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UROLOGY - REVIEW

Open partial nephrectomy: ancient art or currently available technique?

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Abstract Renal cell carcinoma (RCC) accounts for 3 % of adult solid tumors, with the highest incidence between 50 and 70 years of age. Nephron-sparing surgery was initially reserved to patients with small renal masses detected in anatomically or functionally solitary kidney or in the presence of multiple bilateral tumors or hereditary forms of RCC, which posed a high risk of developing a tumor in the contralateral kidney. Nowadays, partial nephrectomy (PN) has grown up to an established approach for the treatment of small renal masses. In patients with T1a-staged RCCs, PN has proven to be associated with better survival, long-term renal function preservation with lower dialysis need or renal transplantation. Currently, most of the kidney masses are incidentally detected, up to 40 %, with smaller size due to the widespread use of imaging modalities such as ultrasound, computed tomography and magnetic resonance. Here we review the role of open PN in the management of small renal masses particularly focusing on indications, oncological outcomes and comparison with laparoscopic and robotic PN. Recent studies demonstrate that PN confers better survival, oncologic equivalence and lower risk of severe chronic kidney disease compared to radical nephrectomy becoming then the gold-standard surgical technique, even if increasingly challenged by laparoscopic and/or robot-assisted partial nephrectomy which in the hands of experts seems to achieve comparable outcome results albeit with slightly higher complication rate.

Keywords Partial nephrectomy · Renal cell carcinoma · Surgery · Laparoscopy

Introduction

Renal cell carcinoma (RCC) accounts for 3 % of adult solid tumors, with the highest incidence between 50 and 70 years of age [1]. Almost 20,000 renal cancer patients are estimated yearly in the European Union. A paradigm shift in the diagnosis and management of renal masses has transpired over the last decade, with an increased incidence of small renal masses and a trend toward tumor downgrade at diagnosis [2]. Currently, most of the kidney masses are incidentally detected, up to 40 %, with smaller size due to the widespread use of imaging modalities such as ultrasound, computed tomography and magnetic resonance. This accounts for RCC incidence increase worldwide at an earlier stage, which can be successfully cured by surgery [3, 4]. Historically, radical nephrectomy has been the gold-standard surgical treatment [5]. The management of small-localized renal tumors has evolved substantially over time, with an increasing emphasis on renal preservation and function. Several studies have in the meanwhile demonstrated oncological equivalence of partial nephrectomy compared with radical nephrectomy for stage I lesions [6]. Although 5-year cancer-specific survival is >90 % regardless of surgical approach, evidence favoring partial nephrectomy over radical nephrectomy due to the less-invasive surgery clearly emerged with parallel lower incidence of postoperative

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chronic kidney disease (CKD) and associated adverse cardiovascular outcomes reduction [7, 8].

Partial nephrectomy has, therefore, become the preferred nephron-sparing surgery (NSS) in elective settings, and it is now offered to patients with unilateral small renal masses and normal contralateral kidney function. Therefore, the National Comprehensive Network and European Association of Urology updated current guidelines recommending partial nephrectomy in the above-mentioned setting when technically feasible.

Nephron-sparing surgery was initially reserved to patients with small renal masses detected in anatomically or functionally solitary kidney or in the presence of multiple bilateral tumors or hereditary forms of RCC, which posed a high risk of developing a tumor in the contralateral kidney [9]. Nowadays, partial nephrectomy has grown up to an established approach for the treatment of small renal masses (<4 cm). In fact, in patients with T1a-staged RCCs, PN has proven to be associated with better survival, long-term renal function preservation with lower dialysis need or renal transplantation [10]. As a result, PN is increasingly being advocated for treating larger, T1b RCCs, in particular if the tumor's shape and location allows a sizeable segment of kidney preservation with the appealing surgical option of a shorter hospital stay and a better cosmetic outcome in the presence of similar oncologic results [11, 12]. With the parallel rapid evolution of laparoscopic techniques, open PN is increasingly being challenged by laparoscopic partial nephrectomy due to a documented lower overall morbidity at comparable oncological outcome [13]. PN has then increased over the past decade accounting for 24.7 % of all surgeries performed for the treatment of organ-confined renal masses in 2008 [14]. The introduction of robotic technology has continued to alter the landscape accounting for 47 % of all partial nephrectomies at academic US centers in 2011, though a center bias and publication bias likely exist [15]. The learning curve for robotic-assisted laparoscopic nephrectomy has been shorter with respect to laparoscopic partial nephrectomy, explaining, in part, why the rate of partial nephrectomy remained relatively stagnant before the robotic-assisted laparoscopic nephrectomy, despite an increase in small renal masses detection rate. Thermal ablation techniques, including radiofrequency ablation and cryoablation, are alternative minimally invasive nephron-sparing treatments for small renal lesions. These techniques, which can be performed using a percutaneous or laparoscopic approach, do not require dissection and clamping of the renal hilum, conferring therefore a minimal ischemic insult. Although promising, the oncological and renal efficacy of thermal ablation in comparison with partial nephrectomy have yet established because of small sample size and lack of long-term follow-up data among exiting studies [16]. Patients selected for contemporary open PN (OPN) have evolved into a more complex population by virtue of having a greater incidence of central tumors and tumors in a solitary kidney [17]. Here we review the current status of open partial nephrectomy for the treatment of renal tumors, providing an update on the indications, disease-free and disease-specific survival outcomes, benefits and risks, limitations and technical aspects of the surgery, intra- and postoperative complications and post-treatment follow-up protocols. We selected for this review 94 studies. Studies were identified by searching electronic databases and scanning reference lists of articles. A bibliographic search covering the period from January 1980 to December 2014 was conducted using PubMed/MEDLINE and EMBASE database. Studies were excluded if they were single case reports, meeting abstracts and conference proceedings. The following search terms were used: Partial nephrectomy; Renal cell carcinoma; Surgery; Laparoscopy. Studies were excluded if they were single case reports, meeting abstracts and conference proceedings. Identified studies were reviewed and selected if they reported the surgical approach and the oncologic outcomes of patients surgically treated for RCC. Inclusion or exclusion of studies was performed hierarchically based first on the title of the report, then on the abstract and finally on the contents of the full text considering quality of research and the appropriateness of the methods used. A study was accepted for inclusion on the basis of agreement of two investigators (MS, GB); any disagreement on study inclusion was resolved by consulting a third investigator (GT).

Partial nephrectomy: indications

Partial nephrectomy for nephron-sparing removal of renal masses in solitary kidneys, bilateral masses or in patients with poor renal function has been the standard of care for years and has definitively supplanted radical nephrectomy [18]. The accumulating knowledge in the field of renal oncology has progressively lead to an increasing use of partial nephrectomy for the management of small renal masses, even in the absence of identifiable renal insufficiency as the oncological outcomes compare favorably with those of radical nephrectomy. Indications can be classified as absolute (single kidney, severe renal failure, bilateral renal tumor) relative (abnormal contralateral kidney, metabolic disease associated with renal failure, genetic syndrome with tumor multifocality) or elective (peripheral tumor, tumor $\leq$4 cm in young and healthy patients, tumor $\geq$4 cm when feasible), the selection always based on technique viability and desirable optimal cancer control [19].

Partial nephrectomy and oncologic and survival outcome

Actually, little doubt exists concerning the oncological efficacy and outcomes in the treatment of T1a tumors in appropriately selected patients. Some, albeit decreasing, controversy still exists regarding treatment of stage T1b tumors (4–7 cm) secondary to the small risk of local tumor recurrence (4–6 %) and multifocality (5–6 %) [20].

In fact, partial nephrectomy for T1b renal tumors poses a higher surgical challenge since clinical tumor size is known to be associated with the risk of tumor progression and survival [21]. It has also been traditionally used as a predictor of complexity and morbidity of NSS and represents the most important predictor of cancer-related outcome. This is an important selection criterion for partial nephrectomy. This assumption was based on Cleveland Clinic data; the T1 stage was subdivided into T1a and T1b stage [22]. On their retrospective review, the authors showed that there was a significant fall in 5- and 10-year cancer-specific survival rate and rise in the recurrence, if tumor size increases above 4 cm. Fergany et al. [23] found cancer-specific survival of 98 % for tumor <4 cm size, of which 2 % cases were elective. Tumor size, laterality, and pathological stage were found to be significant risk factors for cancer-specific death. Patients with tumor >4 cm were significantly more likely to die of disease than those with tumors <4 cm. For each 1 cm increase in the tumor size, the risk of death rose by 20 %. Subsequent studies have shown that in elective partial nephrectomy for T1b in carefully selected patients, the oncological outcomes were equivalent to radical nephrectomy. Belldegrun et al. [24] found equivalent disease-free survival between partial nephrectomy for T1b and radical nephrectomy. Patard et al. [25] did not find any significant difference for distant or local recurrence among patients undergoing radical nephrectomy or partial nephrectomy, in a multi-institutional trial, for T1b lesions. Thresher et al. [26] did not find any increase in cancer-specific mortality between T1a and T1b lesions. Although data for T1b NSS are encouraging, the careful patient selection is of outmost importance as the peripheral tumor location is the most common in these series. Data supporting PN in T1b tumors are currently available and sustain its consideration for all tumors up to 7 cm in size.

Preservation of the largest amount of healthy renal parenchyma is of paramount importance when the excision of a localized renal mass is needed. Although the adoption of PN in current clinical practice remains slower than desired outside teaching and high-volume institutions even for smaller tumors and a recent American Urological Association survey showed that urologists are more likely to perform PN for smaller and less exophytic small renal masses, there is today increasing evidence of the excellent oncologic and functional results of NSS also for the treatment of larger and more complex localized renal tumors [19, 27, 28]. However, prospective clinical trials providing data on long-term oncological outcome of NSS for renal tumors larger than 4 cm are still lacking. Following NSS for RCC, cancer-free survival dramatically dropped in patients with tumors larger than 4 cm compared with those with smaller tumors [29].

Hence, careful selection for elective patients with T1b-staged RCCs is mandatory. Clearly tumor localization, shape (endophytic vs. exophytic) and site (lower pole vs. upper pole vs. hilar and centrally located) are important features in the decision making for a nephron-sparing approach [30]. Surgical feasibility obviously does not automatically imply the treatment of choice. Joniau et al. [31] published a retrospective study of NSS for the treatment of T1b tumors in a high-volume institute. With a median tumor size of 4.5 cm (range 4.1–7 cm), the mean renal ischemia time was 14.1 min (range 3.5–45 min) with no significant difference in mean blood loss between patients with or without renal pedicle clamping (542 vs. 385 ml). The 5-year progression-free survival, cancer-specific survival and overall survival (OS) rates were 84, 99 and 72 %, respectively. The projected 5-year local recurrence and systemic recurrence free survival rate were 94 and 90 %, respectively. Thompson et al. [32] analyzed 1159 patients with 4–7 cm unilateral, solitary, cortical renal masses with 873 radical nephrectomies and 286 partial nephrectomies. PN patients were significantly more likely to have a solitary kidney (10 vs. 0.2 %) and chronic kidney disease (15 vs. 7 %), with no significant difference in overall survival (OS) but more than twice risk to dying of RCC. Pahernik et al. [33] showed the oncological safety of elective NSS in 102 patients with T1a RCC compared with 372 patients with T1b RCC. The estimated 5-year cancer-specific survival rate was 97.9 and 95.8 % for T1a and T1b tumors, respectively. The survival rate free of local recurrence at 5 years was 98.5 and 98.3 % for small and large tumors, respectively.

Partial nephrectomy complications

Renal failure, postoperative hemorrhage, urine leak and urinary fistula are the most frequently seen complications after open NSS and for many years they constituted major disincentive to many urologists. Procedure-related complications included retroperitoneal hemorrhage, pneumothorax, adjacent organ injury and small bowel obstruction too. The lower incidence of complications in the present patient series can be attributed to the greater experience that urologists have gained with this technique and the higher prevalence of incidental small tumors.

Twenty years ago, in 1994, Campbell et al. [34] reported a complication rate after open PN of 37 % for symptomatic tumors and of 22 % for incidental tumors. Van Poppel et al. [35] compared the complication rate of elective open NSS surgery and RN for low stage, incidentally detected, solitary, small (<5 cm) RCCs in a prospective study in the presence of a normal contralateral kidney concluding that NSS can be performed safely in this patient group with slightly higher complication rates after RN. Stephenson et al. [36] stated that either tumor size, tumor location (central vs. polar) or imperative versus elective indication were associated with complications of PN, while at multivariate analysis operative timed solitary kidney were significantly associated with procedure-related complications of PN.

Published data from patients with tumors >4 cm identify a 12 % rate of surgical complication rate of surgical complications and a 5 % rate of urinary fistula for OPN; complication rates for laparoscopic series appear to range from 20 to 37 % with a urinary fistula rate of 7 %. This appear comparable with the single study of robot-assisted PN for tumors >4 cm that cites a urinary fistula of 5 % [36, 37]. On the other hand, considering renal function, at 6–12 months, open PN has a significantly lower creatinine level compared with laparoscopic radical nephrectomy patients [38]. This information must be given to patients when they are informed about the short-term risks of the two different approaches.

Open versus laparoscopic partial nephrectomy

Laparoscopic PN (LPN) for renal cancer was introduced in 1993 [39] but remained controversial until approximately a decade later, when larger series with long follow-up showed the oncologic safety of the laparoscopic approach and the possibility to duplicate the open PN technique [40, 41].

Nevertheless, owing to its technical difficulty and steep learning curve, LPN remained restricted mostly to reference centers. Several studies have alluded to the prolonged learning curve of LPN, especially in comparison with the relative ease of laparoscopic radical nephrectomy [15, 42]. Thus, the rise in LPN appeared offset by a concomitant rise in LPN. The relatively slower uptake of LPN likely reflects the substantial technical expertise (i.e., hilar clamping, intracorporeal suturing) required to perform complex surgery [43]. Laparoscopy can duplicate the results of most open surgeries: Some previous studies showed that LPN was associated with less postoperative analgesic requirement, earlier hospital discharge and more rapid convalescence. However, the major challenges for the laparoscopic surgeon performing LPN are hemostasis, longer operative time and the avoidance of ischemic damage. For these reasons, LPN continues to be performed in a minority of centers. Major concerns against LPN obviously regard complications, including (a) bowel injury, (b) bleeding, (c) tumor spillage, and (d) increased ischemia time [44–46]. Bowel injury during LPN is one of the most feared complications as high as 0.8 % due to thermal damage (50 %) and traumatic access (32 %) [47]. Unfortunately, the majority of bowel injuries are not recognized intraoperative becoming evident in the postoperative period only, usually after an uneventful course as peritonitis. Bleeding during LPN is a major issue although improved surgical techniques and skills together with the use of new hemostatic sealants such as fibrin glue-coated collagen patch, which contains purely human coagulation factor components, can be helpful to minimize this risk [48]. The risk of tumor spillage at port sites was initially suspected in the first era of LPN, luckily not confirmed [49]. The detrimental effect of warm ischemia on renal function has long been recognized. Traditionally, 30 min of warm ischemia has been considered to be the maximum ischemic insult a normal kidney can be exposed to without permanent loss of function [50].

More recent data suggest that this is 20 min at most, but every minute of ischemia even below this limit is damaging. In OPN, this can in part be compensated by slush ice cooling of the kidney, but in spite of this, OPN techniques avoiding renal ischemia altogether are finding increasing interest. It is worth noting that the concern for increased warm ischemia time (WIT) in patients undergoing LPN is more than 50 %. Preservation of maximum functional kidney tissue is one of the goals in PN; however, longer warm ischemia times have been reported with LPN compared to open NSS [23].

At LPN, clamping of the renal pedicle is generally considered necessary for adequate vision at the time of parenchymal dissection. Techniques for renal cooling at LPN with slush ice cooling or transarterial hypothermic perfusion have been developed, but they are complex and not have not found general acceptance [50].

Although WIT has been strongly associated with acute renal failure, its correlation with chronic renal damage is controversial as other factors such as the width of healthy tissue removed with the tumor and the method of renorrhaphy or the hemostatic energy applied on the surgical bed may play a role in its development [51]. The general trend in LPN is, therefore, to reduce renal ischemia as much as possible by limiting it to the time of actual tumor dissection and performing renal reconstruction and hemostasis after declamping. This results in higher blood loss. Clearly, this further raises the technical changes the surgeon faces at LPN, already considered one of the most demanding laparoscopic operations in urology with a steep learning curve [52]. In a broader evaluation of complication rates of the two compared different surgical techniques in different studies, an higher incidence in LPN is described by Gill et al. [38] in a retrospectively study that evaluated 771 LPN and 1028 OPN performed at three high-volume institutions during a 7-year period. LPN patients had less mean blood loss, shorter operating times, and shorter hospitalization. These positive results were in part linked to significant smaller mean tumor size, more tumors in a peripherally/exophytic position, a better performance status in LPN: However, higher mean warm ischemia time, higher postoperative complications and higher need for subsequent interventions were detected in LPN calling for hands of experienced surgeons to perform it for solitary renal tumors treatment. Marszalek et al. [12] retrospectively compared 100 consecutive LPN with 100 consecutive OPN with a comparable overall complication rate of (19 % in the LPN and 14 % in the OPN) but even in this paper intraoperative complications were significantly higher in the LPN group. Uprightly when stratifying complications according to the Simmons and Gill grading system, more grade 3 complications, requiring reintervention, were seen in the LPN group. Hemorrhagic and urine leak complications occurred more frequently in LPN, while positive margins were comparable in both groups. In a large single-center series of partial nephrectomy for renal masses, Lane et al. [53] compared the outcome of OPN in 169 solitary kidneys with LPN in 30 solitary kidneys. Although tumors in the OPN group were larger (and more frequently in a hilar/central location than in the LPN group), only 24 % complications were observed after OPN as compared to 43 % after LPN, with a tenfold lower postoperative need for dialysis and a lower ischemia time. In a multivariate analysis accounting for age, tumor size and time of warm ischemia, the risk of postoperative complications following LPN was 2.54 times higher than OPN ($p < 0.05$). For these reasons, the authors suggested to treat renal tumor in solitary kidneys with OPN. The location and size of the mass to be removed are defining parameters for the technical complexity and also morbidity of LPN [54]. When adding in the need for considerable experience with this type of surgery, it becomes obvious that OPN still plays a significant role in the management of more difficult lesions. Liu et al. [55] reported a matched-pair comparison of 212 patients who underwent LPN or OPN. The surgical, oncologic and functional outcomes were retrospectively compared. Surgical time, renal arterial occlusion time, estimated blood loss and postoperative hospitalization days were significantly shorter in the LPN group ($p < 0.01$) with comparable complications rate; however, LPN had a higher intraoperative complication rate due to 12 subcutaneous emphysemas. The LPN group was followed up with a mean time of 29 months and the OPN group with a mean time of 30 months. All patients survived, and no distant relapse or metastasis was observed. The reduction of glomerular filtration rate was more evident after LPN at 3-month follow-up ($p < 0.01$) but similar between the two groups at 30.2-month follow-up. Matin et al. [56] addressed the comparison of elective OPN and LPN stating that the laparoscopic approach led to a faster recovery and shorter hospital stay at cost of worse long-term renal damage.

Similar results were detected by Tan et al. [43] with significantly lower probability of requiring intensive care unit time and shorter median length of stay (3 vs. 5 days, $p < 0.001$) for LPN, with no in difference rehospitalization or operative mortality. While the frequency of postoperative complications was similar, LPN was accompanied by twofold greater probability of genitourinary complications and postoperative hemorrhage. The only retrospective comparative series of LPN and OPN that included renal tumors greater than 4 cm in size only showed a lower EBL, WIT and length of hospital stay for LPN. However, these results must be interpreted with caution due to the small sample size of the LPN group (54 vs. 226 patients) and the lack of evaluation of other tumor characteristics and surgical challenge by nephrometry scoring systems [57]. At the same time, several single, multi-institutional and population-based studies consistently showed similar CSS rates and better preservation of renal function for OPN compared to radical nephrectomy for tumors greater than 4 cm in size. On the basis of these findings, partial nephrectomy should be performed for T1b renal tumors whenever technically feasible. Focusing on complications, OPN remains at present the gold-standard technique since LPN requires higher skill in the presence of higher complication rates. Laparoscopic provide comparable results in surgical, oncologic and renal function outcomes for T1N0M0 stage even if renal tumors that are difficult to access are still a major challenge for LPN. Table 1 summarizes OPN, LPN and RPN outcomes in the cited papers.

Open versus robotic laparoscopic partial nephrectomy

Robotic partial nephrectomy (RPN) was first described by Gettman et al. [58] in 2004. Singh has recently reviewed the surgical technique [59] that has changed during time. Since then, robotic assistance has allowed for an increasing number of patients to undergo NSS through a minimally invasive approach. However, a major issue in this era of cost-constraint has been the question of whether robotic-assisted surgery is financially sustainable. Robot-assisted partial nephrectomy (RAPN) allows magnified stereoscopic visualization and the use of articulated robotic instruments under precise control. RAPN reduces the technical

Table 1 OPN, LPN and RPN outcome comparison

	OPN (*n*)	LPN (*n*)	RPN (*n*)	Outcome
Gill et al. [38]	1028	771	–	LPN: less mean blood loss, shorter operating times and shorter hospitalization, higher mean warm ischemia time, higher postoperative complications and higher need for subsequent interventions
Marszalek et al. [12]	100	100	–	LPN: higher intraoperative complications (more grade 3 complications)
Lane et al. [53]	169	30	–	LPN: more overall complications rate
Liu et al. [55]	97	115	–	LPN: shorter surgical time, renal arterial occlusion time, less estimated blood loss and shorter postoperative hospitalization, higher intraoperative complications rate
Lee et al. [62]	234	–	69	RPN: longer ischemia time
Simhan et al. [63]	136	–	81	Comparable ischemia time
Minervini et al. [64]	198	–	105	RPN: reduction of blood loss, surgical complications and less hospital stay
Ficarra et al. [67]	368	–	415	RPN: lower risk of bleeding and postoperative complications, similar early oncological outcome
Lucas et al. [68]	54	15	27	OPN: shorter operative time, high blood loss, shorter WIT

challenges associated with tumor dissection and parenchymal reconstruction and potentially overcomes the limitations of the pure laparoscopic approach, while maintaining its advantages in terms of minimal invasiveness. RPN appears to be a more reproducible approach with improved dexterity, magnified three-dimensional visualization and better ergonomics, which may bridge the gap between the LPN and OPN [60, 61]. In comparison with OPN, RPN provides comparable perioperative and functional outcomes with the added benefits of better postoperative pain control and a shorter postoperative hospital length of stay. There is a controversy on ischemia time with OPN versus RPN. Lee et al. [62] reported a significant longer ischemia time in the RPN group (23 vs. 19 min, $p < 0.001$), while Simhan et al. [63] and two other prospective non-randomized comparative studies detected comparable ischemia time, possibly due to higher surgeons' experience [61, 64]. In recently reported series of RPN for complex renal tumors (higher nephrometry score, multifocal or completely endophytic), the ischemia time can still be controlled at about 20 min [65].

Regarding the postoperative renal function outcome, in a large tertiary-care center series comparing RPN and OPN no significant difference in eGFR change at a mean follow-up of 21.3 months was detected [60]. In that study, however, more patients with solitary kidney were treated with OPN (12.1 vs. 0 %, $p < 0.001$), which can intrinsically influence the estimation of eGFR in the OPN group. Similar results published by Lee and Masson-Lecomte [62, 66] proved the equivalence between RPN and OPN. More recently, Ficarra et al. [67] reported a multicenter matched-pair analysis in which 200 RPNs and 200 OPNs were examined. In that series, EBL and length of stay (LOS) were more favorable after RPN than OPN and no differences were recorded regarding intraoperative complications, blood transfusions, high grade, postoperative complications and absolute eGFR decline at 3 months after surgery. The protective effect of RPN in EBL (00 vs. 150 ml, $p < 0,001$) is marginal. What's more, since the amount of blood loss could be underestimated, for blood loss might not be fully recognized due to gravity effects on the blood into more dependent abdominal compartments that go unrecognized and unsuctioned from the body cavity. This effect may be of little clinical significance for it is not predictive of EBL > 400 ml in multivariable analysis. In this regard, it may be better to assess the change in perioperative hemoglobin or hematocrit. However, there could be difference in hydration status in the perioperative setting that might affect accurate measurement. It is interesting to note that there were no significant differences between the two approaches in operative time but a significantly longer warm ischemia time with RPN than OPN in Ficarra's study.

Lucas et al. [68] compared robotic partial nephrectomy (RPN), laparoscopic partial nephrectomy (LPN) and open partial nephrectomy (OPN), controlling for tumor size, patient age, sex and nephrometry score. Ninety-six partial nephrectomy procedures were reviewed: 27 RPN, 15 LPN and 54 OPN. RPN, LPN and OPN had similar median tumor size (2.4, 2.2 and 2.3 cm, respectively), nephrometry score (6.0 each) and preoperative glomerular filtration rate (71.5, 84.6, and 77.0 mL/min/1.73 m2, respectively). Blood loss was higher for OPN (250 ml) than for RPN or LPN (100 ml). Operative time was shorter in OPN (147 min) than in RPN (190 min) or LPN (195 min). Median warm ischemia time was shorter for OPN (12.0 min) than for RPN (25.0 min) or LPN (29.5 min). Cold ischemia time for OPN was 25.0 min. A 10 % glomerular filtration rate decline occurred in 10 RPN, 5 LPN and 29 OPN cases. Median hospital stay for LPN and RPN was 2.0 vs. 3.0 d for OPN. Urine leak occurred in 1 RPN and 3 OPN cases. Postoperative complications occurred in 4 RPN (3 were Clavien grade 2 or less), 1 LPN (grade 1) and 7 OPN (6 were grade 2 or less) cases. Initial experience of RAPN shows comparable perioperative results and shorter WIT compared to LPN, but the available oncological follow-up is at present time still short. Further studies are needed to better define the role of the robotic approach for partial nephrectomy of T1b tumors [69, 70]. The emergence of the robotics platform and its application to laparoscopic partial nephrectomy may improve the accessibility of this technique to urologists more broadly. In fact, owing to its more rapid learning curve and enhanced transferability of surgical skills, the diffusion of robot-assisted laparoscopic partial nephrectomy is already well under way [71]. Accordingly, the promotion of LPN, conventional as well as robotic, may be the most effective lever not only to extend the convalescence benefits of minimally invasive surgery but also to increase the use of nephron sparing globally [61].

Anyway in the laparoscopic and robotic era OPN is still a gold standard in centers where Lap and robot procedure are not routinely performed.

Partial nephrectomy: costs analysis

Nephron-sparing surgery and minimal invasive surgery are ideal options in terms of safety and reduced morbidity in SRM treatment. However, even if almost 50 % of early-diagnosed RCCs in US are SRMs (cT1a), less than half of them have been managed with NSS. Many reasons can be addressed as follows: steeper learning curve, higher operating time, increased mental/physical stress and higher costs. Therefore, proper surgical training and available budget should be taken into consideration. Besides, fiscal responsibility, cost control measures and even patient's socio-demography (i.e., race, gender, income, education) have become important healthcare issues [72]. Despite growing evidence for the clinical effectiveness of minimally invasive approaches to PN, few groups have compared costs of these approaches with those of OPN [73]. New technologies such as robotics are associated with increased costs and are often implemented without considering clinical benefit of financial burden. For example, LPN has gained momentum since it was first described in 1993 but concerns of added healthcare costs were warranted, given the increased expense of newly developed laparoscopic instrumentation. The higher cost of LPN can be compensated by the decreased hospitalization. Although the role of RALPN will be better defined after long-term oncological and functional outcomes are established, a cost analysis comparing RALPN to LPN and OPN is prudent to ensure proper healthcare resource allocation, given the increasing incidence of small renal masses and the gaining popularity of robotics in urology [74]. Estimated anesthesia and doctors/nurses fees are directly related to the operative time and for obvious reasons, a more rapid surgery might reduce these charges. As the pendulum swings toward RALPN and minimally invasive surgery, the benefits must be weighed against not only warm ischemia time but also the difference in instrument and maintenance costs. Barbash and Glied [75] analyzed the Nationwide Inpatient Sample and found the median cost of PN did not vary significantly by approach, ranging from US$15,724 for RALPN to US$12,401 for LPN and US$11,870 for OPN. In addition to the variable costs per case, the net cost difference of RALPN is exacerbated when factoring in the $1–2.5 million capital acquisition cost of the robotic platform follow-up. Alemozzafar et al. [76] compared hospital costs associated with RALPN, LP and OPN and factored in variable costs, fixed costs and length of hospital stay. Variable costs were similar. These costs included OR supplies, time, anesthesia and inpatient care. OR supplies contributed a greater cost for RALPN and LPN than OPN ($2418 vs. $1987 vs. $181), whereas inpatient costs were higher for OPN than for LPN or RALPN. RALPN and LPN were found to represent less costly alternatives to OPN if maintenance costs were not included and hospital stay for RALPN and LPN was <2 days and OR time <195 and 224 min, respectively. Overall analysis costs makes RPN more expensive followed by LPN than OPN that remains cheaper. Laydner et al. [77] compared the costs associated with NSS done through the robotic, laparoscopic and open approaches. Overall, they observed no significant difference between RPN and OPN and a median cost advantage for LPN of $313 and $632 over OPN and RPN, respectively. However, after stratifying the groups by similar RNSs, costs of RPN, LPN and OPN were similar for tumors with low and intermediate complexity.

The small number of patients with highly complex tumors undergoing PN through minimally invasive approaches precluded a meaningful comparison in this subset. Unexpectedly, they observed that OPN had higher anesthesia costs. The higher tumor complexity and ASA scores of patients who underwent OPN are likely part of the explanation for this finding. If we include the robot purchase and maintenance cost in the analysis, each RPN would be approximately $1300 and $1000 more expensive than LPN and OPN, respectively. Overall costs of minimally invasive surgery can be limited by reducing the use of disposable equipment, short LOS, reduced OR time and increasing surgical volume. Use of the minimally invasive equipment is an important variable, and therefore, only high-volume programs may be able to achieve cost equivalence to OPN [73]. Emerging countries (Africa and the Middle East) are now starting to change their current practice, thus introducing LPN and RPN and facing cost/analysis issues [78].

Conclusions

This paper represents a first comprehensive review that considers all the variables connected to the three surgical techniques of partial nephrectomy. While in the past partial nephrectomy was performed only for the essential indications of a renal tumor in an anatomical or functional solitary kidney, it has progressively become the preferred surgical technique for T1 renal masses treating. Nowadays, PN is the gold-standard technique to treat small renal masses and all non-ablative techniques must pass the test of time to be considered equally effective. Comparisons between different treatment modalities are always difficult, as the preoperative characteristics of patients (i.e., age, medical comorbidities, tumor size and tumor configuration) may affect outcome as well as surgeons' skill. RPN is an easier and more reproducible approach with improved dexterity, magnified three-dimensional visualization and better ergonomics, which surely overhead the technical and training gap between the LPN and OPN. In conclusion, LPN and RPN represent two treatments options that combine the benefits of minimally invasive surgery (i.e., easier and more rapid convalescence) and nephron-sparing surgery (i.e., renal preservation). Nevertheless, LPN remains technically complex with a longer training curve and the need for the surgeon to practice in a high-volume center. In this era of minimally invasive surgery, RPN enables the surgeon to reach the same target as employing LPN without the outlined technical limitations.

For these reasons, it can be appointed as the gold-standard procedure for PN.

OPN can be regarded as a possible treatment in medium–low volume centers with less experience in laparoscopic and robotic procedures or in countries where the procedure costs is still an issue. It is also important to be aware that in tertiary centers or those with minimally invasive expertise, the open approach is now mainly reserved for imperative indications and for removal of selected, more challenging tumors, thereby leading to a potential underestimation of the outcome of NSS with this approach. It is not ethical for patients to undergo radical surgery just because the urologists involved do not have adequate experience with PN or have concerns about their capacity to manage its possible complications. Patients should be involved in the final treatment decision and, when appropriate, referred to tertiary centers.

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Compliance with ethical standards

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

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

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