Contemporary minimal-invasive nephron-sparing surgery

Christian Schwentner[1], Saladin H. Alloussi[1], Christian Radmayr[2], Daniela Colleselli[1], David Schilling[1], Karl-Dietrich Sievert[1], Arnulf Stenzl[1]

[1]Department of Urology, Eberhard-Karls-University Tuebingen, Germany and the Department of Urology and [2]Pediatric Urology, Medical University Innsbruck, Austria

KEY WORDS

nephron-sparing surgery ◗ partial nephrectomy ◗ laparoscopy ◗ renal cell cancer ◗ small renal mass

ABSTRACT

To assess the current status and future perspectives of minimal-invasive nephron-sparing surgery (NSS) including extirpative and ablative techniques.

Minimally invasive nephron-sparing surgery for renal tumors comprises extirpative laparoscopic partial nephrectomy (LPN) and ablative procedures such as cryoablation, radiofrequency ablation, as well as radiosurgery.

Minimally invasive nephron-sparing surgery modalities offer reduced morbidity as compared with open partial nephrectomy. Recent trials comparing laparoscopic partial nephrectomy and open partial nephrectomy demonstrated equivalent cancer-specific survival.

Encouraging long-term data are becoming increasingly available for laparoscopic partial nephrectomy and cryoablation. However, some concerns remain about incomplete tumor cell kill after radiofrequency ablation.

Radiosurgery is a promising new technology, but is still experimental. The increasing availability of robotic assistance in urologic oncology also allows for novel therapeutic concepts such as single-port laparoscopy.

Open and laparoscopic partial nephrectomies are the standard-of-care for treating small renal masses, with LPN becoming the preferred option in high-volume uro-oncology centers. Continuing research adds to the value of ablative technologies.

INTRODUCTION

The annual incidence of renal cell carcinoma has consistently increased over the past decades. In the US, in 2008, there were more than 55,000 new cases, resulting in over 13,000 deaths [1, 2]. The greatest increase however, has occurred in small, localized tumors, which represent up to 66% of all renal tumors [3]. The widespread use of cross-sectional imaging that has consequently led to increased incidental detection of small renal masses in asymptomatic patients [4]. Since 2006, radical nephrectomy performed as a laparoscopic procedure is accredited as standard procedure for organ-limited tumors in the guidelines of the European association of urology. However, partial nephrectomy is a valid alternative for many small renal masses, as it provides excellent oncologic control, while maximizing the preservation of renal parenchyma. Elective partial nephrectomy has become an emerging standard of care for patients with renal tumors less than 4 cm in size. The laparoscopic approach (LPN), first described in 1993, has been shown to provide functional and oncologic outcomes equivalent to those of open surgery while offering the patient more rapid recovery times [5-8]. Nevertheless, LPN remains a difficult technique, largely because of the challenge of intracorporeal suturing. Besides extirpative techniques, ablative procedures including cryoablation, radiofrequency ablation (RFA), and radiosurgery are completing the clinical menu of minimally invasive nephron-sparing surgery for the small renal mass.

Herein, we aim to give an overview about the current status and our own experience with these minimal-invasive techniques.

PARTIAL NEPHRECTOMY

In this section, we will focus on laparoscopic and robotic partial nephrectomy.

Laparoscopic partial nephrectomy (LPN)

LPN must duplicate the technical aspects of open nephron-sparing surgery (NSS) to maintain its oncological principles. The challenge is to achieve definitive margin free tumor excision in a bloodless field under ischemia time constraints, followed by reliable hemostatic renorrhaphy.

The first LPN was performed transperitoneally by Winfield et al.and retroperitoneally by Gill et al. [9, 10]. The initial experience was limited to small, peripheral, solitary, and exophytic tumors [11, 12]. These indications have been expanded to hilar and intrarenal tumors, solitary kidneys, larger tumors (T1b and T2), and tumors in the presence of renovascular disease [13].

Nowadays, the main contraindication to LPN is lack of surgeon expertise with advanced laparoscopy. Robotic assistance may help to overcome this limitation. Previous ipsilateral open surgery is also a relative contraindication. If LPN appears too technically challenging in selected cases open partial nephrectomy remains the procedure of choice.

Technical aspects

Retroperitoneal versus transperitoneal approach

We generally favor a transperitoneal approach. Once the kidney is completely mobilized most tumor locations – even posterior masses – are easily accessible. The retroperitoneal approach is especially useful for polar lesions allowing for a more favorable suturing angle. Generally, limited space is considered to be the main limitation of the retroperitoneal approach. Hence, surgeon preference is probably the most important factor selecting the approach [14].

Surgical strategy: Four ports are usually required for right-sided lesions while three are sufficient for the left side. Intelligent port placement and adequate exposure of the kidney and the tumor are critical to perform an excision with negative margins. The kidney needs to be completely mobilized so that it can be appropriately positioned for ablation and subsequent reconstruction [15]. Before the hilar clamp is applied one needs to be confident with the opera-

Tab. 1. Complications of the largest series of LPN.

Author	No. of pts	Mean tumor size cm	Overall complications (%)	Hemorrhage (%)	Urine leak (%)	Renal failure (%)	Vascular, organ, pleural injury (%)	Medical complications (%)
Ramani et al [27]	200	2.9	66 (33.0)	20 (10.0)	9 (4.5%)	4 (2.0)	3 (1.5)	24 (12.0)
Simmons et al [28]	200	3.0	38 (19.0)	11 (5.5)	4 (2.0)	1 (0.5)	2 (1.0)	18 (9.0)
Wright et al [29]	49	2.3	7 (14.3)	1 (2.0)	2 (4.1)	0	0	4 (8.2)
Venkatesh et al [30]	123	2.6	26 (21.1)	3 (2.4)	13 (10.6)	0	0	10 (8.1)
Schiff et a [l31]	66	2.2	6 (9.0)	1 (1.5)	2 (3.0)	0	1 (1.5)	2 (3.0)
Link et al [32]	217	2.6	27 (12.4)	4 (1.8)	3 (1.4)	2 (0.9)	0	15 (6.9)
Bollens et al [40]	39	2.3	12 (30.7)	1 (2.5)	3 (7.7)	0	0	8 (20.5)
Abukora et al [33]	78	2.1	23 (29.5)	6 (7.7)	5 (6.4)	0	2 (2.6)	10 (12.8)
Porpiglia et al [34]	90	3.1	22 (24.4)	7 (7.8)	4 (4.4)	0	0	11 (12.2)
Total	1062	2.7	227 (21.4)	54 (5.1)	45 (4.2)	7 (0.7)	8 (0.8)	102 (9.6)

tive strategy including the parenchymal defect and all suturing angles. Most importantly, peritumoral fat is maintained *en bloc* over the tumor, both for oncological reasons and to optimize atraumatic manipulation of the mass during excision (Fig. 1). Tumor rupture should be avoided in any case to prevent spillage. The tumor resection margin should be scored using monopolar cautery including an adequate safety margin of healthy tissue.

Conventional laparoscopic suturing is very time consuming [13]. Therefore innovative methods such as clipped suture lines were introduced into clinical practice. Non-absorbable clips should be used best for parenchymal closure (Fig. 2), resulting in permanent and efficient hemostasis. Absorbable clips should be used for the renal pelvis and for the inner parenchyma [16].

Vascular pedicle control and warm ischemia

There is no consensus about the clamping technique to be employed (artery, artery and vein, intermittent occlusion). We are occluding the artery and vein separately, using laparoscopic bulldog clamps. Ho et al. proposes an elegant method for hilar control using vessel loops in conjunction with Hemolock-Clips®. Warm ischemia time (WIT) has to be limited to 30 min. If WIT exceeds 60 minutes irreversible kidney damage is very likely to occur. Desai et al. found a correlation between renal function and the amount of parenchyma excised after LPN [17]. Lane et al. evaluated 1,049 patients undergoing either LPN or OPN and described WIT as a significant surgically modifiable predictor for postoperative renal dysfunction [18]. In contrast to traditional renal reconstruction some authors advocate a more progressive strategy involving early hilar unclamping. In this 'early unclamping technique', only the initial parenchymal suture is performed with the hilum clamped while renorrhaphy itself and bolstering sutures are done under ongoing circulation. WIT has been shown to be significantly lower with this technique compared with conventional reconstruction (31 *vs.* 13.9 min, P<0.0001). Interestingly, the incidence of postoperative hemorrhage was not elevated [19].

Cold ischemia

Gill et al. reported the first experience of minimally invasive renal cooling during LPN in 2003 [20]. After kidney mobilization and placing in an Endocatch II bag (US surgical, Norwalk, Connecticut, USA), the intact hilum was clamped and the bag filled with ice slush through a port site. Kidney temperature was kept between 5 and 19°C. Janetschek et al. used an angiocatheter to perfuse the kidney with a 4°C crystalloid solution [21]. A temperature of 25°C was achieved. We also employed this technique during LPN but currently we do not perform cooling anymore mainly for two reasons: usually an interventional radiologist is required to place the arterial catheter significantly exceeding overall OR-time. With increasing expertise one is usually able to perform even complex reconstruction in less than 30 minutes. We believe that cooling will be rather replaced by other innovative techniques such as early unclamping or robotic assistance [17].

Hemostasis

Only hilar clamping provides a reliable method of obtaining a bloodless field during tumor excision. Gettman et al. proposed radiofrequency coagulation before excision of a renal mass in 10 patients [22]. Median estimated blood loss was 125 ml. Another monopolar radiofrequency device capable of dissection, hemostasis, and coagulation without clamping has been reported with a mean estimated blood loss of 352 ml in 10 patients [23]. Potential disadvantages of coagulative devices for LPN are collateral damage to adjacent renal vasculature and collecting system and difficulty in distinguishing tumor from normal parenchyma. The adjunctive use of a gelatin matrix thrombin sealant (Floseal®, Baxter Healthcare, Deerfield, Illinois, USA) has become very popular. Its benefits were evaluated comparing two groups of patients who underwent LPN at the Cleveland Clinic. The Floseal® group had significantly decreased overall and hemorrhagic complication rates as compared to the group not using Floseal®. The relatively high price actually remains the only limitation for the use of this effective agent in NSS [24].

We are additionally using an Argon beam coagulator as in open surgery. This technique has been shown to improve hemostasis, additionally we believe that the laser will also improve the oncologic efficacy [25].

Reconstruction of the collecting system

Some surgeons still favor the insertion of a ureteral catheter prior o LPN allowing for retrograde injection of methylene blue to accurately identify and repair pelvicalyceal defects. However, most laparoscopists do not routinely apply a retrograde catheter anymore further reducing the overall operative times. As a consequence of the increasing complexity of LPN WIT tends to be longer in patients who underwent pelvicalyceal suture repair subsequently leading to a longer hospital stay [26].

Spectrum of complications of LPN

The spectrum of complications typically involves immediate and delayed hemorrhage, urinary leakage as well as renal failure. In a meta-analysis including a total of 1,062 patients published by Zimmermann the overall complication rate was 21.4%, including postoperative hemorrhage (5.1%), urine leak (4.2%), and renal failure (0.7%). See table 1 [27-34].

Tab. 2. Oncologic outcomes of the largest series of LPN.

Author	No. of patients	Mean tumor size (cm)	CSS (%)	Positive surgical margins (%)	Local recurrence (%)	Mean follow-up (mo)
Lane et al [36]	58	2.9	100	1.7	1.7	68
Permpongkosol et al [37]	85	2.4	97. 6	2.4	1.7	40
Gill et al [38]	771	2.7	99.3	1.6	1.4	14
Porpiglia et al [39]	34	3.2	100	2.9	0	16
Bollens et al [40]	39	2.3	100	2.6	0	15

Presence of solitary kidney and increased ischemia time were predictors of postoperative complications [35].

Oncologic outcomes

Regarding the largest series of LPN comprising 987 patients cancer-specific survival is between 97.6 and 100%. Positive margins were found in 1.6% to 2.9% of all cases, however recurrence rates were less than 1.7% underlining the limited relevance of the margin status [36-40]. See table 2.

Comparison of laparoscopic partial nephrectomy and open partial nephrectomy

A multi-institutional study compared 1,800 patients with a single renal tumor undergoing either LPN (n = 771) or OPN (n = 1029). Patients who underwent OPN were older, had larger tumors, and more solitary kidneys (P <0.001). WIT was 10 min during LPN. However, preservation of renal function was achieved in 97.9% of LPN and 99.6% of OPN. Hospital stay and operative time were shorter in the LPN group. Overall postoperative complications were higher in the LPN group (18.6 *vs.* 13.7%), particularly hemorrhagic complications (4.2 *vs.* 1.6%). Positive margins for cancer were similar (1.6 *vs.* 1%). Local (1.4 *vs.* 1.5%) and distant (0.9 *vs.* 2.1%) recurrences were also equivalent. Cancer-specific survival at 3 years was 99.3 and 99.2%, respectively [41]. Hence, LPN yields equivalent oncologic results offering reduced morbidity [12].

Robotic partial nephrectomy

In theory, robotic assistance may ameliorate the challenge of minimally invasive renal reconstruction, thereby rendering the technique more attractive to urologists with limited laparoscopic experience [42]. The development of the da Vinci surgical system® (Intuitive Surgical Corp., Sunnyvale, California, USA) offers a unique surgical experience that allows for complex procedures to be performed more easily by a greater number of surgeons than the conventional laparoscopic approach. This system is well established in urology and has been successfully utilized for several procedures, including radical prostatectomy. The unique benefits of robot-assisted surgery include three-dimensional visualization, magnification, 6 degrees of freedom at the distal instrument wrist, absence of the fulcrum effect, and the elimination of tremors. These features decrease the technical difficulty of procedures and have been shown to shorten the learning curve of robotic surgery. The majority of current robotic series report a hybrid procedure, with the initial steps of the procedure performed with standard laparoscopic transperitoneal dissection [43-46]. Specifically, the laparoscopic approach is typically utilized for colon mobilization, dissection of the kidney, and exposure of the renal capsule and hilar structures. Once the hilum is ready for clamping, the da Vinci robot is docked, and the remainder of the procedure is performed robotically. Operative results for robotic partial nephrectomy have been similar to those of laparoscopic partial nephrectomy. Collectively, the robotic series includes tumors with a mean size of 2.0-3.6 cm (range 0.8-6.0 cm). Mean warm ischemic times ranged from 21 to 32 min (range 13-45 min), with mean estimated blood loss ranging from 92 to 329 ml (range 25-500 ml), and mean total operative times ranging from 155 to 279 min (range 87-375 min). The average length of hospital stay ranged from 1.5 to 4.7 days (range 1-7 days) and demonstrated a downward trend with increased experience in most series. Although robotic partial nephrectomy is a relatively new technique, the oncologic outcomes from the robotic series appear to parallel those reported in the laparoscopic partial nephrectomy literature. These results, which are comparable to most laparoscopic series, show that robotic-assisted partial nephrectomy may indeed be an alternative to laparoscopic partial nephrectomy [28-48]. However, it should be noted that the bulk of available literature consists of non-randomized and retrospective analysis, which are subject to bias. Prospective randomized trials will be necessary to further validate these data.

At the time of writing, no proven advantage of RPN over LPN has emerged, but RPN may allow wider dissemination of minimal-invasive NSS.

Future technologies for NSS

1. Single-incision laparoscopic surgery (SILS)

Several techniques for single-incision surgery have been established. Novel port access systems like Unix-X, R-port and Gelport allow for laparoscopic procedures through a single umbilical incision. Unix-X was used in the group of Remzi and colleagues 2008 in colorectal cancer, and showed promising result after right hemicolectomy in a case report [49]. Report was established by Rane already in 2008. Five patients underwent therapeutic laparoscopic interventions (2 nephrectomies, one orchidopexy, one orchidectomy, and one ureterolithotomy). They stated that the R-port allows laparoscopic surgery to be performed safely. Desai et al. reported about the technical feasibility of nephrectomy using the same device. So far SILS remains experimental for NSS [50].

The group of Merchant and colleagues worked with Gelport as single incision access. They used this system for cholecystectomy and described the possibility to extend the use of this laparoscopic device.

The authors also complain about the difficulties of "clashing" instruments leading to further technical challenges of this technique.

Stein et al. propose a hybrid robot-laparoscopy technique in nephron-sparing surgery through a single port device (Gelport). They accessed the kidney transperitoneally, after mobilization of the kidney they docked on the robot to excise the tumor robotically without hilar clamping using the harmonic scalpel and hemo-lok clips. Blood loss was 600 ml and required transfusion of 1 unit of red blood cells. Tumor size was 11 cm. They praised the advantage of this single port system in combination with the robotic approach by the increased space due to robotic assistance, the flexibility of the instruments and the favorable assistant access [51].

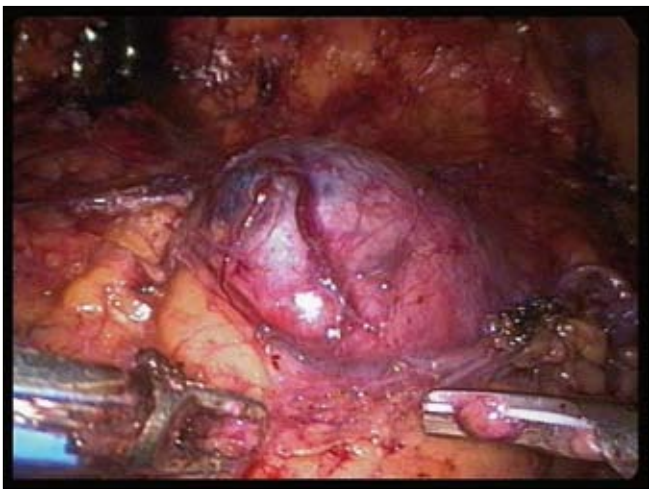

Fig. 1. Laparoscopic view of a T1a renal tumor.

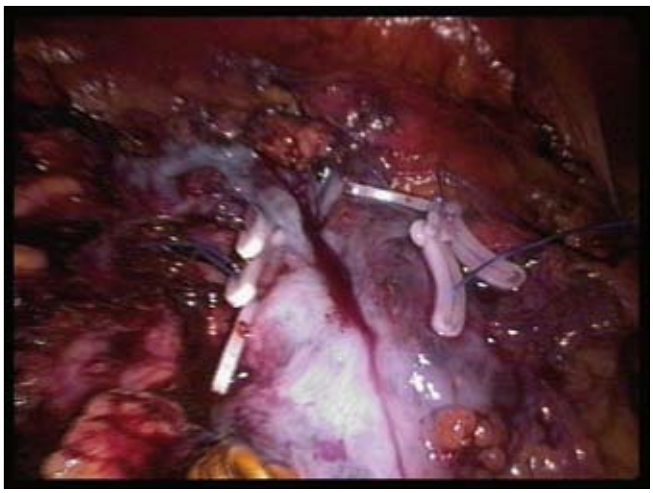

Fig. 2. Parenchymal reconstruction using clipped sutures and fibrin glue.

2. Natural orifice translumenal endoscopic surgery (NOTES)

This highly new innovative technique in nephron sparing surgery has not been yet introduced into clinical routine. It is an experimental new approach which is mainly established nowadays in the porcine model. Haber et al. describe their experience in the porcine model demonstrating that this new technique may be safe and feasible. Beside an endoscopic transvaginal access in female pigs they also reported about hybrid models of laparoscopy and robotic surgery. Especially in the robotic assisted surgery they praised the improvement in suturing by the advances of the robotic instruments [52].

The lack of scars is currently considered to be the main advantage of this approach while its overall invasiveness remains debatable. Still we have to keep our eye on the rapid development of NOTES in uro-oncology.

Ablative options

Radiofrequency ablation: RFA induces thermal damage by converting radiofrequency waves into heat. The goal of RFA is to induce a temperature of 50-1,008°C throughout the tumor [53]. RFA can be performed open, laparoscopically, or percutaneously. Candidates include those with small, contrast enhancing, solid renal masses less than 4 cm which are located at some distance from the ureteropelvic junction, the renal hilar vessels, and preferably not involving the pelvicalyceal system [5]. Tumor location is the most important determinant of the surgical approach. Laparoscopic RFA has the advantage of probe insertion under direct vision, avoiding adjacent organ damage. The percutaneous approach is preferred for posterior tumors, is well tolerated, and can be performed under sedation, potentially on an outpatient basis. The RFA probe can be inserted under ultrasound, CT, or MRI guidance. Ukimura et al. reported the use of real-time virtual ultrasonography (RVS, Hitachi Medical Corporation, Japan) as a navigational tool for percutaneous RFA in 10 patients [55]. The mean (range) tumor diameter was 2.8 (1.0-4) cm. All tumors were visualized on CT/RVS and precise imaging was possible. Carey and Leveillee described the use of non-conducting temperature probes independent of the RFA electrode in order to achieve real-time temperature monitoring of the ablation zone [56]. The ablation was continued until all of the peripheral temperature monitors registered 60°C for at least 15 s. In the 36 patients treated (37 tumors) with an average follow-up of 11.3 months (1-44), the re-treatment rate was 8.1%. Two major complications occurred, ureteropelvic junction obstruction and delayed hemorrhage. Park et al. reported 94.8% cancer-specific survival for small tumors (mean size 2.4 cm), with a mean follow-up of 19.5 months [57]. They also reported 94 tumors in 78 patients (mean size 2.4 cm). Over a mean follow-up period of 25 months, recurrence-free survival was 96.8%, cancer specific survival was 98.5%, and overall survival was 92.3%.

Cryoablation: The pathophysiology of the cryolesion begins as the extracellular space freezes and osmolarity increases leading an efflux of intracellular fluid into the extracellular compartment [58]. The initial damage to the cells is due to the hypertonic intracellular solute, changes in pH, and protein denaturation. Extracellular ice formation also causes mechanical disruption of the cell membranes. With further cooling, ice crystals may form within the cell. Delayed tissue injury occurs within hours and days after cryoablations, due to microvascular injury, diminished tissue perfusion, and delayed cell death [59]. To perform cryoablation, liquid argon is currently the most commonly used cryogen. A slow, passive thaw may be more effective than a rapid and active thaw. Two freeze-thaw cycles have been shown to produce a larger area of necrosis in an animal model when compared with a single cycle and remains our current preference [60]. Animal models demonstrate that a temperature of -19.4°C or less results in complete cell death [61]. In clinical protocols, the target temperature is approximately -40°C with extent of the ice ball at least 0.5 cm beyond the target lesion. Ability to perform intraoperative ultrasound monitoring of the ice ball is one advantage of cryoablation over RFA.

Percutaneous approach: The advantages of a percutaneous approach, apart from being less invasive, include shorter hospitalization, excellent ice-ball monitoring with cross-sectional imaging (MRI or CT), decreased pain medication requirement, and cost-effectiveness over the laparoscopic approach [62]. Percutaneous renal cryoablation is currently performed with the use of CT scan guidance, open gantry MRI or ultrasound [63]. Percutaneous ablation is typically reserved for posterior tumors.

Single-port approach: Goel and Kaouk reported single-port laparoscopic renal cryoablation in four patients [64]. They used a single port with multichannel access (Uni-X Single Port Access Laparoscopic System, Pnavel Systems, Morganville, New Jersey, USA) and specially designed curved laparoscopic instruments. For the retroperitoneal approach, the multichannel port was inserted at the tip of the 12th rib using an open Hasson technique and for the transperitoneal approach it was inserted through a 1.5-cm semicircular incision at the inner edge of the umbilicus. After exposing the tumor, intraoperative biopsy was performed, and a 3.8-mm cryoprobe (Endocare, Irvine, California, USA) was inserted under ultrasound guidance. All the procedures were successfully completed. No intraoperative complications developed. This approach might allow laparoscopic cryoablation procedures to be performed en-

tirely through the patient's umbilicus and enable essentially scarless abdominal surgery with additional reduced wound morbidity.

Radiosurgery: Radiation induces single-stranded and double-stranded DNA breaks, which causes apoptosis and prevents successful cell division. If the dose of radiation is high enough, direct necrosis is achieved. Ponsky et al. reported three patients with a renal tumor of 4 cm or less, candidates for surgical treatment who underwent radiosurgery followed by a partial nephrectomy after 8 weeks [65]. Before the procedures, the patients underwent a CT scan with percutaneous placement of image guidance markers in or near the tumor under local anesthesia. The patients received a total of 16 Gy in four fractions delivered over 2 days. At 8 weeks after radiosurgical treatment, a preoperative CT scan was obtained, and the patient underwent surgery (partial or radical nephrectomy). Mean follow-up was 56 weeks (52-62 weeks); no acute toxicities and no changes in renal function were noted. The initial two patients had histologically demonstrated viable tumor remnants. No viable tumor was seen in the last patient. There was no change in the tumor size after 8 weeks. By dividing the radiation dose into multiple separate individual beams, radiosurgical technology can deliver high-focal doses of radiation necessary to ablate a lesion completely, without increasing collateral damage. By incorporating respiratory gating, stereotactic radiosurgery can now be delivered to the kidney in real time. The ablative radiation dose remains to be determined, and the correlation between the pathologic findings and the CT scan is essential for appropriate evaluation and confirmation of tumor destruction.

CONCLUSIONS

Excision still is the reference standard for the treatment of small renal masses. Five-year oncological and functional outcomes of LPN are encouraging and similar to open surgery. LPN is technically challenging, but has been shown to achieve similar intermediate-term cancer cure and renal function results in centers with advanced laparoscopic expertise. Larger series with longer follow-up and prospective randomized studies are needed to confirm the safety and efficacy of LPN. Robotic technology is likely to enhance the diffusion of LPN since it speeds up the learning curve. However, financial limitations may be the major problem.

Cryoablation is the most studied among the ablative techniques so far. Preliminary data indicate that this modality could be the preferred option for small renal tumors not suitable for LPN. Radiosurgery is a promising new technology, but further studies are needed to address its oncological and functional results.

REFERENCES

1. Jemal A, Siegel R, Ward E et al: *Cancer statistics, 2008*. CA Cancer J Clin 2008; 58: 71-96.
2. Hock L, Lynch J, Balaji K: *Increasing incidence of all stages of kidney cancer in the last 2 decades in the United States: an analysis of surveillance, epidemiology and end results program data*. J Urol 2002; 167: 57-60.
3. Volpe A, Jewett M: *Thae natural history of small renal masses*. Nat Clin Pract Urol 2005; 2: 384-390.
4. Janetschek G, Abdelmaksoud A, Bagheri F et al: *Laparoscopic partial nephrectomy in cold ischemia: renal artery perfusion*. J Urol 2004; 171: 68-71.
5. McDougall E, Clayman R, Chandhoke P et al: *Laparoscopic partial nephrectomy in the pig model*. J Urol 1993; 149: 1633-1636.
6. Bhayani S, Rha K, Pinto P et al: *Laparoscopic partial nephrectomy: effect of warm ischemia on serum creatinine*. J Urol 2004; 172: 1264-1266.
7. Gill I, Kavoussi L, Lane B et al: *Comparison of 1,800 laparoscopic and open partial nephrectomies for single renal tumors*. J Urol 2007; 178: 41-46.
8. Dash A, Vickers A, Schachter L et al: *Comparison of outcomes in elective partial vs radical nephrectomy for clear cell renal cell carcinoma of 4-7 cm*. BJU Int 2006; 97: 939-945.
9. Winfield HN, Donovan JF, Godet AS, Clayman RV: *Laparoscopic partial nephrectomy: initial case report for benign disease*. J Endourol 1993; 7: 521-526.
10. Gill IS, Delworth MG, Munch LC: *Laparoscopic retroperitoneal partial nephrectomy*. J Urol 1994; 152: 1539-1542.
11. McDougall EM, Elbahnasy AM, Clayman RV: *Laparoscopic wedge resection and partial nephrectomy: the Washington University experience and review of the literature*. JSLS 1998; 2: 15-23.
12. Janetschek G, Jeschke K, Peschel R et al: *Laparoscopic surgery for stage T1 renal cell carcinoma: radical nephrectomy and wedge resection*. Eur Urol 2000; 38: 131-138.
13. Turna B, Aron M, Gill IS: *Expanding indications for laparoscopic partial nephrectomy*. Urology 2008; 72 (3): 481-487.
14. Porpiglia F, Volpe A, Billia M, Scarpa RM: *Laparoscopic versus open partial nephrectomy: analysis of the current literature*. Eur Urol 2008; 53 (4): 732-742.
15. Janetschek G: *Laparoscopic partial nephrectomy: how far have we gone?* Curr Opin Urol 2007; 17: 316-321.
16. Häcker A, Albadour A, Jauker W et al: *Nephron-sparing surgery for renal tumours: acceleration and facilitation of the laparoscopic technique*. Eur Urol 2007; 51 (2): 358-365.
17. Desai MM, Gill IS, Ramani AP et al: *The impact of warm ischaemia on renal function after laparoscopic partial nephrectomy*. BJU Int 2005; 95: 377-383.
18. Lane BR, Babineau DC, Poggio ED et al: *Factors predicting renal function outcome after partial nephrectomy*. J Urol 2008; 180 (6): 2363-2368.
19. Nguyen MM, Gill IS: *Halving ischemia time during laparoscopic partial nephrectomy*. J Urol 2008; 179: 627-632.
20. Gill IS, Abreu SC, Desai MM et al: *Laparoscopic ice slush renal hypothermia for partial nephrectomy: the initial experience*. J Urol 2003; 170: 52-56.
21. Janetschek G, Abdelmaksoud A, Bagheri F et al: *Laparoscopic partial nephrectomy in cold ischemia: renal artery perfusion*. J Urol 2004; 171: 68-71.
22. Gettman MT, Bishoff JT, Su LM et al: *Hemostatic laparoscopic partial nephrectomy: initial experience with the radiofrequency coagulation-assisted technique*. Urology 2001; 58: 8-11.
23. Urena R, Mendez F, Woods M et al: *Laparoscopic partial nephrectomy of solid renal masses without hilar clamping using a monopolar radio frequency device*. J Urol 2004; 171: 1054-1056.
24. Gill IS, Ramani AP, Spaliviero M et al: *Improved hemostasis during laparoscopic partial nephrectomy using gelatin matrix thrombin sealan*t. Urology 2005; 65 (3): 463-466.
25. Lucioni A, Orvieto MA, Zorn KC et al: *Efficacy of the argon beam coagulator alone in obtaining hemostasis after laparoscopic porcine heminephrectomy: a pilot study*. Can J Urol 2008; 15 (3): 4091-4096.
26. Desai MM, Gill IS, Kaouk JH et al*: Laparoscopic partial nephrectomy with suture repair of the pelvicaliceal system*. Urology 2003; 61: 99-104.
27. Ramani AP, Desai MM, Steinberg AP et al: *Complications of laparoscopic partial nephrectomy in 200 cases*. J Urol 2005; 173: 42-47.
28. Simmons MN, Gill IS: *Decreased complications of contemporary laparoscopic partial nephrectomy: use of a standardized reporting system*. J Urol 2007; 177: 2067-2073.
29. Wright JL, Porter JR: *Laparoscopic partial nephrectomy: comparison of transperitoneal and retroperitoneal approaches*. J Urol 2005; 174: 841-845.
30. Venkatesh R, Weld K, Ames CD et al: *Laparoscopic partial nephrectomy for renal masses: effect of tumor location*. Urology 2006; 67: 1169-1174.
31. Schiff JD, Palese M, Vaughan Jr ED et al: *Laparoscopic vs open partial nephrectomy in consecutive patients: the Cornell experience*. BJU Int 2005; 96: 811-814.
32. Link RE, Bhayani SB, Allaf ME et al: *Exploring the learning curve, pathological outcomes and perioperative morbidity of laparoscopic partial nephrectomy performed for renal mass*. J Urol 2005; 173: 1690-1694.

33. Abukora F, Nambirajan T, Albqami N et al: *Laparoscopic nephron sparing surgery: evolution in a decade*. Eur Urol 2005; 47: 488-493.
34. Porpiglia F, Volpe A, Billia M et al: *Assessment of risk factors for complications of laparoscopic partial nephrectomy*. Eur Urol 2008; 53: 590-598.
35. Turna B, Frota R, Kamoi K et al: *Risk factor analysis of postoperative complications in laparoscopic partial nephrectomy*. J Urol 2008; 179: 1289-1294.
36. Lane BR, Gill IS: *5-year outcomes of laparoscopic partial nephrectomy*. J Urol 2007; 177: 70-74.
37. Permpongkosol S, Bagga HS, Romero FR et al: *Laparoscopic versus open partial nephrectomy for the treatment of pathological T1N0M0 renal cell carcinoma: a 5-year survival rate*. J Urol 2006; 176: 1984-1988.
38. Gill IS, Colombo Jr JR, Moinzadeh A et al: *Laparoscopic partial nephrectomy in solitary kidney*. J Urol 2006; 175: 454-458.
39. Porpiglia F, Fiori C, Terrone C et al: *Assessment of surgical margins in renal cell carcinoma after nephron sparing: a comparative study: laparoscopy vs open surgery*. J Urol 2005; 173: 1098-1101.
40. Bollens R, Rosenblatt A, Espinoza BP et al: *Laparoscopic partial nephrectomy with "on-demand" clamping reduces warm ischemia time*. Eur Urol 2007; 52: 804-810.
41. Gill IS, Kavoussi LR, Lane BR et al: *Comparison of 1,800 laparoscopic and open partial nephrectomies for single renal tumors*. J Urol 2007; 178: 41-46.
42. Shapiro E, Benway BM, Wang AJ, Bhayani SB: *The role of nephron-sparing robotic surgery in the management of renal malignanc*. Curr Opin Urol 2009; 19 (1): 76-80.
43. Deane L, Lee H, Box G et al: *Robotic versus standard laparoscopic partial/wedge nephrectomy: a comparison of intraoperative and perioperative results from a single institution*. J Endourol 2008; 22: 947-952.
44. Aron M, Koenig P, Kaouk J et al: *Robotic and laparoscopic partial nephrectomy: a matched-pair comparison from a high-volume center*. BJU Int 2008; 102: 86-92.
45. Caruso R, Phillips C, Kau E et al: *Robot assisted laparoscopic partial nephrectomy: initial experience*. J Urol 2006; 176: 36-39.
46. Gettman M, Blute M, Chow G et al: *Robotic-assisted laparoscopic partial nephrectomy: technique and initial clinical experience with DaVinci robotic system*. Urology 2004; 64: 914-918.
47. Bhayani SB, Figenshau RS: *The Washington University renorrhaphy for robotic partial nephrectomy: a detailed description of the technique*. J Robot Surg 2008; 2: 139-140.
48. Rogers CG, Menon M, Weise ES et al: *Robotic partial nephrectomy: a multi-institutional analysis*. J Robot Surg 2008; 2: 141-143.
49. Remzi FH, Kirat HT, Kaouk JH, Geisler DP: *Single-port laparoscopy in colorectal surgery*. Colorectal Dis 2008; 10 (8): 823-829.
50. Desai MM, Rao PP, Aron M et al: *Scarless single port transumbilical nephrectomy and pyeloplasty: first clinical report*; BJU Int 2008; 101 (1): 83-88.
51. Stein RJ, White WM, Goel RK et al: *Robotic Laparoendoscopic Single-Site Surgery Using GelPort as the Access Platform*. Eur Urol 2009; Mar 31. Epub ahead of print.
52. Haber GP, Crouzet S, Kamoi K et al: *Robotic NOTES (Natural Orifice Transluminal Endoscopic Surgery) in reconstructive urology: initial laboratory experience*. Urology 2008; 71 (6): 996-1000.
53. Goldberg SN, Gazelle GS, Mueller PR: *Thermal ablation therapy for focal malignancy: a unified approach to underlying principles, techniques, and diagnostic imaging guidance*. AJR Am J Roentgenol 2000; 174: 323-331.
54. Park S, Cadeddu JA: *Outcomes of radiofrequency ablation for kidney cancer*. Cancer Control 2007; 14: 205-210.
55. Ukimura O, Mitterberger M, Okihara K et al: *Real-time virtual ultrasonographic radiofrequency ablation of renal cell carcinoma*. BJU Int 2008; 101: 707-711.
56. Carey RI, Leveillee RJ: *First prize: direct real-time temperature monitoring for laparoscopic and CT-guided radiofrequency ablation of renal tumors between 3 and 5 cm*. J Endourol 2007; 21: 807-813.
57. Park S, Anderson JK, Matsumoto ED et al: *Radiofrequency ablation of renal tumors: intermediate-term results*. J Endourol 2006; 20: 569-573.
58. Lovelock JE: *The haemolysis of human red blood-cells by freezing and thawing*. Biochim Biophys Acta 1953; 10: 414-426.
59. Gill IS, Novick AC: *Renal cryosurgery*. Urology 1999; 54: 215-219.
60. Woolley ML, Schulsinger DA, Durand DB et al: *Effect of freezing parameters (freeze cycle and thaw process) on tissue destruction following renal cryoablation*. J Endourol 2002; 16: 519-522.
61. Chosy SG, Nakada SY, Lee FT Jr, Warner TF: *Monitoring renal cryosurgery: predictors of tissue necrosis in swine*. J Urol 1998; 159: 1370-1374.
62. Permpongkosol S, Nielsen ME, Solomon SB: *Percutaneous renal cryoablation*. Urology 2006; 68: 19-25.
63. Stein RJ, Kaouk JH: *Renal cryotherapy: a detailed review including a 5-year follow-up*. BJU Int 2007; 99: 1265-1270.
64. Goel RK, Kaouk JH: *Single Port Access Renal Cryoablation (SPARC): a new approach*. Eur Urol 2008; 53: 1204-1249.
65. Ponsky LE, Mahadevan A, Gill IS et al: *Renal radiosurgery: initial clinical experience with histological evaluation*. Surg Innov 2007; 14: 265-269.

Correspondence

Christian Schwentner
Department of Urology
University Hospital Tuebingen
3, Hoppe-Seyler Street
72076 Tuebingen, Germany
phone: +49 07 071 29 803 49
christian.schwentner@med.uni-tuebingen.de