. There was one focal positive margin in a patient submitted to RFA assisted LPN, but this patient remained disease-free after 1 year treatment.

In these studies the authors reserved the use of this RFA technique for polar, small, exophytic lesions. There are some advantages related to complete tumor removal instead of only ablation, providing better oncologic approach for the patient. There is also minimal blood loss and good visualization during tumor excision. The limitations are concerned about the need for a learning curve with the RFA probes, the challenge to perform centrally located tumor excisions with high risk of collecting system injury. An additional clinical experience with larger diameter tumors and long-term follow-up is necessary to confirm the real value of this technique.

ARGOM-BEAM COAGULATOR: HEMOSTATIC ENERGY

The argon beam coagulator (ABC) provides hemostasis by delivering radiofrequency electrical energy to tissue across a jet of argon gas. The device uses a non-contact, monopolar, electrothermal type of hemostasis (44).

The first report using the ABC was from Daniell et al. when they reported its use in cholecystectomies in animals and humans. They concluded that the ABC allowed a safely hemostasis and effective controlled tissue electrocoagulation (45).

These techniques have been used associated to others kind of hemostatic agents, and with different approaches by another authors with relatively success (46-48).

The ABC allows a good visualization without smoke, safe hemostatic tissue electrocoagulation, with a rapid non-touching technique. The lack of smoke and the non-touching technique facilitate laparoscopic application. In the authors' opinion, this kind of energy is well used to coagulate cortex vessels after closing the parenchymal defect but has limited application for larger, infiltrating tumors. The use of the device must be done with caution because of the risk of gas embolism caused by intra-abdominal overpressurization during a laparoscopic procedure; to minimize the associated risks we must leave one instrument cannula open to drain the gas and have a good patient monitorization (e.g., end-tidal CO_2, Doppler flow).

CONCLUSIONS

LPN has emerged and gained popularity in selected centers worldwide, and new energy sources have been employed to minimize the level of difficulty of the procedure. The key to achieve an ideal procedure remains in simplify the technique as regards closure of collecting system and minimal blood loss without the need for hilar occlusion. The improved energy sources may further decrease operative time, warm ischemia time, and morbidity. The different devices presented are evolving but until today, no one has been totally superior and only the future will show us which of these instruments will stand the test of time.

CONFLICT OF INTEREST

None declared.

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