

Comparison between a 1.92- μ m fiber laser and a standard HF-dissection device for nephron-sparing kidney resection in a porcine in vivo study

Dirk Theisen-Kunde · Sönke Tedsen · Christian DoeHN ·
Dieter Jocham · Ingo Kausch von Schmeling

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Abstract Nephron-sparing surgery was performed in a porcine model with a 1.92- μ m fiber laser dissection device in comparison to a standard high-frequency dissection device. In nine pigs, general anesthesia and a median laparotomy were performed to expose both kidneys. On six kidneys (three HF and three laser) a partial renal parenchyma resection of the lower pole without opening of the renal pelvis was performed (group A). On 12 kidneys (four HF and eight laser), a hemi nephrectomy with opening of the renal pelvis was performed (group B). Total resection time including hemostasis of the remaining tissue was 501 ± 394 s in group “A-laser” vs. 176 ± 139 s in group “A-HF”. For the group “B”, the total resection time was 1174 ± 501 s (B laser) vs. 960 ± 407 s (B-HF). Blood loss was 28 ± 22 ml in group “A laser” vs. 15 ± 15 ml in group “A-HF”. In group “B”, the blood loss was 98 ± 73 ml (B laser) vs. 137 ± 118 ml (B-HF). No ischemic time for the kidneys was needed in group “A” for both dissection devices. In group “B”, ischemia of the kidneys was performed three times during the eight laser procedures (420 ± 60 s) and only once at the four HF procedures (1,260 s). Healing process was observed over 4–6 weeks, survival rate was 100%, and no

renal fistulas were found after the survival period. In conclusion, no significant differences were found between the compared dissection devices. However, the laser system with the flexible transmission fiber may have an advantage for a laparoscopic approach by steerable instruments.

Keywords Renal cell carcinoma · RCC · Nephron-sparing surgery · Laser · Tumor ablation · Hemostasis

Introduction

Renal cell carcinoma (RCC) is the most common malignancy of the kidney and accounts for about 3% of adult cancers [1]. Surgery remains the only curative treatment for RCC. For over 40 years, radical nephrectomy has been the “gold standard” for surgical treatment of RCC.

Yet, with the widespread routine use of computed tomography (CT) and abdominal ultrasound, the number of incidental renal masses has highly increased. For the majority of these tumors, radical nephrectomy is a clear overtreatment, and the indication for nephron-sparing surgery is today applied in an increasing number of patients [2]. The primary aim of nephron-sparing surgery is to excise the tumor within a margin of normal renal parenchyma. This can only be achieved within a bloodless field. Therefore, hilar clamping with concurrent warm or cold ischemia is performed in many patients. However, warm ischemia should be limited to 20 min and cold ischemia to 35 min [3]. Also, hemostasis after tumor excision is important.

Although the benefits of laparoscopy and robot-assisted laparoscopy have been demonstrated in terms of less operative pain and faster reconvalescence, the widespread application of laparoscopic nephron-sparing surgery has

D. Theisen-Kunde (✉)
Institute of Biomedical Optics (BMO),
University of Lübeck,
Peter Monnik Weg 4,
23538 Lübeck, Germany
e-mail: theisen@bmo.uni-luebeck.de

S. Tedsen · C. DoeHN · D. Jocham
Department of Urology, University Hospital
Schleswig-Holstein, Campus Lübeck,
Lübeck, Germany

I. Kausch von Schmeling
Department of Urology and pediatric Urology,
Ammerland Clinic Westerstede,
Lübeck, Germany

been limited by concerns about hemostasis, prolonged warm ischemia and the inherent technical difficulties of intracorporal suturing [4–6]. Usually, the issue of hemostasis is more important when laparoscopic techniques are applied (compared to open operative techniques).

There is no general agreement of how hemostasis is best performed. The original method is surgical stitches and renorrhaphy in ischemia. Several tissue sealants and adhesives may serve as a barrier to leakage and as a hemostat. To obtain hemostasis and avoid warm ischemia during renal surgery, especially nephron-sparing surgery, several investigators have evaluated a number of energy-based technologies without the need for hilar clamping. Monopolar or bipolar cautery as well as argon beam coagulation, CO₂-, Nd:YAG-, Holmium-, and KTP laser systems were frequently associated with some kind of drawback mostly related to poor hemostasis, enhanced necrosis area, injury of other organs, smoke development, or tumor cell spillage [7].

The need for fast and precise dissection devices with reliable hemostasis is obvious. This has been the background for the development of a fiber laser dissection device system with an approval for clinical trials according to the MDD 93/42 Annex VIII (Medical laser Centre Lübeck, Lübeck, Germany) emitting a wavelength at 1.92 μm and a maximal power of 50 W [8]. Former studies showed promising results for kidney resection using an experimental laser dissection device emitting at a wavelength at 1.94 μm [9, 10]. For soft tissue dissection, the absorption coefficient of water is the major parameter for the efficiency of the highly complex and dynamic laser ablation process. It was shown that the water absorption coefficient changes with the temperature of the water [11]. Especially for different wavelengths at a local maximum of the absorption coefficient of water the slope of the variation can be negative or positive. For example, the slope for 1.92 μm is positive and the slope for 1.94 μm is negative [12]. A positive slope yields to a more efficient ablation caused by an increase of the absorption coefficient during the ablation process. Therefore, in this study a laser dissection device emitting a wavelength at 1.92 μm was used in an animal study with a survival period up to 6 weeks in comparison to a standard high-frequency (HF) dissection device.

Materials and methods

Laser and HF dissector

Based on a CW thulium fiber laser (IPG laser GmbH, Burbach, Germany), emitting a wavelength at 1.92 μm and a maximal power at 50 W, a surgical dissection device was

developed at the Medical laser Centre Lübeck, Lübeck, Germany, with an approval for clinical trials according to the MDD Annex VIII [8]. For partial porcine renal parenchyma resection and hemi nephrectomy, laser radiation (30 W) was transmitted via a 365- μm fiber with a polished distal fiber tip that was fixed in a stainless-steel tube. The procedure was performed in contact mode; power density at the distal fiber tip was 28.6 kW/cm². In comparison, a standard HF-Dissector (VIO 300D, Erbe Elektromedizin GmbH, Tübingen, Germany) was used in the DRY-CUT Modus with an energy of 180 W and a lancet-shaped knife electrode (2.35 \times 19 mm).

Animal experiments

All animals treated in this study were cared for in accordance with the European convention on animal care with approval of the ministry for Environment, Nature Conservation and Agriculture of the Land Schleswig-Holstein, Germany.

The surgical treatment was performed under sterile operating room conditions. In nine pigs weighing between 35 and 45 kg, general anesthesia and median laparotomy was performed to expose both kidneys. Appropriate antibiotic coverage was administered prior to the operation. Heart rate and oxygen saturation were measured continuously. On six kidneys (three HF and three laser) a partial renal parenchyma resection of the lower pole without opening of the renal pelvis was performed (group A). On 12 kidneys (four HF and eight laser) a hemi nephrectomy with opening of the renal pelvis was performed (group B). For both dissection devices, the resection was started without ischemia. In cases of larger blood loss by a dissected blood vessel, the kidney vessels were temporarily clamped and bleeding was stopped by emission of laser radiation to the bleeding spot for at least 5 s or by the coagulation mode of the HF device. If the hemostasis by the dissection device was not successful, surgical stitches were performed. After the procedure, all pigs survived for a planned time period of 4–6 weeks. Then, the animals were anesthetized again, killed, and the healing process of the kidneys was evaluated by histological analysis (H&E staining). The final evaluation data included total resection time, blood loss, mass of dissected tissue, and total ischemic time if needed. Data were compared by mean value, standard deviation and two-tailed *t* test. Data differences were called significant if *t* < 0.05.

Results

Surgical treatment

For all treatments, the resected mass and the resected area were equivalent for groups A and B. Therefore, the

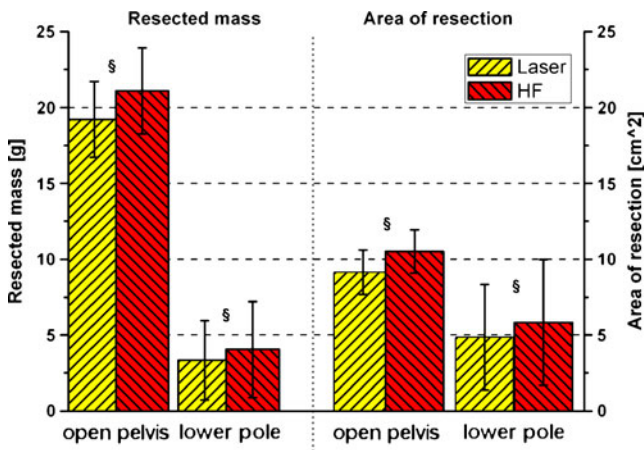


Fig. 1 Area (cm²) and weight (g) of resected tissue (“\$” not significant)

investigated data are comparable to each other (Fig. 1). For group A (lower pole resection), the total resection time needed was around three times shorter (176 ± 139 s) for the HF device compared to 501 ± 394 s for the laser device (not significant). For opened pelvis (group B), the pure resection time with the HF device was significant shorter (210 ± 60 s) than with the laser device (730 ± 415 s). However, the time for hemostasis of the remaining tissue was longer in the HF subgroup (750 ± 381 s) than in the laser subgroup (443 ± 192 s). Finally, the total resection time (first cut until hemostasis) for group B was not significantly different for both devices (laser $1,174 \pm 501$ s vs. HF 960 ± 407 s; Fig. 2).

Blood loss was 28 ± 22 ml in group “A laser” vs. 15 ± 15 ml in group “A-HF”. In group “B”, the blood loss was 98 ± 73 ml (B laser) vs. 137 ± 118 ml (B-HF) (all not significant) (Fig. 3).

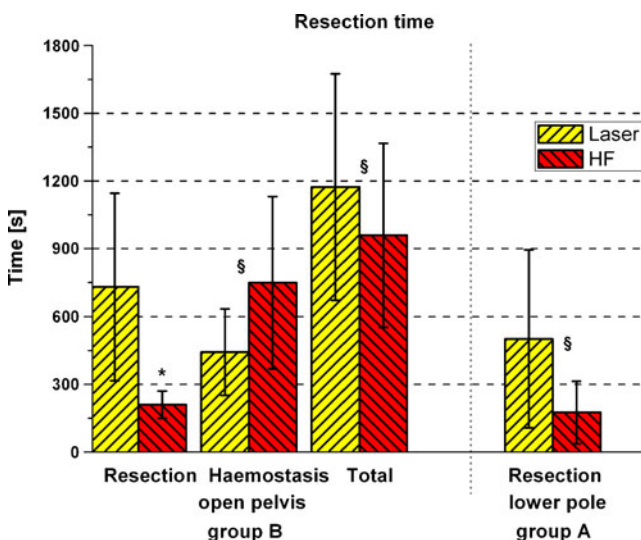


Fig. 2 Time period (min) needed for the different nephron-sparing operation scenarios (“\$” not significant – “*” significant $t < 0.05$)

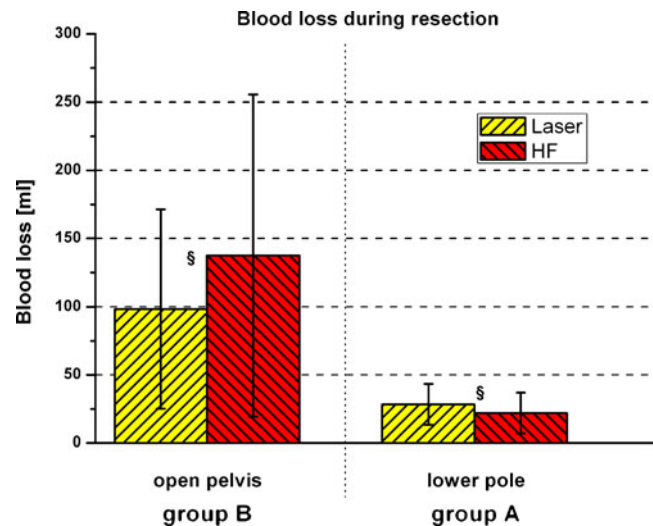


Fig. 3 Blood loss (ml) during partial kidney resection by 1.92-μm laser- and HF-dissection device (“\$” not significant)

No ischemic time for the kidneys was needed in group A for both dissection devices. In group B, warm ischemia of the kidneys was performed in three cases during the eight laser procedures (420 ± 60 s) and only once during the HF procedures (1,260 s).

The healing process was observed over 4–6 weeks, survival rate was 100%, and no complication occurred during the survival period. All data are summarized in Table 1.

Histology

Figure 4 shows histology (H&E stained) of the dissected area. Directly after tissue dissection, the carbonization zone was more pronounced in the laser-dissected tissue compared to the tissue dissected by the HF device. After 43 days, chronic granulomatous inflammation of foreign body reaction type with giant cells and scar formation were observed for both devices.

Discussion

With the growing demand for new approaches to renal cell carcinomas, the ability to perform precise tumor excision without hilar clamping in a hemostatic environment will undoubtedly expand the role of nephron-sparing surgery in urologic surgery; predominantly also for the laparoscopic approach. With further developments in minimally invasive technology, the use of laser technique has raised as a promising tool for resection of renal parenchyma in its ability to provide bloodless dissection by simultaneous coagulation of the tissue. Conventional techniques for hemostasis such as surgical sutures or more recently

Table 1 Summary of the evaluated data by mean value±standard deviation

	Lower pole (group A)		Open pelvis (group B)	
	HF <i>n</i> =3	Laser <i>n</i> =3	HF <i>n</i> =4	laser <i>n</i> =8
Resected mass [g]	4.1±3.2	§ 3.3±2.6	21.1±2.8	§ 19.2±2.5
Dissected area [cm ²]	5.8±4.2	§ 4.9±3.5	10.5±1.4	§ 9.2±1.5
Resection time [s]	176±139	§ 501±394	210±60	* 730±415
Time for hemostasis of remaining tissue [s]	/	/	750±381	§ 443±192
Total time [s]	176±139	§ 501±394	960±407	§ 1174±501
Blood lost [ml]	15±15	§ 28±22	137±118	§ 98±73
Ischemic time [s]	/	/	480/360/420	1260
Complication during survival period	0	0	0	0
Renal fistula after survival period	0	0	0	0

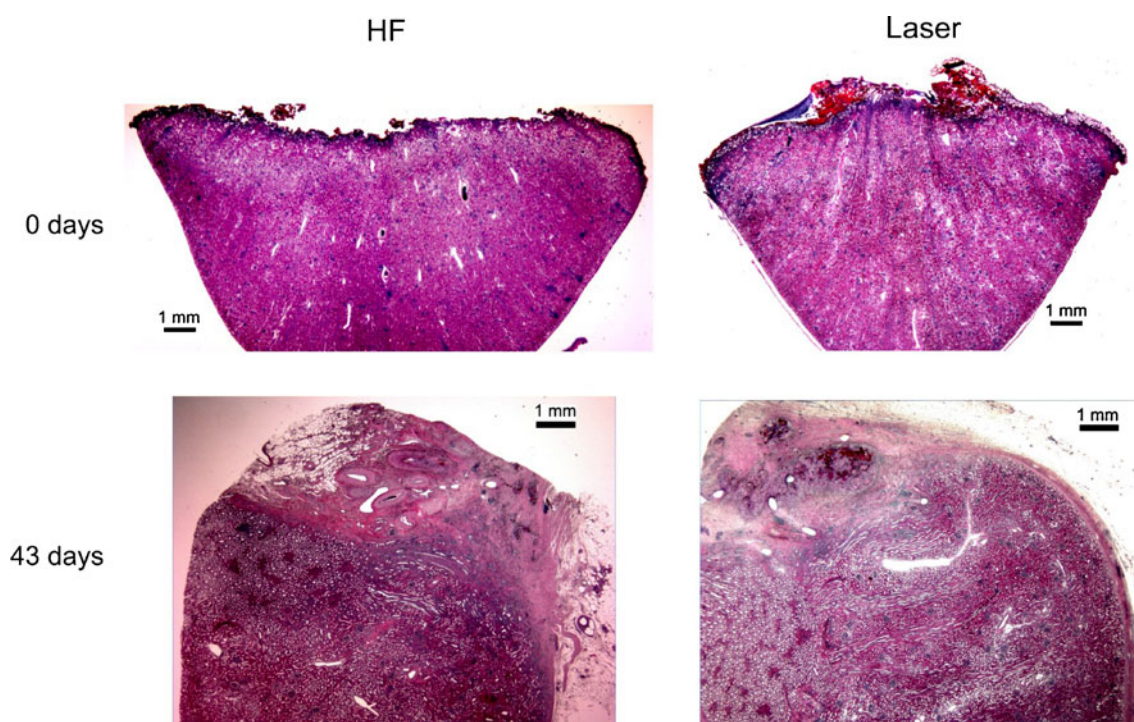
(“§” not significant –
 “*” significant *t* < 0.05)

application of tissue sealants and adhesives, require ischemia. Monopolar cautery is probably the most often used energy-based device for attempting low blood loss during partial nephrectomy. However, care must be taken to avoid injurious current transfer to surrounding structures. The argon beam coagulator is an electrosurgical generator with non-inflammable gas. The gas creates a more even distribution of the energy and better sealing of tissues but serious complications have been described [7]. The use of other devices such as Ultracision, Ligasure, or SonoSurg has been associated with significant hemorrhage and was not recommended alone for partial nephrectomy [13, 14].

Initial applications of lasers in organ-sparing renal surgery were performed in the 1970s. Here, the CO₂ and the Nd:YAG lasers were frequently associated with poor hemostasis results.

In the last 10 years, several lasers have been used for partial nephrectomy without ischemia.

The Holmium In 2002, the YAG laser was investigated in one study with three patients [15]. The authors found that the use of the holmium laser at 0.8 J and 40 Hz was effective in providing hemostasis, although tissue sealants were also applied to the partial nephrectomy bed in all cases. Blood loss ranged between 50 and 500 ml. The

**Fig. 4** Histology (H&E staining) taken directly after tissue dissection (*top*) and after 43 days survival period (*bottom*). Bars indicate 1 mm

hemostasis was limited by smoke development and blood splashing onto the camera lens, which reduced visibility. In addition, the laser produced a significant amount of tissue vaporization and liquid, which, in theory, could promote tumor-cell spillage. Comparable positive and negative characteristics of the laser were described in subsequent animal studies in 2004 [16].

Diode lasers have also been evaluated. In a female farm pig model, partial nephrectomy was performed using a 980-nm diode laser. The laser was insufficient for hemostasis in three of the ten partial nephrectomies and adjunctive hemostatic clips were necessary [17].

KTP lasers of 532-nm wavelength and 80 W were used in calf and pig models. The hemostatic properties were reported to be excellent. In the pig model, mean blood loss was 28.57 and 30 ml [18, 19]. However, smoke development again was a particular problem, which could be overcome by continuous saline irrigation.

A CW solid state thulium laser (wavelength=2,013 nm) has been evaluated in both animal and clinical series. In 2007, Bui et al. used 30 W delivered by a 365- μ m fiber in a porcine model [20]. The estimated blood loss was less than 50 ml with minimal smoke and minimal tissue charring. Limitations of this study are that additional fibrin glue was used and that only renal cortex was treated. Clinically, Gruschwitz et al. reported about seven partial nephrectomies. The resection time was less than 20 min without any blood loss [21]. Mattioli et al. performed one laparoscopic and eight open partial nephrectomies. The blood loss was 156 ml for laparoscopic and 260 ml for open surgery [22]. Both authors noted that the 2,013-nm CW solid state thulium laser can coagulate vessels up to 1.5 mm. The blood loss and the resection time of the animal study presented here are less than the reported clinical data. Due to the fact of a more complex situation on individual patients, a comparison should be done with clinical data of the thulium fiber laser in the near future.

In contrast to the solid-state laser system described above, a thulium fiber laser emitting a wavelength of 1.92 μ m was used in this study. The advantage of the 1.92- μ m laser radiation compared to 2.01 μ m is the two-times-higher absorption coefficient of water for the 1.92- μ m radiation. Also, the absorption coefficient increases during the ablation process for 1.92 μ m, while for 2.01 μ m the coefficient decreases. Due to this effect the thermal damage zone of the dissected tissue is around half the size using 1.92 μ m laser radiation compared to 2.01 μ m laser radiation [23].

In our experiments, partial kidney resection was easily and quickly performed by the use of a 1.92- μ m laser dissection device. Hemostasis was highly sufficient. During resection with open pelvis, blood loss was less compared to the conventional HF-dissection device (not significant). Using the large lancet knife of the HF device the pure

resection of the tissue was faster but the hemostatic properties were poor compared to the laser device. Therefore, hemostasis of the remaining tissue took more time during the HF procedure. During the coagulation of the remaining tissue, the laser dissection device works in a non-contact mode (5 mm), therefore, no sticking of the instrument occurs, as seen when the HF device is used. One potential disadvantage of all energy devices is the thermal damage of the resection zone, which makes the assessment of intraoperative fresh-frozen sections of the resection margin difficult. The oncological control and safety must certainly be an issue of further larger trials. The histological evaluation with H&E staining showed a two-times-larger carbonized zone in the laser group than in the HF group, but the thermal damage zones for both devices were small, being less than 2 mm in depth. This is comparable to previous results with the holmium and diode laser and smaller than with the KTP or Nd:YAG laser (2.5–7 mm) [24, 25]. After the survival period, the histology showed no major differences for both dissection techniques.

In conclusion, no significant differences were found between the compared dissection devices. However, apart from the fact that in general medical laser systems are more expensive than HF devices, the 1.92- μ m laser system is a promising device for urological surgery, especially for laparoscopic approaches with steerable instruments. Meanwhile, after agreement of the local ethical committee, a first successful application was performed in a patient with a 2-cm pT1a renal cell cancer. A thulium fiber laser dissection device was used for an open resection of the tumor without ischemia, and blood loss was 50 ml. The postoperative course of the patient after 3 months was uneventful.

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