Comparison of Renal Function between Robot-Assisted and Open Partial Nephrectomy as Determined by Tc 99m-DTPA Renal Scintigraphy

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Received: 7 July 2015
Accepted: 14 January 2016

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We compared postoperative renal function impairment between patients undergoing robot-assisted partial nephrectomy (RAPN) and those undergoing open partial nephrectomy (OPN) by using Tc-99m diethylenetriaminepentaacetic acid (DTPA) renal scintigraphy. Patients who underwent partial nephrectomy by a single surgeon between 2007 and 2013 were eligible and were matched by propensity score, based on age, tumor size, exophytic properties of tumor, and location relative to the polar lines. Of the 403 patients who underwent partial nephrectomy, 114 (28%) underwent RAPN and 289 (72%) underwent OPN. Mean follow-up duration was 35.2 months. Following propensity matching, there were no significant differences between the two groups in tumor exophytic properties \( P = 0.818 \) or nephrometry score \( P = 0.527 \). Renal ischemic time \((24.4 \text{ minutes vs. } 17.8 \text{ minutes, } P < 0.001)\) was significantly longer in the RAPN group than in the OPN group, while the other characteristics were similar. Multivariate analysis showed that greater preoperative renal unit function \( P = 0.011 \) and nephrometry score \( P = 0.041 \) were independently correlated with a reduction in glomerular filtration rate. The operative method did not correlate with renal function impairment \( P = 0.704 \). Postoperative renal function impairment was similar between patients who underwent OPN and those who underwent RAPN, despite RAPN having a longer ischemic time.

Keywords: DTPA; Delayed Graft Function; Nephron Sparing Surgery; Scintigraphy; Robot-assisted Partial Nephrectomy

INTRODUCTION

The development of diagnostic organ imaging has resulted in increased detection rates of renal cell carcinoma, downward staging of tumors to stage 1, and a decrease in the sizes of tumors detected. Partial nephrectomy (PN) has similar oncologic outcome (1) but has been associated with better conservation of renal function than radical nephrectomy (RN) (2). Thus, American Urological Association guidelines recommend PN as the standard treatment for T1a tumors, but there are still many methods of PN that could be considered.

Further developments in minimally invasive techniques and surgical apparatuses have resulted in laparoscopic PN (LPN) becoming an alternative to open PN (OPN), since LPN is associated with reduced surgical morbidity rates and similar intermediate-term cancer survival (3). LPN, however, demands advanced surgical skills, has a gradual learning curve, and requires perseverance, all of which limit its widespread use (4).

The advent of robotic surgical systems has helped reduce the technical challenges posed by LPN and made the learning curve more rapid, without negatively affecting perioperative outcomes (5–7). But some studies have indicated that, robot-assisted partial nephrectomy (RAPN) tend to have a longer ischemic time, although RAPN was regarded as a suitable alternative to OPN (8–10). Unfortunately, comparative studies until now about renal function were mainly focused on total glomerular filtration rate (GFR), not split renal function. Of course, result of these studies is important, but more than 5 percent of renal cell carcinoma (RCC) patients can be suffered by cancer of contralateral kidney (11). In view of that point, comparison of renal function of operated kidney according to surgical methods may have significant implications.

This study was designed to compare long term post-operative renal function change in patients undergoing RAPN and OPN. Since the choice of operation has been affected by the intricacy of the tumor, propensity score matched cohorts were compared.

MATERIALS AND METHODS

Between 2007 and 2013, 418 patients underwent PN at our institution. Among them, patients who underwent two operations...
on the same kidney and with Von Hippel-Lindau disease, a horse-shoe kidney, or a ruptured angiomyolipoma were excluded (n = 15). From these, a cohort of 403 patients (including 114 who underwent RAPN and 289 who underwent OPN) were selected and included in this study. To reduce the differences of patient characteristics between the two surgical methods, patients were matched by propensity score on patient age and tumor size, depth, and location. The nephrometry score was categorized as low, 4-6; intermediate, 7-9; or high, 10-12 (12). Among 114 RAPN patients, 84 patients underwent Tc-99m diethylenetriaminepentaacetic acid (DTPA) scintigraphy 3 months, 1, and 2 years after surgery, and 84 OPN patients were propensity matched 1:1 with RAPN patients.

The selection of operational method was based on discussions with patients, while taking into consideration tumor mass characteristics, patient comorbidities, and costs. In Korea, national insurance covers only OPN, making RAPN more than twice as expensive as OPN. Data collected retrospectively from patient records included age, sex, operation method, body mass index (BMI), pre- and post-operative GFR, tumor size and location, comorbidities (including diabetes mellitus and hypertension), R.E.N.A.L. nephrometry score (including radius, exophytic property, nearness to the sinus, anteriority, and location relative to the polar lines of the tumor), perioperative variables (including operation time, ischemic time, and hospital days), complication (according to Clavien-Dindo classification, grade 3 or 4 defined as severe complication) (13), and pathology results. Preoperative DTPA scintigraphy was performed not earlier than 3 months before surgery and postoperative renal function was measured 3 months after surgery. Subsequent DTPA scintigraphy was generally performed annually.

All RAPNs were performed with the da Vinci Surgical System using a transperitoneal approach and the 4-arm technique. The camera port was placed 6 cm above the umbilicus at the lateral position and the assistant 12 mm port was placed near the cranial side of the umbilicus. Three 8 mm working ports were located on the side of the abdomen undergoing surgery. Only the renal artery was clamped with bulldog clamps, without thermoregulatory manipulation. During the operation, pneumoperitoneum pressure was maintained at 12 mmHg. OPN was performed using a flank and retroperitoneal approach, with the patient mainly in the lateral position. We used the same bulldog clamps for clamping the renal artery and used ice for cooling the kidney during excision of the mass. Clamping time was the time from when the bulldog clamps were applied to the renal artery to the time they were removed, and was reported to the operator every 5 minutes by the scrub nurse. Exposed calyces, bleeding foci, and parenchymal defects were sutured horizontally with hemostats using an interrupted (in RAPN) and continuous (in OPN) suture maneuver. An ultrasound probe was used to determine the cutting plane in patients with endophytic tumor.

Kidney function was evaluated by performing DTPA renal scintigraphy. Patients were maintained on usual hydration and were asked to drink 300-500 mL of water 30 minutes before scanning. After a 1 scout view was obtained, 5 mCi of 99mTc-DTPA was injected, with 80 images captured during the next 20 minutes. If excretion was limited, 80 post voiding images were obtained additionally after micturition. The Gates’ method was used to determine glomerular filtration rate and the Taylor method was used to correct attenuation. Low energy all-purpose (LEAP) collimator and Syngo MI Apps 2008A program (Siemens, Munich, Germany) were used.

Categorical variables were reported as frequency and proportions, and compared using Student’s t-tests. Continuous variables were reported as mean and standard deviation, and compared using Mann-Whitney U tests. All tests were two-sided, with significance defined as \( P < 0.05 \). Multivariate regression analysis was performed to identify factors affecting postoperative deterioration of renal function. All statistical analyses were performed using SPSS ver. 18.0 software (IBM Co., Armonk, NY, USA).

**Ethics statement**

The study was approved by the institutional review board of Asan Medical Center (IRB No. 2014-1181). Informed consent was waived by the board.

**RESULTS**

Table 1 shows the demographic and clinical characteristics of the initial cohort of 403 patients prior to propensity matching. Of these 403 patients, 114 (28.3%) underwent RAPN and 289 (71.7%) underwent OPN. Patients undergoing RAPN were significantly more likely to have exophytic tumors \( (P < 0.001) \) and lower nephrometry scores \( (P = 0.005) \). In addition, ischemic time was longer in patients who underwent RAPN (23.9 minutes vs. 19.8 minutes, \( P < 0.001 \)), but hospital stay was shorter (7.1 days vs. 8.7 days, \( P < 0.001 \)) and the overall complication rate was lower (21.9% vs. 35.8%, \( P = 0.004 \)). Histologic type of tumor was similar in the two groups \( (P = 0.223) \). Follow-up duration after operation was similar in both groups (34.7 months vs. 35.1 months, \( P = 0.883 \)) and GFR decline at DTPA was also similar (2.0 mL/min/1.73 m\(^2\) vs. 2.4 mL/min/1.73 m\(^2\), \( P = 0.774 \)). In Fig. 1, split renal functions of patient are compared, showing no difference between the two operational methods.

The demographic and clinical characteristics of the matched cohort are shown in Table 2. Unlike before matching, there were no significant group differences in the rates of exophytic tumors \( (P = 0.818) \) or nephrometry scores \( (P = 0.527) \). The propensity matched RAPN and OPN groups were similar in age, mass size, preoperative GFR of solitary renal units (41.8 mL/min/1.73 m\(^2\))
vs. 42.8 mL/min/1.73 m$^2$, $P = 0.553$), and renal function impairment (1.9 mL/min/1.73 m$^2$ vs. 1.5 mL/min/1.73 m$^2$, $P = 0.806$). Renal ischemic time (24.4 minutes vs. 17.8 minutes, $P < 0.001$) and operation time (216.9 minutes vs. 196.9 minutes, $P < 0.001$) were significantly longer in the RAPN group, but the hospital stay was overall significantly shorter (7.1 days vs. 8.4 days, $P < 0.001$) in the RAPN group. Complication rates did not differ significantly between the two groups (14.3% vs. 23.8%, $P = 0.116$). In the RAPN group, two patients required transfusion and one required angioembolization. In the OPN group, six patients required transfusion, one experienced wound dehiscence, and one required angioembolization. The RAPN group showed sim-
ilar split renal function (33.6 mL/min/1.73 m² vs. 33.7 mL/min/1.73 m², \(P = 0.916\)) at 3 months and low split renal function at 1 year (34.4 mL/min/1.73 m² vs. 37.8 mL/min/1.73 m², \(P = 0.114\)) and 2 years (37.7 mL/min/1.73 m² vs. 40.5 mL/min/1.73 m², \(P = 0.264\)) after the operation, but showed no significant difference compared with OPN (Fig. 2). At 3 years after PN, both groups showed similar split renal function again (41.4 mL/min/1.73 m² vs. 40.5 mL/min/1.73 m², \(P = 0.788\)).

Factors affecting the change in GFR were analyzed by univariate and multivariable analysis (Table 3). Univariate analysis of patient characteristics showed that preoperative renal unit function (\(\beta = -0.21, P = 0.014\)) and nephrometry score (\(\beta = -1.16, P = 0.025\)) correlated with postoperative renal function impairment. Multivariate analysis showed that greater preoperative renal unit function (\(\beta = -0.24, P = 0.011\)) and nephrometry score (\(\beta = -1.14, P = 0.041\)) were correlated with reduced GFR.

### Table 2. Clinical/pathological characteristics of the two groups following propensity score matching

| Parameters                        | RAPN (n = 84) | OPN (n = 84) | \(P\) value |
|-----------------------------------|---------------|--------------|-------------|
| Mean age, yr ± SD                 | 52.5 ± 11.8   | 52.7 ± 12.1  | 0.923       |
| Gender, No. (%)                   |               |              | 0.396       |
| Male                              | 57 (67.9)     | 62 (73.8)    |             |
| Female                            | 27 (32.1)     | 22 (26.2)    |             |
| Mean body mass index, kg/m² ± SD  | 25.6 ± 3.9    | 25.4 ± 3.3   | 0.781       |
| Diabetes, No. (%)                 | 10 (11.9)     | 10 (11.9)    | 1.000       |
| Hypertension, No. (%)             | 36 (42.9)     | 37 (44.0)    | 0.876       |
| Mean mass size on CT, cm ± SD     | 2.5 ± 0.9     | 2.5 ± 1.4    | 0.884       |
| Side, No. (%)                     |               |              | 0.877       |
| Right                             | 43 (51.2)     | 44 (52.4)    |             |
| Left                              | 41 (48.8)     | 40 (47.6)    |             |
| Exophytic properties of tumor, No. (%) |          |              | 0.818       |
| Exophytic tumor                   | 49 (58.3)     | 48 (57.1)    |             |
| Mesophytic tumor                  | 33 (39.3)     | 35 (41.7)    |             |
| Endophytic tumor                  | 2 (2.4)       | 1 (1.2)      |             |
| Grade of R.E.N.A.L. nephrometry score, No. (%) |    | 0.527       |
| Low (4-6)                         | 49 (58.3)     | 53 (63.1)    |             |
| Intermediate & high (7-12)        | 35 (41.7)     | 31 (36.9)    |             |
| Pathologic outcome, No. (%)       |               |              | 0.095       |
| RCC                               | 77 (91.7)     | 72 (85.7)    |             |
| Angiomyolipoma                    | 4 (4.8)       | 4 (4.8)      |             |
| Oncocytoma                        | 0 (0.0)       | 6 (7.1)      |             |
| Others                            | 3 (3.6)       | 2 (2.4)      |             |
| Positive surgical margin, No. (%) | 0 (0.0)       | 2 (2.4)      | 0.155       |
| Mean operation time, min ± SD     | 216.9 ± 47.1  | 196.9 ± 40.7 | 0.004       |
| Mean Ischemic time, min ± SD      | 24.4 ± 6.2    | 17.8 ± 5.4   | < 0.001     |
| Mean hospital days ± SD           | 7.1 ± 1.4     | 8.4 ± 2.9    | < 0.001     |
| Mean follow up duration, mon      | 36.1 ± 18.7   | 35.5 ± 19.5  | 0.838       |
| Preoperative GFR ± SD, mL/min/1.73 m² | 41.8 ± 9.3   | 42.8 ± 10.9  | 0.553       |
| GFR decline at final DTPA ± SD, mL/min/1.73 m² | 1.9 ± 8.5  | 1.5 ± 13.2  | 0.806       |
| Overall complication, No. (%)     | 12 (14.3)     | 20 (23.8)    | 0.116       |
| Severe complication, No. (%)      | 1 (1.2)       | 2 (2.4)      | 0.560       |

RAPN, robot-assisted partial nephrectomy; OPN, open partial nephrectomy; SD, standard deviation; R.E.N.A.L, radius, exophytic property, nearness to the sinus, anteriority, and location relative to the polar lines of the tumor; RCC, renal cell carcinoma; GFR, glomerular filtration rate; DTPA, diethylenetriaminepentaacetic acid.

### Table 3. Multivariate analysis for predictive factors of GFR reduction after partial nephrectomy

| Variables                        | Univariate analysis | Multivariate analysis |
|----------------------------------|---------------------|-----------------------|
|                                  | Beta                | 95% CI                | \(P\) value | Beta                | 95% CI                | \(P\) value |
| Age (continuous)                 | 0.01                | -0.13                 | 0.15       | 0.06                | -0.09                 | 0.21       | 0.415 |
| Sex (male vs. female)            | -0.99               | -4.70                 | 2.72       | 0.599               | -2.67                 | -6.51                 | 1.18     | 0.173 |
| Diabetes (yes vs. no)            | -0.55               | -5.76                 | 4.66       | 0.834               | -0.47                 | -6.13                 | 5.18     | 0.869 |
| Hypertension (yes vs. no)        | 1.29                | -2.11                 | 4.68       | 0.456               | 0.29                  | -3.38                 | 3.97     | 0.875 |
| Ischemic time (continuous)       | -0.10               | -0.36                 | 0.16       | 0.452               | -0.07                 | -0.38                 | 0.25     | 0.672 |
| Preoperative GFR on DTPA (continuous) | -0.21            | -0.37                 | -0.04      | 0.014               | -0.24                 | -0.42                 | 0.06     | 0.011 |
| R.E.N.A.L. score (continuous)    | -1.16               | -2.17                 | 0.15       | 0.025               | -1.14                 | -2.23                 | 0.05     | 0.041 |
| Operative method (RAPN vs. OPN)  | -0.42               | -3.79                 | 2.95       | 0.806               | 0.77                  | -3.23                 | 4.77     | 0.704 |

GFR, glomerular filtration rate; CI, confidence interval; DTPA, diethylenetriaminepentaacetic acid; R.E.N.A.L, radius, exophytic property, nearness to the sinus, anteriority, and location relative to the polar lines of the tumor; RAPN, robot assisted partial nephrectomy; OPN, open partial nephrectomy.
DISCUSSION

PN is the gold standard for the management of small renal masses, but the surgical method varies. RAPN has now begun to be an alternative option to OPN because robot can offer a three-dimensional view of the operating field and fully flexible wristed-instrument motion, and overcome the learning curve for LPN (14). Several previous studies have compared RAPN with OPN and support the trend of increased use of RAPN (15-18).

However, most of these studies analyzed the functional outcomes using the serum creatinine level, an indicator of total renal function and the Modification of Diet in Renal Disease (MDRD) equation, which is used to calculate estimated GFR, can be affected by age and ethnic group (19). Furthermore, estimated GFR calculated from creatinine level has only a limited role in patients with a GFR > 60 mL/min/1.73 m² (20), who accounted for 89% of the patients in our cohort.

Studies of split renal function after PN have also been reported, and these can be divided into two groups: studies of patients with a single kidney, and studies using renal scintigraphy such as mercaptoacetyltriglycine (MAG3) or DTPA scintigraphy. The former studies included many variations of nephron conserving operations, such as OPN (21), LPN (22), and RAPN (23), and proved that PN was feasible in single kidney patients. However, these studies failed to analyze the impact of the surgical method on functional outcome. In addition, there is a tendency to apply more lenient indications to prevent the complete loss of renal function and dialysis (23), these studies revealed a relatively long renal ischemic time compared with that of the typical population, including the population reported in the present study. Furthermore, the function of the contralateral kidney increases to compensate for PN (24), which is something that cannot occur in solitary kidney patients. Therefore, it is hard to apply these studies to RCC patients with normal contralateral kidney.

MAG3 renal scintigraphy has also been used to analyze solitary renal function after PN in several studies (25-28), but revealed similar issues to those found in single kidney studies, such as lack of analysis of the operational method. MAG3, the most widely-used method in current practice, has several distinctive advantages over DTPA, especially for neonates and patients with suspected urinary obstruction. However, because the results are shown as relative values, operated kidney function could be affected by contralateral kidney function. For example, deterioration of renal function of the contralateral kidney due to renal stone may result in overestimation of operated-side renal function.

In this study, we not only analyzed the impact of the surgical method on functional outcomes using DTPA renal scintigraphy, but also analyzed other factors that can affect renal function (Table 3). As shown by several studies, greater preoperative GFR and nephrometry scores show significant correlation with deterioration of renal function (29-31); however, the fact that there is no relationship between functional outcome and ischemic time can be difficult to understand at first glance. In fact, there was a significant difference in ischemic time between the RAPN cohort and the OPN cohort after propensity matching (Table 2). To fully address this issue, several studies have reported that irreversible renal damage to the healthy contralateral kidney may be avoided by limiting ischemia time to less than 30 or 40 minutes (32-34), and 16.7% of patients who underwent RAPN had ischemia times longer than 30 minutes. Other studies have also argued that ischemia time has less of an effect on renal function over the long-term, although this opinion is controversial (29, 30,35). Thus, we interpret our data to indicate that the longer ischemia times of RAPN patients could have created a tendency toward lower renal function at 1 year and 2 years after surgery, but that renal function recovered at 3 years after the operation.

This study had several limitations. First, it was not a randomized controlled trial; however we matched patients by propensity score matching to minimize bias. Second, the potential effects of the RAPN learning curve should not be ignored. Although all operations were performed by a single surgeon, the proficiency of the surgeon in the two methods differed at the beginning of the study. However, the change in GFR between RAPN patients in the first half of the study and those in the second half was similar. Furthermore, the results of this study may help alleviate the hesitation surgeons might have in performing robotic surgery. Finally, the average follow-up period of patients was 3 years but about half of the patients had shorter follow-up period than 3 years.

In conclusion, long term postoperative reduction in operated renal function was similar between patients who underwent RAPN and those who underwent OPN, even when DTPA renal scintigraphy was used to determine GFR. RAPN showed similar functional outcome, despite its relatively longer ischemic time. Studies with larger groups are warranted to confirm results of the present study.

DISCLOSURE

None of the contributing authors has any conflicts of interest to declare, including specific financial interests or relationships and affiliations relevant to the subject matter or materials discussed in the manuscript.

AUTHOR CONTRIBUTION

Conception and coordination of the study: Lee C, Kwon T, Kim CS. Design of ethical issues: Lee C, Kwon T, Yoo S, You D. Acquisition of data: Lee C, Lee C, Jung J. Data review: Kwon T, Yoo S, You D, Kim CS. Statistical analysis: Lee C, Lee C, You D, Yoo S,

http://dx.doi.org/10.3346/jkms.2016.31.5.743

http://jkms.org
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REFERENCES

1. Van Poppel H, Da Pozzo L, Albrecht W, Mateev V, Bono A, Borkowski A, Colombel M, Klotz L, Skinner E, Kearns T, et al. 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 2011; 59: 543-52.

2. Huang WC, Levey AS, Serio AM, Snyder M, Vickers AJ, Raj GV, Scardino PT, Russo P. Chronic kidney disease after nephrectomy in patients with renal cortical tumours: a retrospective cohort study. Lancet Oncol 2006; 7: 735-40.

3. Porpiglia F, Vulpe A, Billia M, Scarpa RM. Laparoscopic versus open partial nephrectomy: analysis of the current literature. Eur Urol 2008; 53: 732-42.

4. Ficarra V, Bhayani S, Porter J, Buffi N, Lee R, Cestari A, Mottrie A. Predictors of warm ischemia time and perioperative complications in a multicenter, international series of robot-assisted partial nephrectomy. Eur Urol 2012; 61: 395-402.

5. Mottrie A, De Naeyer G, Schattenberg P, Carpentier P, Sangalli M, Ficarra V. Impact of the learning curve on perioperative outcomes in patients who underwent robotic partial nephrectomy for parenchymal renal tumours. Eur Urol 2010; 58: 127-32.

6. Aboumarzouk OM, Stein RJ, Eyraud R, Haber GP, Chlosta PL, Somani BK, Kaouk JH. Robotic versus laparoscopic partial nephrectomy: a systematic review and meta-analysis. Eur Urol 2012; 62: 1023-33.

7. Froghi S, Ahmed K, Khan MS, Dasgupta P, Challacombe B. Evaluation of robotic and laparoscopic partial nephrectomy for small renal tumours (T1a). BJU Int 2013; 112: E322-33.

8. Benway BM, Bhayani SB, Rogers CG, Dulabon LM, Patel MN, Lipkin M, Wang AI, Stifelman MD. Robot assisted partial nephrectomy versus laparoscopic partial nephrectomy for renal tumors: a multi-institutional analysis of perioperative outcomes. J Urol 2009; 182: 866-72.

9. Spenlde PC, Power N, Ghoneim T, Touijer KA, Dalbagni G, Russo P, Coleman JA. Comparison of open and minimally invasive partial nephrectomy for renal tumors 4-7 centimeters. Eur Urol 2012; 61: 593-9.

10. Boylu U, Basatca C, Yildirim U, Onol FF, Gunus E. Comparison of surgical, functional, and oncological outcomes of open and robot-assisted partial nephrectomy. J Minim Access Surg 2015; 11: 72-7.

11. Amano H, Kondo T, Hashimoto Y, Kobayashi H, Izuka J, Shimada K, Nakazawa H, Ito F; Tanabe K. Contralateral metachronous tumor occurrence is more frequently associated with distant metastases or postoperative intrarenal recurrence in renal cell carcinoma patients. Int J Urol 2010; 17: 615-22.

12. Kutikov A, Uzzo RG. The R.E.N.A.L. nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol 2009; 182: 841-53.

13. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schudack RD, de Santibanes E, Pokolj I, Slankamenac K, Bassi C, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg 2009; 250: 187-96.

14. Ahlering TE, Skarecky D, Lee D, Clayman RV. Successful transfer of open surgical skills to a laparoscopic environment using a robotic interface: initial experience with laparoscopic radical prostatectomy. J Urol 2003; 170: 1738-41.

15. Lee S, Oh J, Hong SK, Lee SE, Byun SS. Open versus robot-assisted partial nephrectomy: effect on clinical outcome. J Endourol 2011; 25: 1181-5.

16. Simhan J, Smaldone MC, Tsai KJ, Li T, Reyes JM, Canter D, Kutikov A, Chen DY, Greenberg RE, Uzzo RG, et al. Perioperative outcomes of robotic and open partial nephrectomy for moderately and highly complex renal lesions. J Urol 2012; 187: 2000-4.

17. Oh JI, Byun S, Hong SK, Jeong CW, Lee SE. Comparison of robotic and open partial nephrectomy: Single-surgeon matched cohort study. Can Urol Assoc J 2014; 8: E471-5.

18. Minervini A, Vittori G, Antonelli A, Celia A, Crivellaro S, Dente D, Di Santo V, Frea B, Gacci M, Gritti A, et al. Open versus robotic-assisted partial nephrectomy: a multicenter comparison study of perioperative results and complications. World J Urol 2014; 32: 287-93.

19. Lee CS, Cha RH, Lim YH, Kim H, Song KH, Gu N, Yu KS, Lim CS, Han JS, Kim S, et al. Ethnic coefficients for glomerular filtration rate estimation by the Modification of Diet in Renal Disease study equations in the Korean population. J Korean Med Sci 2010; 25: 1616-25.

20. Stevens LA, Coresh J, Greene T, Levey AS. Assessing kidney function—measured and estimated glomerular filtration rate. N Engl J Med 2006; 354: 2473-83.

21. Fergany AF, Saad IR, Woo L, Novick AC. Open partial nephrectomy for tumor in a solitary kidney: experience with 400 cases. J Urol 2006; 173: 1630-3.

22. Gill IS, Colombo JR Jr, Moinzadeh A, Finelli A, Ukimura O, Tucker K, Kaouk J, Desai M. Laparoscopic partial nephrectomy in solitary kidney. J Urol 2006; 175: 454-8.

23. Hilleny SP, Bhayani SB, Allaf ME, Rogers CG, Stifelman MD, Tanagho V, Mullins JK, Chiu Y, Kaczmarek BF, Kaouk JH. Robotic partial nephrectomy for solitary kidney: a multi-institutional analysis. Urology 2013; 81: 93-7.

24. Choi KH, Yoon YE, Kim KH, Han WK. Contralateral kidney volume change as a consequence of ipsilateral parenchymal atrophy: promotes overall renal function recovery after partial nephrectomy. Int J Urol Nephrol 2015; 47: 25-32.

25. Zargar H, Akca O, Autorino R, Branda LF, Layndner H, Krishnan J, Samra-sekera D, Stein RJ, Kaouk JH. 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 2015; 115: 787-95.
tomy correlates with functional preservation of operated kidney: a multi-institutional assessment using MAG3 renal scan. World J Urol. Forthcoming 2015.

27. Funahashi Y, Yoshino Y, Sassa N, Matsukawa Y, Takai S, Gotoh M. Comparison of warm and cold ischemia on renal function after partial nephrectomy. Urology 2014; 84: 1408-12.

28. Funahashi Y, Hattori R, Yamamoto T, Sassa N, Fujita T, Gotoh M. Effect of warm ischemia on renal function during partial nephrectomy: assessment with new 99mTc-mercaptoacetyltriglycine scintigraphy parameter. Urology 2012; 79: 160-4.

29. Ginzburg S, Uzzo R, Walton J, Miller C, Kurz D, Li T, Handorf E, Gor R, Corcoran A, Viterbo R, et al. Residual parenchymal volume, not warm ischemia time, predicts ultimate renal functional outcomes in patients undergoing partial nephrectomy. Urology 2015; 86: 300-5.

30. Kwon T, Jeong IG, Ryu J, Lee C, Lee C, You D, Kim CS. Renal function is associated with nephrometry score after partial nephrectomy: a study using diethylene triamine penta-acetic acid (DTPA) renal scanning. Ann Surg Oncol 2015; 22 Suppl 3: 1594-600.

31. Khalifeh A, Autorino R, Eyraud R, Samarasekera D, Laydner H, Panama-trassamee K, Stein RJ, Kaouk JH. Three-year oncologic and renal functional outcomes after robot-assisted partial nephrectomy. Eur Urol 2013; 64: 744-50.

32. Koo HJ, Lee DH, Kim IW. Renal hilar control during laparoscopic partial nephrectomy: to clamp or not to clamp. J Endourol 2010; 24: 1283-7.

33. Zargar H, Akca O, Ramirez D, Brandao LF, Laydner H, Krishnan J, Stein RJ, Kaouk JH. The impact of extended warm ischemia time on late renal function after robotic partial nephrectomy. J Endourol 2015; 29: 444-8.

34. Simmons MN, Lieser GC, Fergany AF, Kaouk J, Campbell SC. Association between warm ischemia time and renal parenchymal atrophy after partial nephrectomy. J Urol 2013; 189: 1638-42.

35. Volpe A, Blute ML, Ficarra V, Gill IS, Kutikov A, Pompiglia F, Rogers C, Touijer KA, Van Poppel H, Thompson RH. Renal ischemia and function after partial nephrectomy: a collaborative review of the literature. Eur Urol 2015; 68: 61-74.