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Contact fibre Nd: YAG laser for partial nephrectomy: experimental study in pigs

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Summary. Thirty-two partial nephrectomies were performed without renal cooling on 13 pigs with a contact fibre Nd:YAG laser (10 W) or a steel scalpel with or without a vascular pedicle clamp. Nine pigs had a 2-week follow-up with an abdominal ultrasound 1 week postoperatively. The time for haemostasis was 6.9 ± 5.2 min (mean ± SD) with the laser and 9.1 ± 5.8 min with the steel scalpel when the clamp was used ($P = 0.028$). There was no significant difference in the total operating time (13.2 ± 4.5 min with the laser vs 12.6 ± 4.6 min with the steel scalpel, $P = 0.203$). Intraoperative blood loss was similar in the two groups when the clamp was used. Clamping the renal pedicle decreased the blood loss by 61% in the laser group and 31% in the steel scalpel group. The number of ligatures used was significantly lower in the laser group (3.7 ± 2.6) compared with the steel scalpel group (6.6 ± 3.4) ($P = 0.013$). Five urinomas developed on the laser side and four on the steel scalpel side. These results indicate that the contact fibre Nd:YAG laser method can be used in partial nephrectomy, but it offers no definitive advantage over the conventional technique.

Key words: Kidney surgery – Laser surgery – Partial nephrectomy

Indications for partial nephrectomy include tumours, trauma, congenital abnormalities, vascular malformations, infections and stone disease. The use of partial nephrectomy in the treatment of renal cancer is increasing.

The major complications after partial nephrectomy are bleeding, fistula formation and loss of renal function. To minimize operative bleeding, both CO_2 and non-contact Nd:YAG lasers have been used in experimental and clinical studies with acceptable results [1, 2, 7]. Some authors have reported unsatisfactory results after using Nd:YAG laser alone in partial nephrectomy [11, 13].

The contact Nd:YAG laser technique, which was introduced in 1985, enables the use of lower energy outputs in laser surgery thus minimizing the damage to adjacent tissues [4]. This technique has been reported to have a significant advantage over the CO_2 laser in the resection of splenic tissue [5] and also over the non-contact Nd:YAG laser in the resection of liver [6]. However, the results in partial nephrectomy have not been as promising [7,8]. A recent study by the present authors which compared the efficacy of the combination of the contact and non-contact Nd:YAG laser technique and the steel scalpel in partial nephrectomy failed to show any definitive advantages for the laser technique [14].

The contact fibre Nd:YAG technique utilizes a bare 600 μm fibre with the tip preheated to achieve a spherical shape. The fibre is reusable and less expensive than the contact sapphire probes.

The purpose of the present study was to compare the contact fibre Nd:YAG laser technique and the steel scalpel in partial nephrectomies with a special emphasis on the operation time, operative blood loss, and need for ligation of bleeding vessels.

Materials and methods

Thirty-two partial nephrectomies were performed on 13 pigs weighing 16.5–23.0 kg (means 19.2 kg). Twenty lower pole partial nephrectomies were performed on 10 pigs using the laser on one side and the steel scalpel on the other. Nine of these 10 pigs were followed up for 2 weeks. Twelve partial nephrectomies were done on 3 pigs on both poles of the kidneys (6 resections with the laser, 6 with the steel scalpel) and these pigs were killed immediately. The kidney size ranged from 7.8 × 3.7 × 1.5 cm to 11 × 5.2 × 4 cm (mean 9.3 × 4.4 × 2.6 cm; length × width × thickness in the resection site).

The animals were premedicated with intramuscular ketamine hydrochloride 30 mg/kg (Ketalar, Parke-Davis, Gastleight, Hants). and atropine 0.05 mg/kg (Atropin). Intravenous access was established, and Ringer's lactate solution (500 ml) administered at 60 drops per minute during the procedure. Anaesthesia was achieved by intravenous sodium pentobarbital 8 mg/kg (Mebunat). The

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animals were intubated, connected to a ventilator (Servo), and ventilated with oxygen and nitrous oxide (1:1). The anaesthesia was maintained with doses of 40 mg azaperon (Stresnil, Janssen, Beerse, Belgium) as needed. No relaxants were given. The expiratory carbon dioxide concentration was monitored throughout the anaesthesia. Intramuscular oxytetracycline 400 mg (Terramycin, Pfizer, Sandwich, Kent) was given before the laparotomy to the 10 animals which were followed up for 2 weeks.

The kidneys were exposed through a midline abdominal incision and mobilized completely, and the kidney sizes were recorded. The renal pedicle was clamped with a vascular clamp in 7 pigs (10 resections with the laser, 10 with the steel scalpel). Renal bleeding during partial nephrectomy was controlled by direct manual compression of the renal parenchyma in 6 pigs (6 resections with the laser, 6 with the steel scalpel). Renal cooling was not used. Lower pole guillotine resection was performed on 10 pigs at the junction of the middle and lower thirds of the kidneys with the steel scalpel on one side and with the laser on the other. In 3 pigs both poles of both of the kidneys were resected as an acute experiment. The resection was always done in a paired manner so that the other side served as a control.

An Nd:YAG laser (1.06 µm wavelength; Lasermatic Combolaser Model 5050, Helsinki, Finland) was used at 10 W power setting with a pulse duration of 5 s. The laser core fibre was 600 µm in diameter, and the tip was preheated with 20 W to achieve a spherical tip with a diameter of 1 mm.

The guillotine resection with the laser was done by a gentle, slow motion through the cortex and medulla with the tip perpendicular to the kidney surface. The collecting system was closed with a continuous 4-0 polyglycolic acid (PGA) suture. The pedicle was released, and, if haemorrhage persisted, a suture ligation was performed with 4-0 PGA sutures. On the control side, all bleeding vessels were ligated with 4-0 PGA sutures. The renal capsule was not closed. The retroperitoneum was closed with a continuous 4-0 PGA suture. No drains were used. The abdominal incision was closed in two layers; the peritoneum and fascial layer were closed with 4-0 PGA sutures and the skin with 2-0 polyamide sutures. Each animal in the follow-up group received an intramuscular injection of diclofenac 75 mg (Voltaren, Geigy, Horsham, Sussex) for postoperative pain.

The times for resection, haemostasis, ischaemia and total operation were recorded. The number of ligatures needed for haemostasis and the total energy applied were noted. The blood loss was measured by the weight increase in 10 cm × 10 cm sponges. The weight of the resected parts of the kidneys was measured. Abdominal ultrasound was performed on 6 pigs 1 week after the operation, following an intramuscular injection of ketamine hydrochloride 30 mg/kg. Urography with iohexol 450 mg iodine/kg (Omnipaque) was performed 2 weeks postoperatively. Nine pigs were killed after a 2-week follow-up. At autopsy the diameter of a possible urinoma or perirenal abscess was measured. For light microscopic analysis, specimens from the resection line were fixed in phosphate-buffered (pH 7.0) 4% formaldehyde solution, embedded in paraffin, sectioned, and stained by van Gieson's method.

The results are presented as mean ± standard deviation (SD). The paired Wilcoxon test was used in the statistical calculations. This study was performed following the recommendations and guidelines in the European Convention for protection of vertebrate animals used for experimental and other scientific purposes.

Results

The results are summarized in Tables 1–3. The mean weight of the resected parts of the kidneys was 11 ± 3 g in the laser group and 13 ± 3 g in the steel scalpel group ($P = 0.047$).

Resection time, time for haemostatis, total operation time, ischaemia time

The resection time was longer with the laser, but this was compensated for by the shorter time needed to achieve haemostasis. There was no difference in the total operation time. The ischaemia time was 35% shorter in the steel scalpel group when the clamp was used due to the shorter resection time. The total energy was 1540 ± 290 J (range 1100–2050 J) and it was registered in 9 resections when the clamp was used.

Blood loss and number of ligatures

There was no statistical difference in the blood loss between the two methods. The blood loss was 61% lower in the laser group when the clamp was used compared with compression of the renal parenchyma (25 g vs 63 g). In the steel scalpel group, the equivalent difference was 31% (31 g vs 45 g). In the laser group, fewer (44%) ligatures were needed compared with the steel scalpel group when the clamp was used (3.7 vs 6.6). The difference was 36% (4.5 vs 7.0) between the methods without the clamp.

Postoperative course and complications

There was no mortality related to the resection methods used. One pig had wound dehiscence, jejunal evisceration and gangrene on the second postoperative day. The animal was operated on but died on the third postoperative day. At autopsy paralytic ileus was noted, but the jejunal anastomosis was healthy. There were no abscesses or urinomas, and specimens from the kidney resection lines revealed a coagulum necrosis 2.1 mm wide.

There were five urinomas on the laser side and four on the steel scalpel side at autopsy. The mean diameter of the urinomas was 6.2 cm (range 4.0–13.5 cm) in the laser group and 4.4 cm (range 1.7–11.0 cm) in the steel scalpel group. There were no perirenal abscesses or pyohydronephrosis.

Radiographic and ultrasound findings

The urographic findings were normal in 8 of the 9 pigs after a 2-week follow-up; in 1 pig there was mild hydronephrosis, but at autopsy the kidney was normal. The urinomas were not seen in the urograms, but all of them were evident at the ultrasound examination 1 week postoperatively.

Histology

Renal tissue specimens from 8 of the standard partial nephrectomy cases and from 26 laser cases were examined histologically. Immediately after resection, the average width of thermally damaged tissue in the laser group was 0.24 ± 0.08 mm when the clamp was used and

Table 1. Results of partial nephrectomy in pigs using contact fibre Nd:YAG laser ($n = 16$) and steel scalpel ($n = 16$): resection time and time for haemostasis

	n	Resection time		Time for haemostasis	
		Min	Range	Min	Range
with clamp					
Laser	10	4.1 ± 0.8	2.9–5.0	6.9 ± 5.2	1.8–16.3
Steel scalpel	10	0.6 ± 0.3	0.3–1.3	9.1 ± 5.8	4–20.0
		$P = 0.008$		$P = 0.028$	
without clamp					
Laser	6	4.9 ± 1.0	3.7–6.0	8.1 ± 2.7	4.5–11.0
Steel scalpel	6	0.7 ± 0.3	0.3–1.0	11.6 ± 3.3	7.5–16.0
		$P = 0.028$		$P = 0.080$	

Values are mean ± SD. Analysis was by paired Wilcoxon test

Table 2. Results of partial nephrectomy in pigs using contact fibre Nd:YAG laser ($n = 16$) and steel scalpel ($n = 16$): total operation time and ischaemia time

	n	Total operation time		Ischaemia time	
		Min	Range	Min	Range
with clamp					
Laser	10	13.2 ± 4.5	9.4–21.3	9.3 ± 3.8	4.0–18.5
Steel scalpel	10	12.6 ± 4.6	8.2–20.8	6.0 ± 3.9	2.0–16.5
		$P = 0.203$		$P = 0.005$	
without clamp					
Laser	6	13.0 ± 2.4	9.5–15.0	–	–
Steel scalpel	6	12.3 ± 3.5	8.0–17.0	–	–
		$P = 0.599$			

Values are mean ± SD. Analysis was by paired Wilcoxon test

Table 3. Results of partial nephrectomy in pigs using contact fibre Nd:YAG laser ($n = 16$) and steel scalpel ($n = 16$): blood loss and number of ligatures

	n	Blood loss		Number of ligatures	
		g	Range	No.	Range
with clamp					
Laser	10	25 ± 11	9–46	3.7 ± 2.6	0–8
Steel scalpel	10	31 ± 30	8–114	6.6 ± 3.4	4–13
		$P = 0.515$		$P = 0.013$	
without clamp					
Laser	6	63 ± 30	33–106	4.5 ± 3.0	1–8
Steel scalpel	6	45 ± 14	31–68	7.0 ± 2.4	3–10
		$P = 0.249$		$P = 0.039$	

Values are mean ± SD. Analysis was by paired Wilcoxon test

0.25 ± 0.10 mm without the clamp. Two weeks postoperatively, the width of the fibrotic zone was 11 ± 4 mm in the laser group when the clamp was used and 14 ± 1 mm without the clamp. The width of the fibrotic zone was 12 ± 1 mm in the steel scalpel group 2 weeks postoperatively when the clamp was used and 13 ± 4 mm without the clamp.

Discussion

The present results indicate that partial nephrectomy is technically feasible by the contact fibre Nd:YAG laser method. The main problem in all renal sparing surgery is haemostasis, though a relatively bloodless operative field can be achieved by clamping the renal pedicle. Animal studies have shown that to avoid permanent cellular damage the warm ischaemia time should not exceed 30 minutes [9. 15]. In the present investigation the effect of clamping the renal pedicle was studied during partial nephrectomy, and it was found that blood loss and the number of ligatures were reduced when the clamp was used. Benderev et al. [3] studied damage caused by the non-contact Nd:YAG laser in the canine renal cortex. They found that clamping the main renal artery significantly reduced the depth and width of laser damage when compared with that in the perfused kidney. They used power settings of 5–100 W with an exposure of 1–4 s. The depth of the damage was 1–3 mm with the lower power settings. According to the present preliminary studies the most suitable power setting was 10 W.

Animal studies have shown that the use of manual renal compression to control intraoperative haemorrhage is more deleterious than simple arterial occlusion [10]. In the present study no difference was found in the depth of the coagulation zone when the renal pedicle was closed with a clamp or when the renal parenchyma was compressed during the resection. The blood loss was 61% lower in the laser group and 31% in the steel scalpel group when the clamp was used instead of compression of the renal parenchyma. During the preliminary investigations the attempt was made to coagulate the bleeding sites with the tip of the contact fibre after the resection, but this was found to be ineffective and time-consuming.

The resected parts were 2 g lighter in the laser group, which may be due to the heating effect of the laser.

The most important parameters of the present study were blood loss and total operation time, and no difference was found in these between the methods. The time for haemostasis was shorter and fewer ligatures were needed in the laser group. The laser prevented capillary and venous bleeding from the renal parenchyma, but branches of the renal artery required ligation in the usual way. It is unlikely that improved haemostasis can be achieved by using laser with the larger vessels of the human kidney.

There were no differences in complications between the methods. Five urinomas were seen on the laser resection side and four on the steel scalpel side. The collection system was closed with a continuous suture in one layer, but, contrary to human kidney surgery, the renal capsule was not closed and no drains or ureteral stents were used. The present high incidence of urinomas emphasizes the meticulous closure of the collecting system in partial nephrectomy. Urography was not a sensitive method for the detection of urinomas, but all urinomas were evident at the ultrasound examination.

The contact fibre has many advantages over the sapphire contact tip. It can be cut and used several times when the fibre tip is damaged or encrusted with char. It is less expensive than the sapphire contact tip or sculptured fibreoptic cable [12]. When compared with the non-contact laser technique there is less forward- and back-scattering and the risk of bowel perforation is lower. The tactile feel during the operation is also better. The disadvantages of the contact fibre technique are the same as those of all laser methods, i.e. the expense, the complex technology and the necessity of goggles for the operators.

In conclusion, there was no definitive advantage over the conventional method when the contact fibre Nd:YAG laser technique was used in partial nephrectomy. In future the development of new laser wavelengths with different thermal properties may change the situation.

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