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UROLOGY - REVIEW

Organ-sparing procedures in GU cancer: part 1—organ-sparing procedures in renal and adrenal tumors: a systematic review

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Abstract

Purpose Organ-sparing surgery (OSS) for the kidney and adrenals has emerged as the need for preservation of function is paramount in patients with poor functional reserve. As reports increasingly showed that oncological outcomes were equivalent to radical excision, elective OSS became a viable alternative in patients with otherwise normal reserve. In this review, we summarize the current knowledge of OSS for adrenal and renal tumors.

Materials and methods PubMed, Web of Science and Cochrane Library Central Search were searched for recently published articles up to December 2017. The following keywords were used; "partial adrenalectomy", "adrenal sparing", "partial nephrectomy", "nephron sparing", "kidney/renal cancer".

Results Partial adrenalectomy became an attractive alternative to total adrenalectomy avoiding adrenal insufficiency. Both minimally invasive surgery and ablative techniques were increasingly reported for adrenal OSS with adequate residual adrenal function and excellent oncological outcome. Radical nephrectomy remained for many years as the gold standard of treatment for organ-confined renal cell carcinoma. As the need to reduce the impact on renal function, more conservative approaches were utilized. Soon, the non-inferiority of nephron-sparing surgery to that of radical excision became evident and elective partial nephrectomy was gaining ground as the standard of care for small renal masses in patients with normal contralateral kidneys.

Conclusions Herein, we present a comprehensive review of the current status of OSS in renal and adrenal tumors.

Keywords Organ sparing · Nephron sparing · Partial nephrectomy · Partial adrenalectomy

Abbreviations

AS	Active surveillance
CKD	Chronic kidney disease
CSS	Cancer-specific survival
DFS	Disease-free survival
LPN	Laparoscopic partial nephrectomy
NSS	Nephron-sparing surgery
PN	Partial nephrectomy
RCC	Renal cell carcinoma
RFA	Radiofrequency ablation
RFR	Recurrence-free rate
RN	Radical nephrectomy
RPN	Robotic partial nephrectomy
PTA	Percutaneous thermal ablation
SABR	Stereotactic ablative radiotherapy
SRMs	Small renal masses
SEER	Surveillance, Epidemiology, and End Results
TA	Thermal ablation
WIT	Warm ischemia time

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Adrenal sparing procedures

Most urologists elect total adrenalectomy for removal of adrenal tumors regardless of size or tumor location [1]. This may lead to adrenal insufficiency with the need of chronic steroid replacement. Inadequate steroid replacement can lead to Addisonian crisis (35% post bilateral adrenalectomy) with 3% death rate [2]. On the other hand, excess steroid replacement is associated with many complications including: hypertension, diabetes, premature osteoporosis, peptic ulcers, immunosuppression, hirsutism and increased intraocular pressure [3, 4]. Consequently, partial adrenalectomy, when feasible, has emerged as an attractive alternative to total adrenalectomy.

The volume of the residual adrenal cortical tissue needed to maintain cortical function is a debatable subject. Many authors indicate a thickness margin of 3–5 mm is adequate [5–8]; while other investigators, suggest a volume of one-third of a gland is sufficient [9–11].

Indications

Tumor size

The size of the adrenal mass is important, as it indicates potential malignancy (> 4 cm) as well as a limiting factor in preserving physiological adrenal function. Angeli et al. studied adrenal incidentalomas, and reported an adrenal mass size of 4 cm is an appropriate cutoff to differentiate adrenal carcinoma form other benign histologies [12]. Kaye et al. [13] performed a literature review and reported the outcomes of 417 patients who underwent partial adrenalectomy. There were no cases of adrenocortical carcinoma all over the entire cohort (mean tumor size 2.62 cm, range 0.04–9 cm).

Tumor location

Some authors noted feasible partial adrenalectomy in tumors located anteriorly and at the margins, while those located posteriorly may be more challenging to be managed by partial adrenalectomy [14].

Special considerations

Bilateral adrenal masses in hereditary or non-hereditary syndromes are good indications for partial adrenalectomy. Hereditary adrenal syndromes include many with the most popular; von Hippel–Lindau (VHL) disease and multiple endocrine neoplasia 2 (MEN2) [15, 16]. Partial adrenalectomy in patients with unilateral masses and no hereditary syndromes is indicated by some authors [4, 17]. This is related to the impaired stress response following total adrenalectomy [12].

There is limited literature on the management of the unexpected adrenocortical carcinoma following partial adrenalectomy. In those patients, we believe that if there is a positive margin, completion adrenalectomy should be performed. In those with negative margins, close follow-up is recommended. There are imaging characteristics in preoperative CT scan and MRI that help to avoid such a situation. On CT scan, adrenal adenoma is suspected if the mass has low Hounsfield units (< 10) on unenhanced CT, with rapid (at 15 min) relative contrast washout > 50% or absolute contrast washout > 60% (sensitivity, 56–100%; specificity, 98–100%) [18, 19]. In both CT and MRI; adrenal cortical carcinoma commonly presents as a large mass (5–20 cm), with irregular margins and heterogeneous contrast enhancement with areas of hemorrhage, necrosis and occasional calcifications [20–22].

Surgical techniques

Minimally invasive techniques whether laparoscopic or robotic are becoming the standard for performing a partial adrenalectomy. Key elements in performing the procedure are tumor identification and preservation of cortical blood supply to ensure venous drainage of the adrenal remnant [23]. Intraoperative ultrasound can be used for tumor identification [24]. The use of intravenous indocyanine green during robotic partial adrenalectomy; where the tumor will appear hypoflourescent was described as well [25].

Ablative procedures including radiofrequency ablation, microwave ablation, cryoablation and chemoablation were described in treating small adrenal masses and in the high surgical risk patient [26]. Yang et al. [27] compared the outcomes of patients with adrenocortical aldosteronoma treated by radiofrequency ablation to those received laparoscopic partial adrenalectomy. At 3 years follow-up, both procedures demonstrated similar outcomes with regards to postoperative aldosterone serum level decline.

Oncological and functional outcomes

Tumor recurrence

In the context of adrenal sparing surgery, one has to differentiate between true recurrences in the tumor bed owing to a positive margin versus new tumor forming because of a multifocal disease process [13]. In the largest reported study to date on the outcomes of partial adrenalectomy, Kaye et al. reported a recurrence rate of only 3% with a mean time to recurrence of 113 months (range 36–324) [13]. Data on predictors of recurrence after partial adrenalectomy is lacking. However, patients underwent partial adrenalectomy for pheochromocytoma as part of hereditary syndromes, commonly recurs (0–100%) [3, 6, 9]. The reason of this wide range of recurrence is justified by the length of the follow-up period of the patients, as recurrences are often seen > 10 years after removal of the initial tumor.

Lee et al. demonstrated tumor recurrence rate of 21% (3/15 patients) after partial adrenalectomy at a median follow-up of 11.5 years with most of these recurrences amenable for surgical excision. However, all the patients in Lee's report were suffering from hereditary syndromes (MEN types 1 and 2 and VHL) [6].

Functional outcomes

Adrenal replacement therapy was needed in only 5.3% of patients following partial adrenalectomy in one report where unilateral partial adrenalectomy was the most common procedure offered to patients [13]. The rate of steroid replacement therapy is higher in patients who underwent bilateral partial adrenalectomy (35%) [28].

During the past years, partial adrenalectomy is gaining popularity and become an accepted alternative in the management of adrenal tumors. However, there is a demand of prospective studies comparing the long-term outcomes of partial versus total adrenalectomy in different indications and techniques.

Conservative surgery for renal tumors

Small renal masses (SRM) still may compose a threat to patients' survival as 9% of tumors < 3 cm presented in one large study with metastasis [29]. Being a chemotherapy-resistant, and radio-resistant tumor, surgical excision of organ-confined renal cell carcinoma (RCC) is the mainstay of a curative treatment. Surgical excision must be done with no compromise of the oncological outcome. Radical nephrectomy (RN) remained for many years the gold standard to achieve this goal. Advances in imaging on one hand and the development of minimally invasive techniques lead to a new era of "precision surgery" which provided a tailored management of renal cancer [30]. It was felt that RN may offer a better disease-free survival (DFS) than nephron-sparing surgery (NSS) offered by partial nephrectomy (PN) or tumor enucleation. However, with more recent studies this view was challenged. On the other hand, NSS may offer a significant contribution to preserve renal function.

Oncological outcome of partial nephrectomy

As organ-preserving surgery evolved with the premise of maximum preservation of renal function, it was evaluated for having a non-inferiority oncological outcome compared to RN. A prospective randomized study by the European Organization for Research and Treatment of Cancer addressed this question and though ended prematurely showed that PN is equivalent to RN in overall survival (OS) for solitary RCC lesions ≤ 5 cm [31].

Nephron-sparing surgery is increasing worldwide. Small et al. reported on the utilization of NSS for T1 renal tumors in the US National Cancer Database [32]. Between 2000 and 2008 a 10% annual increase in NSS for T1 tumors was reported. Black race, older patients, ethnic minorities and lack of insurance were factors associated with less utilization of NSS. Fernando et al. analyzed the mandatory nephrectomy reporting in the UK [33]. Of 6042 patients who underwent a nephrectomy procedure, 1044 had NSS. For T1a tumors, 55% had an NSS while 42% had a RN. The NSS group had a median tumor size of 3.4 cm, a minimally invasive technique was utilized in 42%, conversion to open occurred in 4%. Major complication rate (grade => 3) was 5%. The 30-day operative mortality was 0.1%. Positive surgical margins for pT1a tumors was 6.1% which increased for pT3 tumors to 47.8%.

Many retrospective studies showed an excellent long-term oncological outcome for small renal tumors comparable to RN. Nephron-sparing surgery in patients with RCC of a mean diameter of 3 cm and normal contralateral kidney has a 10-year cancer-specific survival of 96.7% and local recurrence-free survival (RFS) of 95.7% [34]. In a large series from a single institution, NSS for T1 tumors was associated with 5.1% recurrence at a median follow-up of 38.3 months [35]. Recurrence was independently associated with tumor stage higher than T1a, bilateral tumors, and multifocality. In a retrospective study comparing NSS with RN for solitary T1 renal tumors, the OS and cancer-specific survival were not significantly different at a mean follow-up of 43.5 ± 22.4 months [36].

Several other uncontrolled studies reported similar findings for larger renal cortical tumors and RCC 4–7 cm in diameter (stage T1b). There was no significant difference between RN and NSS in the overall and cancer-specific survival [37], 12-year cancer-specific survival [38], and Surveillance, Epidemiology, and End Results (SEER) database cancer-specific mortality [39]. Although RN and PN for cT1b have an equivariant oncological outcome, RN, however, was associated with excess loss of renal function, 25% increase in the risk of cardiac mortality, and 17% increased any cause mortality [40].

Recently, PN was evaluated for larger organ-confined tumors up to T2. Mir et al. conducted a meta-analysis comparing RN and PN for renal tumors stages cT1b–cT2 [41]. Partial nephrectomy was associated with better preservation of renal function, but higher complication rate and more blood loss. The PN patients had significantly lower tumor recurrence, cancer-specific mortality, and all-cause mortality. The results might be affected by the younger age and relatively smaller tumors in the PN group.

Theoretically, one caveat of NSS is the possibility to leave residual tumor tissue behind, the impact of which needs to be evaluated. Different authors reported that a positive surgical margin in NSS did not correlate with oncological outcome [42]. Tumor grade and bilaterality but not positive surgical margins were the most significant independent predictors of survival and recurrence, respectively.

There is a consensus from several societies recommending NSS for small renal tumors when surgically feasible. The European Society for Medical Oncology guidelines recommends PN for all patients with T1 tumors when technically feasible [43]. If RN is indicated, it should be carried out by laparoscopy. The European Association of Urology (EAU) guidelines recommend PN rather than RN for localized T1a-b renal tumors if technically feasible regardless of surgical approach [44]. The American Society of Clinical Oncology Clinical Practice Guidelines recommends PN for all patients with SRM amenable to resection. RN for SRM is recommended only when PN is not feasible due to tumor complexity or when it might cause unacceptable morbidity [45]. The American Association of Urology guidelines recommend prioritization of PN for all patients with cT1a tumors [46]. RN is reserved for tumors with high oncological potential determined by size, biopsy results and imaging characteristics. With an expert opinion recommendation, RN is preferred when all three conditions are met including a surgically challenging complex tumor, no prior chronic kidney disease (CKD) and normally functioning contralateral kidney.

Nephron-sparing surgery for Wilms tumor

Nephron-sparing surgery for unilateral non-syndromic Wilms tumor in a selected matched small group of patients was associated with better preservation of renal function in the long-term compared to RN [47]. Three percent of unilateral Wilms tumors patients had an NSS with excellent survival and low recurrence rates [48]. The significance of nephron preservation in those patients is unknown.

Techniques and perioperative outcome

Open-surgical PN was soon followed by the minimally invasive procedure laparoscopic PN (LPN). The early experience reported longer warm ischemia time (WIT) and higher urological complication rates for LPN compared with open PN [49]. More recent studies, however, showed that perioperative outcomes were similar for both procedures [50] as well as the long-term oncological outcome for stage T1 renal tumors [50, 51].

Shikanov et al. reported a median ischemia time for LPN of 29 min [52]. Better immediate postoperative estimated glomerular filtration rate (eGFR) was associated with shorter ischemia time, shorter operative time, use of cold ischemia, and female gender. At the last follow-up more than 1 month, the duration of ischemia was not associated with a change in eGFR, while the absence of DM and smaller tumors were associated with a better eGFR. There are different views on the recovery of renal function when laparoscopic and open techniques are compared. There is a small advantage of LPN over open PN on the 6-month recovery of renal function [53]. However, Springer et al. compared LPN to open PN for cT1 tumors and found no difference in renal function change or oncological outcomes [54]. While challenging LPN might be carried out for recurrent cases. Boris et al. reported on laparoscopic renal intervention after previous retroperitoneal surgery [55]. Laparoscopy was feasible but with a high conversion rate to open surgery in patients who underwent previous PN.

As robotic-assisted surgery evolved providing better maneuverability and suturing to the surgeon, it was adopted for PN (RPN). The perioperative surgical outcome of LPN and RPN were compared in a prospective study and showed comparable results in terms of WIT, blood loss, operative duration and complication rates [56]. In a meta-analysis, RPN was associated with less WIT than LPN [57]. A trifecta of negative surgical margin, minimal change in GFR and no urological complications was achieved with laparoscopic and robotic PN in 68% of patients [58]. Robotic partial nephrectomy may have an advantage over LPN for the larger more complex tumors. RPN provides similar postoperative outcomes to LPN for moderate to highly complex renal tumors except for less conversion to RN [59]. Hankins et al. reported on robotic multiplex PN for complex multiple renal tumors averaging 8.6 tumors per kidney [60]. This complex surgery needed a learning curve but resulted in the preservation of renal function.

Other novel techniques were applied to decrease WIT, improve hemostasis, and better identify the tumor during surgery. Super selective clamping of tumor supplying vessel facilitated resection of challenging medial tumors and permitted zero ischemia time in expert hands for LPN and RPN [61]. In our experience as well as reported by others, Modification of surgical technique by applying a hemostatic agent to the cut surface of the kidney was not associated with increased perioperative bleeding for open PN [62]. Image-guided surgery can improve detectability of renal tumors [63]. This procedure involves molecular imaging that includes several techniques to visualize the tumor intraoperatively.

Tumor enucleation

Compared to RN, tumor enucleation of renal tumors with pT1 was associated with similar oncological outcomes at 5 and 10-year follow-up [64]. Simple enucleation of renal tumors with a median size of 4.8 ± 1.6 cm either with open or robotic techniques resulted in a positive surgical margin of 3.6% and 5-year RFS of 90.8% [65]. Complications $\geq$ grade 3 were reported in 9.3%. A trifecta of negative surgical margins, minimal eGFR decrease, and no urological complications was achieved in 64.3% of patients.

Other minimally invasive treatment for renal tumors

There is an increasing interest in minimally invasive treatments for SRM as an alternative to PN particularly when patients are unfit or unwilling to undergo surgery. Different alternative treatments with long-term follow-up include radiofrequency ablation (RFA) and cryoablation. Active surveillance (AS) and other emerging technologic such as microwave ablation, stereotactic ablative radiotherapy (SABR), and irreversible electroporation were reported albeit mostly having short-term follow-up [66, 67]. The current level of evidence, however, does not provide sufficient answers towards the role of the alternative and focal ablation treatments. A recent review of less invasive treatments for T1a RCC as an alternative to PN did not identify any randomized controlled comparative trial [68]. Many retrospective studies, however, have reported the clinical and oncological outcomes of these treatments.

Active surveillance

Patients with tumors < 4 cm and having a short life expectancy may be offered AS [43]. Jewett et al. reported a prospective multicenter study of AS for SRM in the elderly or infirm patients [66]. Renal biopsy-proven RCC was reported in 101 out of 209 masses. At a mean follow-up of 28 months, the local progression rate was 12% and metastasis 1.1%. The American Urological Association (AUA) guidelines recommend AS as an initial management option for renal tumors < 2 cm [46]. However, a retrospective study from the SEER database reported inferior cancer-specific survival (CSS) in patients with T1a RCC compared to PN or thermal ablation (TA) [69]. In the absence of sufficient evidence, the AUA guideline panel recommends AS when the risk or death outweighs the oncological benefits of intervention [46].

Thermal ablation

Thermal Ablation by RFA and cryoablation are options for tumors ≤ 3 cm in selected patients [43, 46]. Those include high surgical risk patients, impaired renal function, solitary kidneys, and multiple tumors. RFA had a durable favorable oncological outcome in patients at high risk for surgery and T1a tumors followed for a median of 6.4 years [70]. There is an increase in the utilization of TA for RCC. A report from the Swedish cancer registry 2005–2010 showed that 4% of surgical procedures for the treatment of T1a RCC were by TA [71]. The AUA guidelines recommended that patients need counseling for the possibility of higher recurrence rate and the need for follow-up biopsies [46]. Recent reports, however, showed that TA for T1a RCC is equivalent in the oncological outcome to surgical excision with the added advantage of less morbidity suggesting that TA role might not be restricted to comorbid patients [72].

The role of TA in the treatment of RCC is better defined with long-term oncological outcomes. The definition of "long-term" must take into consideration the natural history of RCC. Different treatment modalities for localized RCC are associated with a 20% recurrence rate at 5 years follow-up [73]. Radiofrequency ablation is associated with a median time to recurrence of 2.5 years [70] which is like patients with potentially curable RCC after surgical treatment [74]. Only few studies report long-term oncological outcome for TA with a minimum of 4–5 year mean/median follow-up (Table 1) [70, 75–80].

The real value of TA is more evident when compared with the "gold standard surgery" for localized RCC. The available studies, all retrospective, however, that compared TA and PN or RN for T1a RCC concluded that the CSS was not significantly different between treatment modalities. Talenfeld et al. reported on patients at least 66 years old in the SEER database who underwent TA, PN, or RN for T1a RCC between 2006 and 2011 [81]. The 5-year CSS after percutaneous thermal ablation (PTA) was 95%, versus 98% after PN. The 5-year OS was 77% versus 86%, respectively. RN had a 5-year CCS and OS of 95% and 75%, respectively. In another study of patients in the SEER database, TA and PN were compared in background propensity-matched patients with T1a RCC [82]. The 5-year CSS was similar between the two groups whereas the OS for the PN was significantly improved (91.0%) versus the ablation group, (86.3%). Another study from the SEER database cohort reported the 9-year CSS for propensity-matched patients who underwent TA and PN (96.3% vs. 96.4%) and TA and RN (96.0% vs. 96.1%) with no significant difference [69].

Comparative studies having shorter follow-up outcomes reported similar findings. Sung et al. compared RFA and PN in a matched group of patients with RCC with a mean tumor diameter < 2.5 cm [83]. The 3-years recurrence-free rate (RFR) was 94.7% and 98.9% ($p = 0.266$), respectively. Cooper et al. reported a retrospective study of 49 patients who underwent RFA ($n = 9$), PN ($n = 9$) or RN ($n = 31$) for T1a RCC [84]. Tumor recurrence was reported in two after RFA, one after PN and none of the RN patients.

Some comparative studies included tumors larger than 4 cm in diameter with diverse conclusions. Olweny et al. reported follow-up at least 5 years comparing RFA and PN for T1b RCC [85] showing no significant difference in all oncological outcomes including OS, metastasis-free survival, and DFS. For RFA, the 5-years CSS was 97.2% and local RFS was 91.7%, versus 100%, and 94.6% for PN. Another study, however, showed a survival advantage of PN for larger lesions. Takaki et al. retrospectively compared the outcomes of RFA or RN for T1b RCC [86]. At a 10-year follow-up, the RCC-related survival rate was 94% versus

Table 1 RFA long-term oncological outcome

Study	Patients (lesions)	Size cm Mean/median (range/SD)	Access	RCC *n* (%)	Follow-up Mean/median (range)	Survival (yr)	CCS%	RFS%	DFS%	OS%
Psutka et al. [70]	185	3 (2.1–3.9)	PCA	185 (100)	6.43 yr (5.3–7.7)	5 10	99.4	T1a 96.1, T1b 91.9 T1a 93.2	87.6	73.3
Zagoria et al. [75]	41 (48)	2.6 (0.7–8.2)	PCA	48 (100)	61 m (54–68)	–	–	88	–	–
Ma et al. [76]	52 (58)[a]	2.2 (±0.8)	LAP or PCA	41 (70)	60 m (48–90)	10	100	94.2	–	91.1
Wah et al. [77]	165 (200)	2.9 (1–5.6)	PCA	183 (91.5)	47.6 m (2.6–96)	5	97.9	93.5	–	75.8
Su et al. [78]	168	2.6 (2.0–3.3)	PCA	48	4.1 yr (3.4–4.9)	5	–	86.8	82.3	92.6
Zhang et al. [79]	122	3.4 (±1.1)	LAP or PCA	122 (100)	64.9 m (9–83)	5	98.3	94.2	90.8	98.4
Johnson et al. [80]	106 (112)	2.5 (±0.8)	LAP or PCA	62 (55)	79 m (28.9–121.1)	6	96	–	89	
						10	94		82	49

The definitions of oncologic outcomes [70]: (1) Recurrence-free survival (RFS): patients without disease recurrence in the ablation zone. (2) Disease-free survival (DFS): patients with no disease at last follow-up including both locally recurrent disease and evidence of metastases. (3) Cancer-specific survival (CSS): patients who did not die from RCC. (4) Overall survival (OS): patients who did not die of any cause

CCS cancer-specific survival, *DFS* disease-free survival, *LAP* laparoscopic, *m* month, *n* number, *OS* overall survival, *PCA* percutaneous ablation, *RCC* renal cell carcinoma, *RFA* radiofrequency ablation, *RFS* recurrence-free survival, *yr* year

[a]Selected only patients with ASA score 1 or 2

100%, the DFS 88% versus 84%. In a retrospective comparison between percutaneous RFA and PN, Liu et al. reported a comparable 10-year DFS for RCC ≤ 4 cm, whereas there was an advantage of PN for CRCC tumors > 4 cm [87]. Zhang et al. reported a retrospective study of patients with T1a and T1b who underwent RFA for RCC [79]. Patients who had tumors ≤ 3 cm had a better DFS.

Certain tumor characteristics other than size may affect the choice and outcome of RFA such as location and multifocality. The presence of endophytic lesions may be preferably treated by RFA rather than PN. A study from Korea compared RPN with RFA in matched groups of patients. The 2-year DFS was 100% and 95% respectively [88]. However, the RFA group included significantly more patients with endophytic lesions. Multifocality is another indication for RFA. CT-guided PTA of multifocal RCC lesions was associated with progression-free survival, and DFS rates of 96% and 100% at a mean follow-up of 3.1 years [89]. Certain lesions, however, may risk more complications after RFA. Central and lower pole lesions are risk factors for RFA associated ureteric injury [77]. Camacho et al. reported that TA for T1a RCC with a RENAL nephrometry score ≥ 8 was associated with increased complications, overall recurrence and first-year recurrence [90].

Radiofrequency ablation has a minimal impact on renal function (Table 2) [76, 77, 91, 92]. RFA had less impact on renal function and fewer complications than PN or RN with a comparable oncological outcome. In a retrospective comparison between RFA and PN for T1 RCC, DFS was comparable [93]. Although the RFA group included more single kidneys and worse preoperative renal function, postoperatively renal function preservation was significantly better than in the PN patients. Takaki et al. reported that at 10-year follow-up RFA for T1b RCC was associated with significantly lower percentage decrease in the GFR of 12.5% versus 32.3% for RN [86]. Talenfeld et al. reported that 1-year cumulative renal impairment rates were 11%, 9% and 18% after PTA, PN and RN, respectively [81]. Interestingly, the 1-month non-urologic complication rates were 6%, 29%, and 30% for the three procedures, respectively [81]. The authors concluded that PTA may have a slightly shorter CSS than PN but with less complication, while when compared to RN, PTA has a similar long-term oncological outcome but with fewer complications and renal impairment rates.

Only a few studies reported long-term outcomes of cryoablation with a RFS ranging between 87% and 100% (Table 3) [94–98]. Some reports evaluated the approach of cryoablation. A systematic review compared the results of percutaneous versus laparoscopic approaches of cryoablation [99]. The two techniques had similar RFS and impact on eGFR. The percutaneous cryoablation was more commonly used for posterior lesions and had a shorter hospital stay. Zargar et al. compared percutaneous versus laparoscopic cryoablation for SRM and reported that there was no significant difference in complication rates, 5-year RFS or OS [100]. Faba et al., however, reported a different result. The percutaneous cryoablation for lateral and posterior renal tumors had a significantly lower 5-year RFS than the laparoscopic approach [101].

Few studies compared cryoablation with other treatment modalities for RCC and included larger tumors. Caputo et al. retrospectively compared cryoablation to PN for T1b RCC [102]. After matching patients for baseline characteristics, the 1-year local recurrence rate was significantly higher for the cryoablation group. A study from Japan reported no difference in the long-term clinical outcome of RFA and cryoablation for clinical T1b RCC [103]. Zhou and Arellano compared cryoablation with RFA and CT-guided microwave ablation. The authors reported some short-term advantages of microwave ablation for clinical T1c RCC [104]. The three modalities were comparable in terms of complications and short-term impact on renal function. However, microwave

Table 2 RFA effect on renal function

Study	Patients (lesions)	Size cm (range/SD)	Access	Follow-up months	PRF %
Ma et al. [76]	52 (58)[a]	2.2 ± 0.8	LAP or PCA	60 (48–90)	100
Wah et al. [77]	165 (200)	2.9 (1–5.6)	PCA	47.6 (2.6–96)	98
Seklehner et al. [91]	40 (44)	2.6 (1.5–4.2)	PCA	23.8 (3–59)	Cr increased 1.1–1.25 mg/dl
Takaki et al. [92]	33 (33)	2.9 (1.5–5.0)	PCA	20 (11.6–27.6)	100 (patients with bilateral kidneys)

Cr creatinine, *LAP* laparoscopic, *PCA* percutaneous ablation, *PRF* preserved renal function, *RFA* radiofrequency ablation

[a]Selected only patients with ASA score 1 or 2

Table 3 Cryoablation oncological outcomes

Study	Patients (lesions)	Size cm (range/SD)	Access	RCC *n* (%)	Follow-up months	Survival (year)	Major complications *n* (%)	CCS%	RFS%	DFS%	OS%
Davol et al. [94]	48	2.6 (1.1–4.6)	–	–	64 (36–110)	–	0	100	–	–	–
Meng [95]	138 (142)	2.4	LAP	100 (70.4)	98.8 ± 54.2	–	15 (10.6)	92.6	86.5	–	–
Nielsen et al. [96]	808	25 (19–30)	LAP	514 (64)	36 (14–56)	–	26 (3.2)	–	–	10-yr 80	10-yr 64.4
Breen et al. [97]	433 (484)	3.3	PCA	222 (51)	–	5	–	–	93.9	–	–
Haddad et al. [98]	173 (173)	2.9 (1.3–4.0)	PCA	173 (100)	–	5	9 (5.2)	–	88–100[a]	–	–

The definitions of oncologic outcomes [70]: (1) Recurrence-free survival (RFS): patients without disease recurrence in the ablation zone. (2) Disease-free survival (DFS): patients with no disease at last follow-up including both locally recurrent disease and evidence of metastases. (3) Cancer-specific survival (CSS): patients who did not die from RCC. (4) Overall survival (OS): patients who did not die of any cause

CCS cancer-specific survival, *DFS* disease-free survival, *LAP* laparoscopic, *n* number, *OS* overall survival, *PCA* percutaneous ablation, *RCC* renal cell carcinoma, *RFS* recurrence-free survival, *yr* year

[a]Depending on histologic subtype

ablation had significantly shorter ablation and procedure time and less sedation dosage.

Microwave ablation and other emerging technologies are gaining momentum in the treatment of SRM but still need long-term outcome assessment and comparison with the currently recommended treatment modalities. A prospective study compared microwave ablation of SRM versus PN [105]. The 3-year local RFS was not statistically different. Microwave ablation, however, had the advantage of significantly lower blood loss, fewer complications and less decrease of renal function in the postoperative period. Another novel treatment for RCC is SABR. A recent worldwide multicenter study reported the intermediate term oncological outcome of SABR for RCC [106]. The 4-year CSS and progression-free survival were 91.9% and 65.4%, respectively, and was negatively affected by tumor size and multifraction treatment. There was an associated significant decrease of eGFR by 5.5 ± 13.3 mL/min from baseline.

Renal function

Recovery of renal function after RN

The main premise of adopting a NSS is the preservation of renal function. Loss of renal mass following RN is to be avoided whenever possible. However, several reports challenged this view indicating that renal function recovery is common after RN. Zabor et al. showed that 45% of patients recovered their preoperative GFR within 2 years after RN [107]. Recovery of eGFR was associated with larger tumors in patients with normal preoperative eGFR and least with hypertension [108]. In patients with preoperative decreased eGFR, recovery was significantly associated with younger age and female gender. RN patients tend to recover kidney function at a steady rate postoperatively [109]. The patients with preoperative CKD, diabetes, hypertension, or cardiovascular disease did not recover their kidney function. Increasing age and DM were independent risk factors for severe renal impairment.

The impact of NSS on solitary kidney

The precise magnitude of renal function preservation after NSS was evaluated in patients with a solitary kidney [110]. Postoperative GFR decreased by 29% at 1 year and 36% at 5 years. The decrease correlated with the size of the tumor and duration of warm ischemia. A study from Argentina reported an incidence of 6.6% end-stage renal failure at a median follow-up of 27.6 months in patients with a solitary kidney who had NSS [111]. Pahernik et al. reported renal failure requiring dialysis in 11.2% of patient with a solitary kidney who underwent NSS for RCC with a mean diameter of 4.2 cm [112]. Partial nephrectomy in patients with a solitary kidney was associated with recovery of renal function which plateaued at 1 month postoperatively [113]. Better immediate postoperative recovery was associated with shorter WIT, less blood loss and longer duration since nephrectomy of the contralateral kidney. Long-term in addition to short-term recovery was associated with younger age and higher preoperative eGFR.

Zargar et al. compared pre and postoperative renal scans for patients who underwent RPN [114]. The median ipsilateral eGFR preservation was 72% and the overall preservation was 84%. Independent risk factors that were associated with renal function deterioration were the amount of healthy parenchyma removed, WIT, BMI and lower preoperative eGFR.

Significance of NSS on renal function

It is intuitive that PN preserves more renal parenchyma than RN but does that translate into a significant clinical benefit? A study of patients in the SEER database showed that elderly patients with localized renal tumors had higher mortality due to non-cancer causes that correlated with increasing age and comorbidity score [115]. Renal function preservation may have contributed to a better survival in some of those patients? Sun et al. in a study of patients in the SEER database, reported that PN was associated with lower other-cause mortality compared to RN even after adjustment for cancer-specific survival [116]. In a later analysis of the SEER data, NSS was associated with less incidence of moderate renal dysfunction but not severe dysfunction or renal failure [117]. On the other hand, the negative impact on survival was not seen with nephrectomy in other patients. Studies in renal transplant donors showed that OS and renal function was similar to the general population [118]. Competing conclusions from these studies are probably due to the difference in patient characteristics for kidney donors compared to patients with renal tumors and for the retrospective nature of the SEER study including mainly elderly patients.

Head to head comparison of RN and NSS

Several studies showed that NSS had a more favorable impact than RN on renal function, new onset CKD, cardiovascular events and OS. Preservation of renal function is comparable between PN and AS for small renal tumors [119]. Radical nephrectomy, however, is associated with a significant decrease in eGFR. Even with extended ischemia time, PN is associated with better preservation of renal function than RN for cT1 renal tumors [120]. A 2-year follow-up of a cohort of Canadian patients showed that RN is associated with a significant decline of renal function and more prevalent severe renal failure compared to PN [121]. Nephron-sparing surgery is associated with less new-onset CKD compared to RN for renal tumors > 4 cm [122]. Age, ASA score, RN and baseline renal function were independent risk factors associated with the development of CKD. In patients at risk of developing CKD, PN had a more favorable outcome on eGFR than RN [123]. New onset deterioration of eGFR was independently associated with RN, DM and age but not PN or hypertension [123]. Renal insufficiency is more prevalent in patients who underwent RN (12.3%) compared to PN (3.7%) at long-term follow-up [124]. New onset 3-month renal insufficiency was reported in 52% of patients undergoing RN or PN in one series [125]. Independent risk factors for the development of CKD were RN (regardless of surgical approach), and preoperative CKD.

Nephron-sparing surgery is associated with less risk of cardiovascular events than RN in patients with T1 renal tumors and normal renal function at 10-year follow-up [126]. NSS was independently associated with better OS and better renal function compared to RN in patients with unforeseen benign renal tumors [127]. In another study, the advantage of survival was not evident for patients with larger tumors. Jang et al. compared RN with PN for RCC pT1b [128]. The 10-year cancer-specific survival, progression-free survival, and OS were not significantly different. Radical nephrectomy patients, however, had more incidence of new-onset CKD and end-stage renal failure.

Factors modifying NSS effect on renal function

Different factors related to the surgery itself or preexisting comorbidities play a major role in the impact of NSS on renal function. Surgical risk factors include ischemia time, the complexity of the tumor and the amount of renal tissue preserved.

Ischemia time

There is a significant deterioration of renal function with WIT > 40 min [129]. Other studies showed that WIT > 30 min is independently associated with long-term deterioration of renal function [130]. The median GFR saved in the operated kidney after PN is 80% [131]. The rate of recovery of renal function after a limited time (median < 27 min) cold ischemia or warm ischemia was 100 and 92% respectively [131]. Regardless of preexisting poor function, all kidneys recovered well after limited ischemia. In a meta-analysis of PN, factors that contributed to the preservation of renal function were the preoperative renal function, preservation of renal tissue and minimal WIT [132]. Although there was no strong evidence of a safe cutoff duration of WIT, it was suggested that it should be < 25 min.

An attempt to eliminate WIT may improve renal function after PN. To minimize renal ischemic injury during laparoscopic PN, an off-clamp (no ischemia) technique for tumors with a nephrometry score of 4 was utilized and compared to a warm ischemia group [133]. The off-clamp technique was associated with a significantly less change in postoperative eGFR but with a higher estimated blood loss. Shah et al., however, showed that off-clamp LPN was not associated with better renal function than with renal hilar clamping at long-term follow-up of 5 years [134]. The lack of advantage was evident for preexisting renal CKD. In one multicenter study, RPN was associated with less WIT and better renal functional recovery compared to LPN in matched cases [135].

Tumor factors

Renal cancer is an independent risk factor for deterioration of renal function after RN compared to nephrectomy in kidney donors [136]. Additional risk factors included increased age and decreased preoperative eGFR. Partial nephrectomy for more complex renal tumors as expressed by the RENAL nephrometry score is associated with significantly more deterioration of renal function at long-term postoperatively [137]. RN is associated with more change in eGFR for tumors with a RENAL score < 10 compared to PN [138]. The change was not significantly different in lesions > 10 RENAL score. Other reports found that preoperative prediction and RENAL scoring poorly correlated with postoperative measurement of volume preservation [139]. There was no significant difference in the drop of effective renal plasma flow between renal tumors of low or high complexity after RPN [140].

Renal tissue preservation

Several studies evaluated the impact of the amount of renal mass preserved, and the volume of tissue excised on renal function. Some of the studies attempted to isolate confounders as WIT, postoperative complications and the presence of a normal contralateral kidney from their analysis. Others looked at the preoperative assessment of potentially preserved renal tissue and how it may predict postoperative renal function.

Preserved renal tissue

Evaluating 660 patients after PN in a solitary kidney, Lane et al. reported that among the modifiable risk factors, the amount of preserved renal tissue was the most significant predictor for the long-term recovery of renal function [141]. Simmons et al. found that in patients after PN, the amount of functional renal parenchyma preserved independently correlated with the long-term eGFR [142, 143]. In a subsequent study, the authors concluded that within the confines of a WIT < 25 min, long-term recovery of renal function correlated with the amount of functional renal tissue preserved rather than the WIT [143]. The impact of WIT on renal function might be more evident in the short-term follow-up. GFR preservation at discharge was associated with WIT and not the percent functional parenchyma preservation [144]. At longer follow-up, however, preoperative eGFR and percent preservation of functional parenchyma became the significant factors associated with percent preservation of eGFR and not WIT. Both renal tissue mass preservation and ischemia time, however, play the most significant role affecting renal function. Isharwal et al. reported that recovery of renal function after PN was associated primarily with parenchymal mass preservation and ischemia time, whereas the presence of comorbidities did not contribute to functional outcomes [145].

Techniques that maximize renal tissue preservation may have a better impact on renal function preservation. Tumor enucleation using laparoscopic RFA and avoiding ischemia was associated with better renal function preservation and less degree of split GFR decline in comparison with laparoscopic PN [146]. Another study, however, did not reflect the beneficial effect of tumor enucleation on renal function. Blackwell et al. reported that although tumor enucleation correlated with preservation of renal parenchyma compared to standard PN, however, the impact on the preservation of renal function was not significant [147].

Image-based preoperative volumetric assessment of potentially spared renal tissue might predict postoperative functional renal volume [148] and eGFR [149]. Tanaka et al. using preoperative imaging measured percent parenchymal mass preserved after PN and found that it independently correlated with final global GFR though it had a lesser predictive accuracy compared to preoperative GFR [150]. Kuru et al. found that the preoperative assessment predicted early but not mid and long-term renal function [151].

Excised tissue volume

Dagenais et al. retrospectively reviewed 647 patients who underwent RPN at their institution and reported that excisional volume loss correlated with the decline of post-operative GFR, whereas ischemia time and tumor complexity did not [152]. Dong et al. looked at the relative impact of excised versus preserved tissue volume. The authors concluded that the renal mass preserved rather than the volume of tissue excised correlated with preservation of total and ipsilateral renal function [153]. The lesser impact of the excisional volume loss might be explained by its dependence on several modifiable and non-modifiable factors including, sex, tumor characteristics, surgeons experience, open approach and blood loss [154]. It is probably the amount of healthy tissue removed or damaged during PN rather than the tumor volume that determines renal function recovery. Zargar et al. calculated from the pathology specimens the amount of healthy rim of renal parenchyma removed during RPN and reported that it was predictive of ipsilateral renal function preservation as determined by renal scan [114]. In addition, normal tissue volume loss depended on the method of reconstruction during PN [155]. The percentage of resected and ischemic volume correlated with the percent decrease in postoperative eGFR [156]. The extent of the area traumatized by renorrhaphy during RPN predicted the postoperative ipsilateral split renal function [157]. Image-based preoperative estimation of resected and ischemic tissue volume may help predict postoperative renal function as it significantly correlated in one study with the postoperative decline in eGFR [158].

Pre-existing factors

Reported comorbid risk factors include preexisting renal function, age, DM, and cardiovascular disease. Preoperative eGFR is an independent factor of renal function recovery at long-term after LPN [159]. Warm ischemia time, however, affects only the early postoperative renal function recovery. Preoperative renal volume is an independent predictor of postoperative GFR for both PN and RN [160].

Older age is a significant determinant of long-term renal impairment after PN with cold ischemia [161]. Lane et al. showed that PN is associated with a decrease of early and ultimate eGFR that is associated with older age, solitary kidney, preoperative GFR, gender, tumor size and ischemia time [162]. Risk factors for the development of CKD after RN or PN for T1 renal tumors include older age, male gender, RN, preoperative creatinine level and hypertension [137]. Other studies showed that DM was a major risk factor. Renal function recovery after RN for renal tumors is negatively affected by DM, cardiovascular risk factors, older age and preexisting renal impairment [163] and the presence of preoperative glomerulosclerosis was negatively associated with post-PN eGFR at 6 months [164]. For the above reasons, surgeons need to offer NSS for patients with comorbid conditions. Filson et al. showed that patients with both diabetes and hypertension were more likely to receive NSS rather than RN for RCC [165]. Patients with either risk factor alone, however, were not preferentially treated with NSS.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Telenius-Berg M, Ponder MA, Berg B, Ponder BA, Werner S (1989) Quality of life after bilateral adrenalectomy in MEN 2. Henry Ford Hosp Med J 37:160–163
2. Asari R, Scheuba C, Kaczirek K, Niederle B (2006) Estimated risk of pheochromocytoma recurrence after adrenal-sparing surgery in patients with multiple endocrine neoplasia type 2A. Arch Surg 141:1199–1205. https://doi.org/10.1001/archsurg.141.12.1199 (**discussion 1205**)
3. van Heerden JA, Sizemore GW, Carney JA, Grant CS, ReMine WH, Sheps SG (1984) Surgical management of the adrenal glands in the multiple endocrine neoplasia type II syndrome. World J Surg 8:612–621
4. Sasagawa I, Suzuki Y, Itoh K, Izumi T, Miura M, Suzuki H, Tomita Y (2003) Posterior retroperitoneoscopic partial adrenalectomy: clinical experience in 47 procedures. Eur Urol 43:381–385
5. Iihara M, Suzuki R, Kawamata A, Omi Y, Kodama H, Igari Y, Yamazaki K, Obara T (2003) Adrenal-preserving laparoscopic surgery in selected patients with bilateral adrenal tumors. Surgery 134:1066–1072. https://doi.org/10.1016/j.surg.2003.07.027 (**discussion 1072–1073**)
6. Lee JE, Curley SA, Gagel RF, Evans DB, Hickey RC (1996) Cortical-sparing adrenalectomy for patients with bilateral pheochromocytoma. Surgery 120:1064–1070 (**discussion 1070–1071**)
7. Baghai M, Thompson GB, Young WFJ, Grant CS, Michels VV, van Heerden JA (2002) Pheochromocytomas and paragangliomas in von Hippel-Lindau disease: a role for laparoscopic and cortical-sparing surgery. Arch Surg 137:682–688 (**discussion 688–689**)
8. Liao C-H, Chung S-D, Lai M-K, Yu H-J, Chueh S-C (2009) Laparoscopic simultaneous bilateral partial and total adrenalectomy: a longer follow-up. BJU Int 104:1269–1273. https://doi.org/10.1111/j.1464-410X.2009.08523.x
9. Brauckhoff M, Gimm O, Thanh PN, Bar A, Ukkat J, Brauckhoff K, Bonsch T, Dralle H (2003) Critical size of residual adrenal tissue and recovery from impaired early postoperative adrenocortical function after subtotal bilateral adrenalectomy. Surgery 134:1020–1027. https://doi.org/10.1016/j.surg.2003.08.005 (**discussion 1027–1028**)
10. Brauckhoff M, Stock K, Stock S, Lorenz K, Sekulla C, Brauckhoff K, Thanh PN, Gimm O, Spielmann RP, Dralle H (2008) Limitations of intraoperative adrenal remnant volume measurement in patients undergoing subtotal adrenalectomy. World J Surg 32:863–872. https://doi.org/10.1007/s00268-007-9402-y
11. Walz MK (2009) Adrenalectomy for preservation of adrenocortical function. Indication and results. Chir Z Alle Geb Oper Medizen 80:99–104. https://doi.org/10.1007/s00104-008-1612-9
12. Angeli A, Osella G, Ali A, Terzolo M (1997) Adrenal incidentaloma: an overview of clinical and epidemiological data from the National Italian Study Group. Horm Res 47:279–283
13. Kaye DR, Storey BB, Pacak K, Pinto PA, Linehan WM, Bratslavsky G (2010) Partial adrenalectomy: underused first line therapy for small adrenal tumors. J Urol 184:18–25. https://doi.org/10.1016/j.juro.2010.03.052
14. Kok KYY, Yapp SKS (2002) Laparoscopic adrenal-sparing surgery for primary hyperaldosteronism due to aldosterone-producing adenoma. Surg Endosc 16:108–111. https://doi.org/10.1007/s00464-001-8127-5
15. Walther MM, Keiser HR, Linehan WM (1999) Pheochromocytoma: evaluation, diagnosis, and treatment. World J Urol 17:35–39
16. Walther MM, Reiter R, Keiser HR, Choyke PL, Venzon D, Hurley K, Gnarra JR, Reynolds JC, Glenn GM, Zbar B, Linehan WM (1999) Clinical and genetic characterization of pheochromocytoma in von Hippel-Lindau families: comparison with sporadic pheochromocytoma gives insight into natural history of pheochromocytoma. J Urol 162:659–664
17. Roukounakis N, Dimas S, Kafetzis I, Bethanis S, Gatsulis N, Kostas H, Kyriakou V, Michas S (2007) Is preservation of the

adrenal vein mandatory in laparoscopic adrenal-sparing surgery? J Soc Laparoendosc Surg 11:215–218
18. Blake MA, Kalra MK, Sweeney AT, Lucey BC, Maher MM, Sahani DV, Halpern EF, Mueller PR, Hahn PF, Boland GW (2006) Distinguishing benign from malignant adrenal masses: multi-detector row CT protocol with 10-minute delay. Radiology 238:578–585. https://doi.org/10.1148/radiol.2382041514
19. Sangwaiya MJ, Boland GWL, Cronin CG, Blake MA, Halpern EF, Hahn PF (2010) Incidental adrenal lesions: accuracy of characterization with contrast-enhanced washout multidetector CT—10-minute delayed imaging protocol revisited in a large patient cohort. Radiology 256:504–510. https://doi.org/10.1148/radiol.10091386
20. Dunnick NR, Heaston D, Halvorsen R, Moore AV, Korobkin M (1982) CT appearance of adrenal cortical carcinoma. J Comput Assist Tomogr 6:978–982
21. Fishman EK, Deutch BM, Hartman DS, Goldman SM, Zerhouni EA, Siegelman SS (1987) Primary adrenocortical carcinoma: CT evaluation with clinical correlation. AJR Am J Roentgenol 148:531–535. https://doi.org/10.2214/ajr.148.3.531
22. Hedican SP, Marshall FF (1997) Adrenocortical carcinoma with intracaval extension. J Urol 158:2056–2061
23. Imai T, Tanaka Y, Kikumori T, Ohiwa M, Matsuura N, Mase T, Funahashi H (1999) Laparoscopic partial adrenalectomy. Surg Endosc 13:343–345
24. Gupta GN, Benson JS, Ross MJ, Sundaram VS, Lin KY, Pinto PA, Linehan WM, Bratslavsky G (2014) Perioperative, functional, and oncologic outcomes of partial adrenalectomy for multiple ipsilateral pheochromocytomas. J Endourol 28:112–116. https://doi.org/10.1089/end.2013.0298
25. Manny TB, Pompeo AS, Hemal AK (2013) Robotic partial adrenalectomy using indocyanine green dye with near-infrared imaging: the initial clinical experience. Urology 82:738–742. https://doi.org/10.1016/j.urology.2013.03.074
26. Ethier MD, Beland MD, Mayo-Smith W (2013) Image-guided ablation of adrenal tumors. Tech Vasc Interv Radiol 16:262–268. https://doi.org/10.1053/j.tvir.2013.08.008
27. Yang R, Xu L, Lian H, Gan W, Guo H (2014) Retroperitoneoscopic-guided cool-tip radiofrequency ablation of adrenocortical aldosteronoma. J Endourol 28:1208–1214. https://doi.org/10.1089/end.2013.0635
28. Yip L, Lee JE, Shapiro SE, Waguespack SG, Sherman SI, Hoff AO, Gagel RF, Arens JF, Evans DB (2004) Surgical management of hereditary pheochromocytoma. J Am Coll Surg 198:525–534. https://doi.org/10.1016/j.jamcollsurg.2003.12.001 (**discussion 534–535**)
29. Hellenthal NJ, Mansour AM, Hayn MH, Schwaab T (2013) Is there a role for partial nephrectomy in patients with metastatic renal cell carcinoma? Urol Oncol 31:36–41. https://doi.org/10.1016/j.urolonc.2010.08.026
30. Autorino R, Porpiglia F, Dasgupta P, Rassweiler J, Catto JW, Hampton LJ, Lima E, Mirone V, Derweesh IH, Debruyne FMJ (2017) Precision surgery and genitourinary cancers. Eur J Surg Oncol 43:893–908. https://doi.org/10.1016/j.ejso.2017.02.005
31. Van Poppel H, Da Pozzo L, Albrecht W, Matveev V, Bono A, Borkowski A, Colombel M, Klotz L, Skinner E, Keane T, Marreaud S, Collette S, Sylvester R (2011) A prospective, randomised EORTC intergroup phase 3 study comparing the oncologic outcome of elective nephron-sparing surgery and radical nephrectomy for low-stage renal cell carcinoma. Eur Urol 59:543–552. https://doi.org/10.1016/j.eururo.2010.12.013
32. Small AC, Tsao C-K, Moshier EL, Gartrell BA, Wisnivesky JP, Godbold J, Sonpavde G, Palese MA, Hall SJ, Oh WK, Galsky MD (2013) Trends and variations in utilization of nephron-sparing procedures for stage I kidney cancer in the United States. World J Urol 31:1211–1217. https://doi.org/10.1007/s00345-012-0873-6
33. Fernando A, Fowler S, O'Brien T (2016) Nephron-sparing surgery across a nation—outcomes from the British Association of Urological Surgeons 2012 national partial nephrectomy audit. BJU Int 117:874–882. https://doi.org/10.1111/bju.13353
34. Pahernik S, Roos F, Hampel C, Gillitzer R, Melchior SW, Thuroff JW (2006) Nephron sparing surgery for renal cell carcinoma with normal contralateral kidney: 25 years of experience. J Urol 175:2027–2031. https://doi.org/10.1016/S0022-5347(06)00271-0
35. Zargar-Shoshtari K, Kim T, Simon R, Lin H-Y, Yue B, Sharma P, Spiess PE, Poch MA, Pow Sang J, Sexton WJ (2015) Surveillance following nephron-sparing surgery: an assessment of recurrence patterns and surveillance costs. Urology 86:321–326. https://doi.org/10.1016/j.urology.2015.05.013
36. Lai TC, Ma WK, Yiu MK (2016) Partial nephrectomy for T1 renal cancer can achieve an equivalent oncological outcome to radical nephrectomy with better renal preservation: the way to go. Hong Kong Med J 22:39–45. https://doi.org/10.12809/hkmj144482
37. Thompson RH, Siddiqui S, Lohse CM, Leibovich BC, Russo P, Blute ML (2009) Partial versus radical nephrectomy for 4 to 7 cm renal cortical tumors. J Urol 182:2601–2606. https://doi.org/10.1016/j.juro.2009.08.087
38. Milonas D, Skulcius G, Baltrimavicius R, Auskalnis S, Kincius M, Matjosaitis A, Gudinaviciene I, Smailyte G, Jievaltas M (2013) Comparison of long-term results after nephron-sparing surgery and radical nephrectomy in treating 4- to 7-cm renal cell carcinoma. Medicina 49:223–228
39. Meskawi M, Becker A, Bianchi M, Trinh Q-D, Roghmann F, Tian Z, Graefen M, Perrotte P, Karakiewicz PI, Sun M (2014) Partial and radical nephrectomy provide comparable long-term cancer control for T1b renal cell carcinoma. Int J Urol 21:122–128. https://doi.org/10.1111/iju.12204
40. Weight CJ, Larson BT, Fergany AF, Gao T, Lane BR, Campbell SC, Kaouk JH, Klein EA, Novick AC (2010) Nephrectomy induced chronic renal insufficiency is associated with increased risk of cardiovascular death and death from any cause in patients with localized cT1b renal masses. J Urol 183:1317–1323. https://doi.org/10.1016/j.juro.2009.12.030
41. Mir MC, Derweesh I, Porpiglia F, Zargar H, Mottrie A, Autorino R (2017) Partial nephrectomy versus radical nephrectomy for clinical T1b and T2 renal tumors: a systematic review and meta-analysis of comparative studies. Eur Urol 71:606–617. https://doi.org/10.1016/j.eururo.2016.08.060
42. Lopez-Costea MA, Bonet X, Perez-Reggeti J, Etcheverry B, Vigues F (2016) Oncological outcomes and prognostic factors after nephron-sparing surgery in renal cell carcinoma. Int Urol Nephrol 48:681–686. https://doi.org/10.1007/s11255-016-1217-z
43. Escudier B, Porta C, Schmidinger M, Algaba F, Patard JJ, Khoo V, Eisen T, Horwich A (2014) Renal cell carcinoma: ESMO Clinical Practice Guidelines for diagnosis, treatment and follow-up. Ann Oncol 25(Suppl 3):iii49–i56. https://doi.org/10.1093/annonc/mdu259
44. Ljungberg B, Bensalah K, Canfield S, Dabestani S, Hofmann F, Hora M, Kuczyk MA, Lam T, Marconi L, Merseburger AS, Mulders P, Powles T, Staehler M, Volpe A, Bex A (2015) EAU guidelines on renal cell carcinoma: 2014 update. Eur Urol 67:913–924. https://doi.org/10.1016/j.eururo.2015.01.005
45. Finelli A, Ismaila N, Bro B, Durack J, Eggener S, Evans A, Gill I, Graham D, Huang W, Jewett MAS, Latcha S, Lowrance W, Rosner M, Shayegan B, Thompson RH, Uzzo R, Russo P (2017) Management of small renal masses: American Society of Clinical Oncology clinical practice guideline. J Clin Oncol 35:668–680. https://doi.org/10.1200/JCO.2016.69.9645

46. Campbell S, Uzzo RG, Allaf ME, Bass EB, Cadeddu JA, Chang A, Clark PE, Davis BJ, Derweesh IH, Giambarresi L, Gervais DA, Hu SL, Lane BR, Leibovich BC, Pierorazio PM (2017) Renal mass and localized renal cancer: AUA guideline. J Urol 198:520–529. https://doi.org/10.1016/j.juro.2017.04.100
47. Cost NG, Sawicz-Birkowska K, Kajbafzadeh A-M, Tourchi A, Parigi GB, Guillen G, DeFoor WRJ, Apoznanski W (2014) A comparison of renal function outcomes after nephron-sparing surgery and radical nephrectomy for nonsyndromic unilateral Wilms tumor. Urology 83:1388–1393. https://doi.org/10.1016/j.urology.2014.01.051
48. Wilde JCH, Aronson DC, Sznajder B, Van Tinteren H, Powis M, Okoye B, Cecchetto G, Audry G, Fuchs J, Schweinitz DV, Heij H, Graf N, Bergeron C, Pritchard-Jones K, Van Den Heuvel-Eibrink M, Carli M, Oldenburger F, Sandstedt B, De Kraker J, Godzinski J (2014) Nephron sparing surgery (NSS) for unilateral wilms tumor (UWT): the SIOP 2001 experience. Pediatr Blood Cancer 61:2175–2179. https://doi.org/10.1002/pbc.25185
49. Gill IS, Kavoussi LR, Lane BR, Blute ML, Babineau D, Colombo JRJ, Frank I, Permpongkosol S, Weight CJ, Kaouk JH, Kattan MW, Novick AC (2007) Comparison of 1,800 laparoscopic and open partial nephrectomies for single renal tumors. J Urol 178:41–46. https://doi.org/10.1016/j.juro.2007.03.038
50. Marszalek M, Meixl H, Polajnar M, Rauchenwald M, Jeschke K, Madersbacher S (2009) Laparoscopic and open partial nephrectomy: a matched-pair comparison of 200 patients. Eur Urol 55:1171–1178. https://doi.org/10.1016/j.eururo.2009.01.042
51. Lane BR, Gill IS (2010) 7-year oncological outcomes after laparoscopic and open partial nephrectomy. J Urol 183:473–479. https://doi.org/10.1016/j.juro.2009.10.023
52. Shikanov S, Lifshitz D, Chan AA, Okhunov Z, Ordonez MA, Wheat JC, Matin SF, Landman J, Wolf JSJ, Eggener SE, Shalhav AL (2010) Impact of ischemia on renal function after laparoscopic partial nephrectomy: a multicenter study. J Urol 183:1714–1718. https://doi.org/10.1016/j.juro.2010.01.007
53. Adamy A, Favaretto RL, Nogueira L, Savage C, Russo P, Coleman J, Guillonneau B, Touijer K (2010) Recovery of renal function after open and laparoscopic partial nephrectomy. Eur Urol 58:596–601. https://doi.org/10.1016/j.eururo.2010.05.044
54. Springer C, Hoda MR, Fajkovic H, Pini G, Mohammed N, Fornara P, Greco F (2013) Laparoscopic vs open partial nephrectomy for T1 renal tumours: evaluation of long-term oncological and functional outcomes in 340 patients. BJU Int 111:281–288. https://doi.org/10.1111/j.1464-410X.2012.11280.x
55. Boris RS, Gupta GN, Benson JS, Linehan WM, Pinto PA, Bratslavsky G (2013) Feasibility and outcomes of laparoscopic renal intervention after prior open ipsilateral retroperitoneal surgery. J Endourol 27:196–201. https://doi.org/10.1089/end.2012.0483
56. Masson-Lecomte A, Bensalah K, Seringe E, Vaessen C, de la Taille A, Doumerc N, Rischmann P, Bruyere F, Soustelle L, Droupy S, Roupret M (2013) A prospective comparison of surgical and pathological outcomes obtained after robot-assisted or pure laparoscopic partial nephrectomy in moderate to complex renal tumours: results from a French multicentre collaborative study. BJU Int 111:256–263. https://doi.org/10.1111/j.1464-410X.2012.11528.x
57. Aboumarzouk OM, Stein RJ, Eyraud R, Haber G-P, Chlosta PL, Somani BK, Kaouk JH (2012) Robotic versus laparoscopic partial nephrectomy: a systematic review and meta-analysis. Eur Urol 62:1023–1033. https://doi.org/10.1016/j.eururo.2012.06.038
58. Hung AJ, Cai J, Simmons MN, Gill IS (2013) "Trifecta" in partial nephrectomy. J Urol 189:36–42. https://doi.org/10.1016/j.juro.2012.09.042
59. Long J-A, Yakoubi R, Lee B, Guillotreau J, Autorino R, Laydner H, Eyraud R, Stein RJ, Kaouk JH, Haber G-P (2012) Robotic versus laparoscopic partial nephrectomy for complex tumors: comparison of perioperative outcomes. Eur Urol 61:1257–1262. https://doi.org/10.1016/j.eururo.2012.03.012
60. Hankins RA, Walton-Diaz A, Truong H, Shih J, Bratslavsky G, Pinto PA, Linehan WM, Metwalli AR (2016) Renal functional outcomes after robotic multiplex partial nephrectomy: the National Cancer Institute experience with robotic partial nephrectomy for 3 or more tumors in a single kidney. Int Urol Nephrol 48:1817–1821. https://doi.org/10.1007/s11255-016-1392-y
61. Ng CK, Gill IS, Patil MB, Hung AJ, Berger AK, de Castro Abreu AL, Nakamoto M, Eisenberg MS, Ukimura O, Thangathurai D, Aron M, Desai MM (2012) Anatomic renal artery branch microdissection to facilitate zero-ischemia partial nephrectomy. Eur Urol 61:67–74. https://doi.org/10.1016/j.eururo.2011.08.040
62. Palacios DA, McDonald M, Miyake M, Rosser CJ (2013) Pilot study comparing the two hemostatic agents in patients undergoing partial nephrectomy. BMC Res Notes. https://doi.org/10.1186/1756-0500-6-399
63. Greco F, Cadeddu JA, Gill IS, Kaouk JH, Remzi M, Thompson RH, van Leeuwen FWB, van der Poel HG, Fornara P, Rassweiler J (2014) Current perspectives in the use of molecular imaging to target surgical treatments for genitourinary cancers. Eur Urol 65:947–964. https://doi.org/10.1016/j.eururo.2013.07.033
64. Minervini A, Serni S, Tuccio A, Siena G, Vittori G, Masieri L, Giancane S, Lanciotti M, Khorrami S, Lapini A, Carini M (2012) Simple enucleation versus radical nephrectomy in the treatment of pT1a and pT1b renal cell carcinoma. Ann Surg Oncol 19:694–700. https://doi.org/10.1245/s10434-011-2003-x
65. Serni S, Vittori G, Frizzi J, Mari A, Siena G, Lapini A, Carini M, Minervini A (2015) Simple enucleation for the treatment of highly complex renal tumors: perioperative, functional and oncological results. Eur J Surg Oncol 41:934–940. https://doi.org/10.1016/j.ejso.2015.02.019
66. Jewett MAS, Mattar K, Basiuk J, Morash CG, Pautler SE, Siemens DR, Tanguay S, Rendon RA, Gleave ME, Drachenberg DE, Chow R, Chung H, Chin JL, Fleshner NE, Evans AJ, Gallie BL, Haider MA, Kachura JR, Kurban G, Fernandes K, Finelli A (2011) Active surveillance of small renal masses: progression patterns of early stage kidney cancer. Eur Urol 60:39–44. https://doi.org/10.1016/j.eururo.2011.03.030
67. Zondervan PJ, Buijs M, De Bruin DM, van Delden OM, Van Lienden KP (2018) Available ablation energies to treat cT1 renal cell cancer: emerging technologies. World J Urol. https://doi.org/10.1007/s00345-018-2546-6
68. Prins FM, Kerkmeijer LGW, Pronk AA, Vonken E-JPA, Meijer RP, Bex A, Barendrecht MM (2017) Renal cell carcinoma: alternative nephron-sparing treatment options for small renal masses, a systematic review. J Endourol 31:963–975. https://doi.org/10.1089/end.2017.0382
69. Xing M, Kokabi N, Zhang D, Ludwig JM, Kim HS (2018) Comparative effectiveness of thermal ablation, surgical resection, and active surveillance for T1a renal cell carcinoma: a Surveillance, Epidemiology, and End Results (SEER)-medicare-linked population study. Radiology 288:81–90. https://doi.org/10.1148/radiol.2018171407
70. Psutka SP, Feldman AS, McDougal WS, McGovern FJ, Mueller P, Gervais DA (2013) Long-term oncologic outcomes after radiofrequency ablation for T1 renal cell carcinoma. Eur Urol 63:486–492. https://doi.org/10.1016/j.eururo.2012.08.062
71. Thorstenson A, Bergman M, Scherman-Plogell A-H, Hosseinnia S, Ljungberg B, Adolfsson J, Lundstam S (2014) Tumour characteristics and surgical treatment of renal cell carcinoma in Sweden. Scand J Urol 48:231–238. https://doi.org/10.3109/21681805.2013.864698

72. Krokidis ME, Kitrou P, Spiliopoulos S, Karnabatidis D, Katsanos K (2018) Image-guided minimally invasive treatment for small renal cell carcinoma. Insights Imaging 9:385–390. https://doi.org/10.1007/s13244-018-0607-4
73. Dabestani S, Thorstenson A, Lindblad P, Harmenberg U, Ljungberg B, Lundstam S (2016) Renal cell carcinoma recurrences and metastases in primary non-metastatic patients: a population-based study. World J Urol 34:1081–1086. https://doi.org/10.1007/s00345-016-1773-y
74. Dabestani S, Beisland C, Stewart GD, Bensalah K, Gudmundsson E, Lam TB, Gietzmann W, Zakikhani P, Marconi L, Fernandez-Pello S, Monagas S, Williams SP, Torbrand C, Powles T, Van Werkhoven E, Meijer R, Volpe A, Staehler M, Ljungberg B, Bex A (2018) Long-term outcomes of follow-up for initially localised clear cell renal cell carcinoma: RECUR database analysis. Eur Urol Focus. https://doi.org/10.1016/j.euf.2018.02.010
75. Zagoria RJ, Pettus JA, Rogers M, Werle DM, Childs D, Leyendecker JR (2011) Long-term outcomes after percutaneous radiofrequency ablation for renal cell carcinoma. Urology 77:1393–1397. https://doi.org/10.1016/j.urology.2010.12.077
76. Ma Y, Bedir S, Cadeddu JA, Gahan JC (2014) Long-term outcomes in healthy adults after radiofrequency ablation of T1a renal tumours. BJU Int 113:51–55. https://doi.org/10.1111/bju.12366
77. Wah TM, Irving HC, Gregory W, Cartledge J, Joyce AD, Selby PJ (2014) Radiofrequency ablation (RFA) of renal cell carcinoma (RCC): experience in 200 tumours. BJU Int 113:416–428. https://doi.org/10.1111/bju.12349
78. Su MZ, Memon F, Lau HM, Brooks AJ, Patel MI, Woo HH, Bariol SV, Vladica P (2016) Safety, efficacy and predictors of local recurrence after percutaneous radiofrequency ablation of biopsy-proven renal cell carcinoma. Int Urol Nephrol 48:1609–1616. https://doi.org/10.1007/s11255-016-1355-3
79. Zhang F, Chang X, Liu T, Wang W, Zhao X, Ji C, Yang R, Guo H (2016) Prognostic factors for long-term survival in patients with renal-cell carcinoma after radiofrequency ablation. J Endourol 30:37–42. https://doi.org/10.1089/end.2015.0454
80. Johnson B, Sorokin I, Cadeddu JA (2018) Ten-year outcomes of renal tumor radiofrequency ablation. J Urol. https://doi.org/10.1016/j.juro.2018.08.045
81. Talenfeld AD, Gennarelli RL, Elkin EB, Atoria CL, Durack JC, Huang WC, Kwan SW (2018) Percutaneous ablation versus partial and radical nephrectomy for T1a renal cancer: a population-based analysis. Ann Intern Med 169:69–77. https://doi.org/10.7326/M17-0585
82. Zhou M, Mills A, Noda C, Ramaswamy R, Akinwande O (2018) SEER study of ablation versus partial nephrectomy in cT1A renal cell carcinoma. Future Oncol 14:1711–1719. https://doi.org/10.2217/fon-2017-0678
83. Sung HH, Park BK, Kim CK, Choi HY, Lee HM (2012) Comparison of percutaneous radiofrequency ablation and open partial nephrectomy for the treatment of size- and location-matched renal masses. Int J Hyperth 28:227–234. https://doi.org/10.3109/02656736.2012.666319
84. Cooper CJ, Teleb M, Dwivedi A, Rangel G, Sanchez LA, Laks S, Akle N, Nahleh Z (2015) Comparative outcome of computed tomography-guided percutaneous radiofrequency ablation, partial nephrectomy or radical nephrectomy in the treatment of stage T1 renal cell carcinoma. Rare Tumors. https://doi.org/10.4081/rt.2015.5583
85. Olweny EO, Park SK, Tan YK, Best SL, Trimmer C, Cadeddu JA (2012) Radiofrequency ablation versus partial nephrectomy in patients with solitary clinical T1a renal cell carcinoma: comparable oncologic outcomes at a minimum of 5 years of follow-up. Eur Urol 61:1156–1161. https://doi.org/10.1016/j.eururo.2012.01.001
86. Takaki H, Soga N, Kanda H, Nakatsuka A, Uraki J, Fujimori M, Yamanaka T, Hasegawa T, Arima K, Sugimura Y, Sakuma H, Yamakado K (2014) Radiofrequency ablation versus radical nephrectomy: clinical outcomes for stage T1b renal cell carcinoma. Radiology 270:292–299. https://doi.org/10.1148/radiol.13130221
87. Liu N, Huang D, Cheng X, Chong Y, Wang W, Gan W, Guo H (2017) Percutaneous radiofrequency ablation for renal cell carcinoma vs. partial nephrectomy: comparison of long-term oncologic outcomes in both clear cell and non-clear cell of the most common subtype. Urol Oncol 35:530.e1–530.e6. https://doi.org/10.1016/j.urolonc.2017.03.014
88. Park BK, Gong IH, Kang MY, Sung HH, Jeon HG, Jeong BC, Jeon SS, Lee HM, Seo SI (2018) RFA versus robotic partial nephrectomy for T1a renal cell carcinoma: a propensity score-matched comparison of mid-term outcome. Eur Radiol 28:2979–2985. https://doi.org/10.1007/s00330-018-5305-6
89. Zhou W, Uppot RN, Feldman AS, Arellano RS (2017) Percutaneous image-guided thermal ablation for multifocal renal cell carcinoma. AJR Am J Roentgenol 209:733–739. https://doi.org/10.2214/AJR.17.18290
90. Camacho JC, Kokabi N, Xing M, Master VA, Pattaras JG, Mittal PK, Kim HS (2015) RENAL (radius, exophytic/endophytic, nearness to collecting system or sinus, anterior/posterior, and location relative to polar lines) nephrometry score predicts early tumor recurrence and complications after percutaneous ablative therapies for renal cell carcinoma: a 5-year experience. J Vasc Interv Radiol 26:686–693. https://doi.org/10.1016/j.jvir.2015.01.008
91. Seklehner S, Fellner H, Engelhardt PF, Schabauer C, Riedl C (2013) Percutaneous radiofrequency ablation of renal tumors: a single-center experience. Korean J Urol 54:580–586. https://doi.org/10.4111/kju.2013.54.9.580
92. Takaki H, Nakatsuka A, Uraki J, Yamanaka T, Fujimori M, Hasegawa T, Arima K, Sugimura Y, Yamakado K (2013) Renal cell carcinoma: radiofrequency ablation with a multiple-electrode switching system—a phase II clinical study. Radiology 267:285–292. https://doi.org/10.1148/radiol.12121070
93. Pantelidou M, Challacombe B, McGrath A, Brown M, Ilyas S, Katsanos K, Adam A (2016) Percutaneous radiofrequency ablation versus robotic-assisted partial nephrectomy for the treatment of small renal cell carcinoma. Cardiovasc Interv Radiol 39:1595–1603. https://doi.org/10.1007/s00270-016-1417-z
94. Davol PE, Fulmer BR, Rukstalis DB (2006) Long-term results of cryoablation for renal cancer and complex renal masses. Urology 68:2–6. https://doi.org/10.1016/j.urology.2006.03.066
95. Caputo PA, Ramirez D, Zargar H, Akca O, Andrade HS, O'Malley C, Remer EM, Kaouk JH (2015) Laparoscopic cryoablation for renal cell carcinoma: 100-month oncologic outcomes. J Urol 194(4):892–896. https://doi.org/10.1016/j.juro.2015.03.128
96. Nielsen TK, Lagerveld BW, Keeley F, Lughezzani G, Sriprasad S, Barber NJ, Hansen LU, Buffi NM, Guazzoni G, van der Zee JA, Ismail M, Farrag K, Emara AM, Lund L, Ostraat O, Borre M (2017) Oncological outcomes and complication rates after laparoscopic-assisted cryoablation: a European Registry for Renal Cryoablation (EuRECA) multi-institutional study. BJU Int 119:390–395. https://doi.org/10.1111/bju.13615
97. Breen DJ, King AJ, Patel N, Lockyer R, Hayes M (2018) Image-guided cryoablation for sporadic renal cell carcinoma: three- and 5-year outcomes in 220 patients with biopsy-proven renal cell carcinoma. Radiology 289:554–561. https://doi.org/10.1148/radiol.2018180249
98. Haddad MM, Schmit GD, Kurup AN, Schmitz JJ, Boorjian SA, Geske J, Thompson RH, Callstrom MR, Atwell TD (2018) Percutaneous cryoablation of solitary, sporadic renal cell carcinoma: outcome analysis based on clear-cell versus papillary subtypes.

J Vasc Interv Radiol 29:1122–1126. https://doi.org/10.1016/j.jvir.2018.02.029

99. Pessoa RR, Autorino R, Laguna MP, Molina WR, Gustafson D, Nogueira L, da Silva RD, Werahera PN, Kim FJ (2017) Laparoscopic versus percutaneous cryoablation of small renal mass: systematic review and cumulative analysis of comparative studies. Clin Genitourin Cancer 15:513–519. https://doi.org/10.1016/j.clgc.2017.02.003
100. Zargar H, Samarasekera D, Khalifeh A, Remer EM, O'Malley C, Akca O, Autorino R, Kaouk JH (2015) Laparoscopic vs percutaneous cryoablation for the small renal mass: 15-year experience at a single center. Urology 85:850–855. https://doi.org/10.1016/j.urology.2015.01.004
101. Faba OR, Sanguedolce F, Grange P, Kooiman G, Bakavicius A, De la Torre P, Palou J (2016) Kidney cancer focal cryoablation trend: does location or approach matter? World J Urol 34:917–923. https://doi.org/10.1007/s00345-015-1716-z
102. Caputo PA, Zargar H, Ramirez D, Andrade HS, Akca O, Gao T, Kaouk JH (2017) Cryoablation versus partial nephrectomy for clinical T1b renal tumors: a matched group comparative analysis. Eur Urol 71:111–117. https://doi.org/10.1016/j.eururo.2016.08.039
103. Hasegawa T, Yamanaka T, Gobara H, Miyazaki M, Takaki H, Sato Y, Inaba Y, Yamakado K (2018) Radiofrequency ablation versus cryoablation for T1b renal cell carcinoma: a multi-center study. Jpn J Radiol 36:551–558. https://doi.org/10.1007/s11604-018-0756-x
104. Zhou W, Arellano RS (2018) Thermal ablation of T1c renal cell carcinoma: a comparative assessment of technical performance, procedural outcome, and safety of microwave ablation, radiofrequency ablation, and cryoablation. J Vasc Interv Radiol 29:943–951. https://doi.org/10.1016/j.jvir.2017.12.020
105. Guan W, Bai J, Liu J, Wang S, Zhuang Q, Ye Z, Hu Z (2012) Microwave ablation versus partial nephrectomy for small renal tumors: intermediate-term results. J Surg Oncol 106:316–321. https://doi.org/10.1002/jso.23071
106. Siva S, Louie AV, Warner A, Muacevic A, Gandhidasan S, Ponsky L, Ellis R, Kaplan I, Mahadevan A, Chu W, Swaminath A, Onishi H, Teh B, Correa RJ, Lo SS, Staehler M (2018) Pooled analysis of stereotactic ablative radiotherapy for primary renal cell carcinoma: a report from the International Radiosurgery Oncology Consortium for Kidney (IROCK). Cancer 124:934–942. https://doi.org/10.1002/cncr.31156
107. Zabor EC, Furberg H, Lee B, Campbell S, Lane BR, Thompson RH, Antonio EC, Noyes SL, Zaid H, Jaimes EA, Russo P (2017) Long-term renal functional recovery following radical nephrectomy for kidney cancer: results from a multi-center confirmatory study. J Urol. https://doi.org/10.1016/j.juro.2017.10.027
108. Zabor EC, Furberg H, Mashni J, Lee B, Jaimes EA, Russo P (2016) Factors associated with recovery of renal function following radical nephrectomy for kidney neoplasms. Clin J Am Soc Nephrol 11:101–107. https://doi.org/10.2215/CJN.04070415
109. Kawamura N, Yokoyama M, Fujii Y, Ishioka J, Numao N, Matsuoka Y, Saito K, Arisawa C, Okuno T, Noro A, Morimoto S, Kihara K (2016) Recovery of renal function after radical nephrectomy and risk factors for postoperative severe renal impairment: a Japanese multicenter longitudinal study. Int J Urol 23:219–223. https://doi.org/10.1111/iju.13028
110. Berczi C, Thomas B, Bacso Z, Flasko T (2016) Long-term oncological and functional outcomes of partial nephrectomy in solitary kidneys. Clin Genitourin Cancer 14:e275–e281. https://doi.org/10.1016/j.clgc.2015.11.014
111. Costabel JI, Marchinena PG, Tirapegui F, Dantur A, Jurado A, Gueglio G (2016) Functional and oncologic outcomes after nephron-sparing surgery in a solitary kidney: 10 years of experience. Int Braz J Urol 42:253–261
112. Pahernik S, Roos F, Wiesner C, Thuroff JW (2007) Nephron sparing surgery for renal cell carcinoma in a solitary kidney. World J Urol 25:513–517. https://doi.org/10.1007/s00345-007-0207-2
113. Ghoneim TP, Sjoberg DD, Lowrance W, Shariat SF, Savage C, Bernstein M, Russo P (2015) Partial nephrectomy for renal tumors in solitary kidneys: postoperative renal function dynamics. World J Urol 33:2023–2029. https://doi.org/10.1007/s00345-015-1581-9
114. Zargar H, Akca O, Autorino R, Brandao LF, Laydner H, Krishnan J, Samarasekera D, Stein RJ, Kaouk JH (2015) Ipsilateral renal function preservation after robot-assisted partial nephrectomy (RAPN): an objective analysis using mercapto-acetyltriglycine (MAG3) renal scan data and volumetric assessment. BJU Int 115:787–795. https://doi.org/10.1111/bju.12825
115. Kutikov A, Egleston BL, Canter D, Smaldone MC, Wong Y-N, Uzzo RG (2012) Competing risks of death in patients with localized renal cell carcinoma: a comorbidity based model. J Urol 188:2077–2083. https://doi.org/10.1016/j.juro.2012.07.100
116. Sun M, Trinh Q-D, Bianchi M, Hansen J, Hanna N, Abdollah F, Shariat SF, Briganti A, Montorsi F, Perrotte P, Karakiewicz PI (2012) A non-cancer-related survival benefit is associated with partial nephrectomy. Eur Urol 61:725–731. https://doi.org/10.1016/j.eururo.2011.11.047
117. Scosyrev E, Messing EM, Sylvester R, Campbell S, Van Poppel H (2014) Renal function after nephron-sparing surgery versus radical nephrectomy: results from EORTC randomized trial 30904. Eur Urol 65:372–377. https://doi.org/10.1016/j.eururo.2013.06.044
118. Ibrahim HN, Foley R, Tan L, Rogers T, Bailey RF, Guo H, Gross CR, Matas AJ (2009) Long-term consequences of kidney donation. N Engl J Med 360:459–469. https://doi.org/10.1056/NEJMoa0804883
119. Danzig MR, Ghandour RA, Chang P, Wagner AA, Pierorazio PM, Allaf ME, McKiernan JM (2015) Active surveillance is superior to radical nephrectomy and equivalent to partial nephrectomy for preserving renal function in patients with small renal masses: results from the DISSRM registry. J Urol 194:903–909. https://doi.org/10.1016/j.juro.2015.03.093
120. Lane BR, Fergany AF, Weight CJ, Campbell SC (2010) Renal functional outcomes after partial nephrectomy with extended ischemic intervals are better than after radical nephrectomy. J Urol 184:1286–1290. https://doi.org/10.1016/j.juro.2010.06.011
121. Mason R, Kapoor A, Liu Z, Saarela O, Tanguay S, Jewett M, Finelli A, Lacombe L, Kawakami J, Moore R, Morash C, Black P, Rendon RA (2016) The natural history of renal function after surgical management of renal cell carcinoma: results from the Canadian Kidney Cancer Information System. Urol Oncol. https://doi.org/10.1016/j.urolonc.2016.05.025
122. Roos FC, Brenner W, Thomas C, Jager W, Thuroff JW, Hampel C, Jones J (2012) Functional analysis of elective nephron-sparing surgery vs radical nephrectomy for renal tumors larger than 4 cm. Urology 79:607–613. https://doi.org/10.1016/j.urology.2011.10.073
123. Satasivam P, Reeves F, Rao K, Ivey Z, Basto M, Yip M, Roth H, Grummet J, Goad J, Moon D, Murphy D, Appu S, Lawrentschuk N, Bolton D, Kearsley J, Costello A, Frydenberg M (2015) Patients with medical risk factors for chronic kidney disease are at increased risk of renal impairment despite the use of nephron-sparing surgery. BJU Int 116:590–595. https://doi.org/10.1111/bju.13075
124. Sorbellini M, Kattan MW, Snyder ME, Hakimi AA, Sarasohn DM, Russo P (2006) Prognostic nomogram for renal insufficiency after radical or partial nephrectomy. J Urol 176:472–476. https://doi.org/10.1016/j.juro.2006.03.090 (**discussion 476**)
125. Barlow LJ, Korets R, Laudano M, Benson M, McKiernan J (2010) Predicting renal functional outcomes after surgery

for renal cortical tumours: a multifactorial analysis. BJU Int 106:489–492. https://doi.org/10.1111/j.1464-410X.2009.09147.x
126. Capitanio U, Terrone C, Antonelli A, Minervini A, Volpe A, Furlan M, Matloob R, Regis F, Fiori C, Porpiglia F, Di Trapani E, Zacchero M, Serni S, Salonia A, Carini M, Simeone C, Montorsi F, Bertini R (2015) Nephron-sparing techniques independently decrease the risk of cardiovascular events relative to radical nephrectomy in patients with a T1a-T1b renal mass and normal preoperative renal function. Eur Urol 67:683–689. https://doi.org/10.1016/j.eururo.2014.09.027
127. Ljungberg B, Hedin O, Lundstam S, Warnolf A, Forsberg AM, Hjelle KM, Stief CG, Borlinghaus C, Beisland C, Staehler M (2016) Nephron sparing surgery associated with better survival than radical nephrectomy in patients treated for unforeseen benign renal tumors. Urology 93:117–123. https://doi.org/10.1016/j.urology.2016.01.037
128. Jang HA, Kim JW, Byun SS, Hong SH, Kim YJ, Park YH, Yang KS, Cho S, Cheon J, Kang SH (2016) oncologic and functional outcomes after partial nephrectomy versus radical nephrectomy in T1b renal cell carcinoma: a multicenter, matched case-control study in Korean patients. Cancer Res Treat 48:612–620. https://doi.org/10.4143/crt.2014.122
129. Godoy G, Ramanathan V, Kanofsky JA, O'Malley RL, Tareen BU, Taneja SS, Stifelman MD (2009) Effect of warm ischemia time during laparoscopic partial nephrectomy on early postoperative glomerular filtration rate. J Urol 181:2438–2443. https://doi.org/10.1016/j.juro.2009.02.026 (**discussion 2443–2445**)
130. Zargar H, Akca O, Ramirez D, Brandao LF, Laydner H, Krishnan J, Stein RJ, Kaouk JH (2015) The impact of extended warm ischemia time on late renal function after robotic partial nephrectomy. J Endourol 29:444–448. https://doi.org/10.1089/end.2014.0557
131. Mir MC, Takagi T, Campbell RA, Sharma N, Remer EM, Li J, Demirjian S, Stein R, Kaouk J, Campbell SC (2014) Poorly functioning kidneys recover from ischemia after partial nephrectomy as well as strongly functioning kidneys. J Urol 192:665–670. https://doi.org/10.1016/j.juro.2014.03.036
132. Volpe A, Blute ML, Ficarra V, Gill IS, Kutikov A, Porpiglia F, Rogers C, Touijer KA, Van Poppel H, Thompson RH (2015) Renal ischemia and function after partial nephrectomy: a collaborative review of the literature. Eur Urol 68:61–74. https://doi.org/10.1016/j.eururo.2015.01.025
133. Wang H-K, Qin X-J, Ma C-G, Shi G-H, Zhang H-L, Ye D-W (2016) Nephrometry score-guided off-clamp laparoscopic partial nephrectomy: patient selection and short-time functional results. World J Surg Oncol. https://doi.org/10.1186/s12957-016-0914-5
134. Shah PH, George AK, Moreira DM, Alom M, Okhunov Z, Salami S, Waingankar N, Schwartz MJ, Vira MA, Richstone L, Kavoussi LR (2016) To clamp or not to clamp? Long-term functional outcomes for elective off-clamp laparoscopic partial nephrectomy. BJU Int 117:293–299. https://doi.org/10.1111/bju.13309
135. Kim JH, Park YH, Kim YJ, Kang SH, Byun SS, Kwak C, Hong SH (2015) Perioperative and long-term renal functional outcomes of robotic versus laparoscopic partial nephrectomy: a multicenter matched-pair comparison. World J Urol 33:1579–1584. https://doi.org/10.1007/s00345-015-1488-5
136. Lee SH, Kim DS, Cho S, Kim SJ, Kang SH, Park J, Park SY, Chang S-G, Jeon SH (2015) Comparison of postoperative estimated glomerular filtration rate between kidney donors and radical nephrectomy patients, and risk factors for postoperative chronic kidney disease. Int J Urol 22:674–678. https://doi.org/10.1111/iju.12784
137. Kim SH, Lee SE, Hong SK, Jeong CW, Park YH, Kim Y-J, Kang SH, Hong S-H, Choi WS, Byun S-S (2013) Incidence and risk factors of chronic kidney disease in korean patients with t1a renal cell carcinoma before and after radical or partial nephrectomy. Jpn J Clin Oncol 43:1243–1248. https://doi.org/10.1093/jjco/hyt149
138. Kopp RP, Liss MA, Mehrazin R, Wang S, Lee HJ, Jabaji R, Mirheydar HS, Gillis K, Patel N, Palazzi KL, Wan JY, Patterson AL, Derweesh IH (2015) Analysis of renal functional outcomes after radical or partial nephrectomy for renal masses ≥ 7 cm using the RENAL score. Urology 86:312–319. https://doi.org/10.1016/j.urology.2015.02.067
139. Zhao J, Zhang Z, Dong W, Remer EM, Li J, Ericson K, Patel T, Almassi N, Hinck B, Zabell J, Tourojman M, Lane BR, Campbell SC (2016) Preoperative prediction and postoperative surgeon assessment of volume preservation associated with partial nephrectomy: comparison with measured volume preservation. Urology 93:124–129. https://doi.org/10.1016/j.urology.2016.02.055
140. Tanaka K, Furukawa J, Shigemura K, Hinata N, Ishimura T, Muramaki M, Miyake H, Fujisawa M (2015) Surgery-related outcomes and postoperative split renal function by scintigraphy evaluation in robot-assisted partial nephrectomy in complex renal tumors: an initial case series. J Endourol 29:29–34. https://doi.org/10.1089/end.2014.0042
141. Lane BR, Russo P, Uzzo RG, Hernandez AV, Boorjian SA, Thompson RH, Fergany AF, Love TE, Campbell SC (2011) Comparison of cold and warm ischemia during partial nephrectomy in 660 solitary kidneys reveals predominant role of nonmodifiable factors in determining ultimate renal function. J Urol 185:421–427. https://doi.org/10.1016/j.juro.2010.09.131
142. Simmons MN, Fergany AF, Campbell SC (2011) Effect of parenchymal volume preservation on kidney function after partial nephrectomy. J Urol 186:405–410. https://doi.org/10.1016/j.juro.2011.03.154
143. Simmons MN, Hillyer SP, Lee BH, Fergany AF, Kaouk J, Campbell SC (2012) Functional recovery after partial nephrectomy: effects of volume loss and ischemic injury. J Urol 187:1667–1673. https://doi.org/10.1016/j.juro.2011.12.068
144. Ginzburg S, Uzzo R, Walton J, Miller C, Kurz D, Li T, Handorf E, Gor R, Corcoran A, Viterbo R, Chen DYT, Greenberg RE, Smaldone MC, Kutikov A (2015) Residual parenchymal volume, not warm ischemia time, predicts ultimate renal functional outcomes in patients undergoing partial nephrectomy. Urology 86:300–305. https://doi.org/10.1016/j.urology.2015.04.043
145. Isharwal S, Ye W, Wang A, Abraham J, Zabell J, Dong W, Wu J, Suk-Ouichai C, Caraballo ER, Gao T, Campbell SC (2018) Impact of comorbidities on functional recovery from partial nephrectomy. J Urol 199:1433–1439. https://doi.org/10.1016/j.juro.2017.12.004
146. Zhu L, Wu G, Huang J, Wang J, Zhang R, Kong W, Xue W, Huang Y, Chen Y, Zhang J (2017) Comparing renal function preservation after laparoscopic radio frequency ablation assisted tumor enucleation and laparoscopic partial nephrectomy for clinical T1a renal tumor: using a 3D parenchyma measurement system. J Cancer Res Clin Oncol 143:905–912. https://doi.org/10.1007/s00432-017-2342-5
147. Blackwell RH, Li B, Kozel Z, Zhang Z, Zhao J, Dong W, Capodice SE, Barton G, Shah A, Wetterlin JJ, Quek ML, Campbell SC, Gupta GN (2017) Functional implications of renal tumor enucleation relative to standard partial nephrectomy. Urology 99:162–168. https://doi.org/10.1016/j.urology.2016.07.048
148. Mibu H, Tanaka N, Hosokawa Y, Kumamoto H, Margami N, Hirao Y, Fujimoto K (2015) Estimated functional renal parenchymal volume predicts the split renal function following renal surgery. World J Urol 33:1571–1577. https://doi.org/10.1007/s00345-014-1470-7
149. Liss MA, DeConde R, Caovan D, Hofler J, Gabe M, Palazzi KL, Patel ND, Lee HJ, Ideker T, Van Poppel H, Karow D, Aertsen M,

Casola G, Derweesh IH (2016) Parenchymal volumetric assessment as a predictive tool to determine renal function benefit of nephron-sparing surgery compared with radical nephrectomy. J Endourol 30:114–121. https://doi.org/10.1089/end.2015.0411
150. Tanaka H, Wang Y, Suk-Ouichai C, Palacios DA, Caraballo ER, Ye Y, Remer EM, Li J, Abouassaly R, Campbell SC (2018) Can we predict functional outcomes after partial nephrectomy? J Urol. https://doi.org/10.1016/j.juro.2018.09.055
151. Kuru TH, Zhu J, Popeneciu IV, Rudhardt NS, Hadaschik BA, Teber D, Roethke M, Hohenfellner M, Zeier M, Pahernik SA (2014) Volumetry may predict early renal function after nephron sparing surgery in solitary kidney patients. SpringerPlus. https://doi.org/10.1186/2193-1801-3-488
152. Dagenais J, Maurice MJ, Mouracade P, Kara O, Malkoc E, Kaouk JH (2017) Excisional precision matters: understanding the influence of excisional volume loss on renal function after partial nephrectomy. Eur Urol 72:168–170. https://doi.org/10.1016/j.eururo.2017.02.004
153. Dong W, Zhang Z, Zhao J, Wu J, Suk-Ouichai C, Aguilar Palacios D, Caraballo Antonio E, Babbar S, Remer EM, Li J, Isharwal S, Zabell J, Campbell SC (2017) Excised parenchymal mass during partial nephrectomy: functional implications. Urology 103:129–135. https://doi.org/10.1016/j.urology.2016.12.021
154. Maurice MJ, Ramirez D, Malkoc E, Kara O, Nelson RJ, Caputo PA, Kaouk JH (2016) Predictors of excisional volume loss in partial nephrectomy: is there still room for improvement? Eur Urol 70:413–415. https://doi.org/10.1016/j.eururo.2016.05.007
155. Bahler CD, Cary KC, Garg S, DeRoo EM, Tabib CH, Kansal JK, Monn MF, Flack CK, Masterson TA, Sandrasegaran MK, Foster RS, Sundaram CP (2015) Differentiating reconstructive techniques in partial nephrectomy: a propensity score analysis. Can J Urol 22:7788–7796
156. Huang W-H, Chang C-H, Huang C-P, Wu H-C, Hsieh I P-F (2017) The percentage of resected and ischemic volume determined by a geometric model is a significant predictor of renal functional change after partial nephrectomy. Int Braz J Urol 43:80–86. https://doi.org/10.1590/S1677-5538.IBJU.2015.0423
157. Masago T, Yamaguchi N, Iwamoto H, Morizane S, Hikita K, Honda M, Sejima T, Takenaka A (2018) The significance of predictable traumatic area by renorrhaphy in the prediction of postoperative ipsilateral renal function. Cent Eur J Urol 71:64–71. https://doi.org/10.5173/ceju.2018.1557
158. Rha KH, Abdel Raheem A, Park SY, Kim KH, Kim HJ, Koo KC, Choi YD, Jung BH, Lee SK, Lee WK, Krishnan J, Shin TY, Cho J-S (2017) Impact of preoperative calculation of nephron volume loss on future of partial nephrectomy techniques; planning a strategic roadmap for improving functional preservation and securing oncological safety. BJU Int 120:682–688. https://doi.org/10.1111/bju.13937
159. Erdem S, Boyuk A, Tefik T, Yucel B, Naghiyev R, Ozsoy M, Verep S, Sanli O (2015) Warm ischemia-related postoperative renal dysfunction in elective laparoscopic partial nephrectomy recovers during intermediate-term follow-up. J Endourol 29:1083–1090. https://doi.org/10.1089/end.2015.0146
160. Jeon HG, Gong IH, Hwang JH, Choi DK, Lee SR, Park DS (2012) Prognostic significance of preoperative kidney volume for predicting renal function in renal cell carcinoma patients receiving a radical or partial nephrectomy. BJU Int 109:1468–1473. https://doi.org/10.1111/j.1464-410X.2011.10531.x
161. Yossepowitch O, Eggener SE, Serio A, Huang WC, Snyder ME, Vickers AJ, Russo P (2006) Temporary renal ischemia during nephron sparing surgery is associated with short-term but not long-term impairment in renal function. J Urol 176:1339–1343. https://doi.org/10.1016/j.juro.2006.06.046 (**discussion 1343**)
162. Lane BR, Babineau DC, Poggio ED, Weight CJ, Larson BT, Gill IS, Novick AC (2008) Factors predicting renal functional outcome after partial nephrectomy. J Urol 180:2363–2368. https://doi.org/10.1016/j.juro.2008.08.036 (**discussion 2368–2369**)
163. Chung JS, Son NH, Byun S-S, Lee SE, Hong SK, Jeong CW, Lee SC, Chae D-W, Choi WS, Park YH, Hong SH, Kim YJ, Kang SH (2014) Trends in renal function after radical nephrectomy: a multicentre analysis. BJU Int 113:408–415. https://doi.org/10.1111/bju.12277
164. Bazzi WM, Chen LY, Cordon BH, Mashni J, Sjoberg DD, Bernstein M, Russo P (2015) Non-neoplastic parenchymal changes in kidney cancer and post-partial nephrectomy recovery of renal function. Int Urol Nephrol 47:1499–1502. https://doi.org/10.1007/s11255-015-1066-1
165. Filson CP, Schwartz K, Colt JS, Ruterbusch J, Linehan WM, Chow W-H, Miller DC (2014) Use of nephron-sparing surgery among renal cell carcinoma patients with diabetes and hypertension. Urol Oncol 32:27.e15–27.e21. https://doi.org/10.1016/j.urolonc.2012.09.014