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ORIGINAL ARTICLE

Partial nephrectomy for hilar tumors: comparison of conventional open and robot-assisted approaches

Hideaki Miyake · Nobuyuki Hinata · Satoshi Imai · Junya Furukawa · Kazushi Tanaka · Masato Fujisawa

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Abstract
Background To characterize clinical advantages in robot-assisted partial nephrectomy (RAPN) for targeting renal hilar tumors, and compare them with those of open PN (OPN).
Methods This study included 31 consecutive patients with renal hilar tumors, consisting of 15 and 16 who received OPN and RAPN, respectively, between January 2012 and May 2014. The perioperative and oncological outcomes of the two approaches were compared. In this series, a hilar tumor was defined as a renal cortical tumor located in the renal hilum that was shown, by preoperative imaging, to be in direct physical contact with the renal artery and/or vein.
Results There were no significant differences between demographic variables of the OPN and RAPN groups. Intended surgical procedures were successfully completed for all 31 cases. Despite lack of a significant difference between ischemia times in the two groups, operative time for RAPN was significantly longer than for OPN, and estimated blood loss during RAPN was significantly less than that during OPN. There were no significant differences between incidence of postoperative complications or percentage decrease in estimated glomerular filtration rate 4 weeks after surgery in the two groups. Indicators of postoperative recovery seemed to favor RAPN compared with OPN, with significant differences. No patient in either group was pathologically diagnosed with a positive surgical margin.
Conclusions These findings suggest that, compared with OPN, RAPN is an effective, safe, and less invasive surgical option for renal hilar tumors.

Keywords Robot-assisted partial nephrectomy · Open partial nephrectomy · Hilar tumor

H. Miyake (✉) · N. Hinata · S. Imai · J. Furukawa · K. Tanaka · M. Fujisawa
Division of Urology, Kobe University Graduate School of Medicine, 7-5-1 Kusunoki-cho, Chuo-ku, Kobe 650-0017, Japan
e-mail: hideakimiyake@hotmail.com

Introduction

Partial nephrectomy (PN) is currently regarded as a standard treatment for patients with renal tumors ≤4 cm and for selected tumors up to 7 cm, because accumulating evidence has shown that PN can achieve equivalent oncological outcomes with the additional benefit of preserving renal function compared with radical nephrectomy [1]. Despite being regarded as a promising minimally invasive approach that reduces morbidity, laparoscopic PN (LPN) has not been widely accepted because of its technical difficulty. As a result, difficult tumor locations have traditionally been regarded as a contraindication to LPN even in the hands of experienced laparoscopic surgeons [2].

PN for renal hilar tumors is particularly challenging in minimally invasive surgery because of close proximity to the major renal vessels and collecting system and the lack of a hilar parenchymal margin for renorrhaphy [3]; therefore, highly complex hilar tumors have commonly been removed by open PN (OPN), for better access to the hilar vessels, direct compression of the parenchyma, and secure renorrhaphy. Since the recent introduction to nephron-sparing surgery of a robot-assisted system which has several advantages, including 7 degrees of motion, 3-dimensional (3D) visualization, elimination of physiological tremors, and improved dexterity [4], several studies have suggested that robot-assisted PN (RAPN) could overcome the technical challenges associated with the conventional laparoscopic procedure, resulting in increased opportunities to apply this novel approach, even for complex hilar tumors [4–7]. To date, however, limited information has been available from comparison of clinical outcomes between OPN and RAPN for renal hilar tumors.

For this reason we retrospectively reviewed perioperative, renal functional, and oncological outcomes for 31 consecutive patients with renal hilar tumors who were treated with either OPN or RAPN between January 2012 and May 2014 at our institution, and conducted a comparative study of the two surgical approaches.

Patients and methods

Patients

After excluding patients with a solitary kidney, this study included 31 consecutive patients with renal hilar tumors, consisting of 15 and 16 who underwent OPN and RAPN, respectively, at our institution between January 2012 and May 2014. The Institutional Research Ethics Committee approved the design of this study, and informed consent was obtained from all of the patients included. At our institution use of OPN or RAPN depends on a variety of factors associated with the characteristics of the patients (comorbidities, body mass index, renal function, anatomic anomalies, and previous surgical procedures) and the tumors (size and location); there were no specific clinical factors identified as absolute contraindications to either procedure. On the basis of these factors, the surgical approach for renal hilar tumors (i.e., OPN or RAPN) was finally selected taking into consideration the preferences of the surgeon and patient. All patients underwent preoperative imaging examination with contrast-enhanced computed tomography (CT) and magnetic resonance imaging. In this study, a hilar tumor was defined as a renal cortical tumor located in the renal hilum that was shown by preoperative imaging examination, and confirmed intraoperatively, to be in direct physical contact with the renal artery and/or vein. All clinical characteristics and operative and postoperative findings were obtained from the patients' medical records. for each patient, the estimated glomerular filtration rate (eGFR) was calculated by use of the Chronic Kidney Disease Epidemiology formula [8], and the RENAL nephrometry score was evaluated on the basis of the preoperative tumor characteristics on imaging examination, as described elsewhere [9]. Postoperative complications were classified by use of the Clavien–Dindo system [10].

Surgical procedures

OPN was performed by a single surgeon (H.M.) using a flank retroperitoneal approach, in accordance with a previously reported procedure with a minor modification [11]. Briefly, ice slush was placed around the kidney, and under cold ischemic conditions involving clamping the renal artery and vein the tumor was excised with an adequate surrounding margin of normal renal tissue. Opened calyces and bleeding sites were sutured and the parenchymal defect was closed with horizontal interrupted sutures.

RAPN was performed by a single surgeon (M.F.) by use of a 3-arm da Vinci® robot system (Intuitive Surgical, Sunnyvale, California, USA) under a pneumoperitoneum of 12 mmHg. In this series, either a transperitoneal or retroperitoneal approach was selected, depending on the location of the renal tumor. The surgical procedures used for RAPN at our institution have been reported in detail elsewhere [12]. Briefly, to assess tumor depth and plan the excision margins, an ultrasound probe was used. Bulldog clamps were placed on the renal artery, and the tumor was circumferentially excised with cold scissors while maintaining a visual margin of approximately 5 mm of the normal parenchyma. The depth of the cortical incision was usually increased to the renal sinus fat, and, upon reaching the central sinus, intra-renal vessels supplying the tumor tissues were clipped and divided. The collecting system and large vessels were closed by 3-0 V-Loc sutures, and parenchymal sutures with 2-0 V-Loc were then placed for cross-compression along the defect. In addition, when judged possible on the basis of preoperative imaging findings, the selective arterial clamping technique was applied for patients undergoing RAPN; that is, this technique was limited to cases with tumors specifically fed by a few segmental arteries. To facilitate selective clamping of the branch arteries, a novel image overlay navigation system was developed and used during RAPN, as described elsewhere [13].

Statistical analysis

All statistical analysis was performed by use of Statview 5.0 software (Abacus Concepts, Berkley, CA, USA). Several clinicopathological factors were analyzed by use of the chi-squared test, the unpaired t test, or the Mann–Whitney U test. A value of $P < 0.05$ was considered significant.

Results

The demographic characteristics of the 31 patients included in this study are summarized in Table 1. There were no significant differences between age, gender, body mass index, American Society of Anesthesiologists score, preoperative eGFR, laterality, tumor size, and RENAL nephrometry score in the OPN and RAPN groups.

In this series the intended surgical approaches were successfully completed for all 31 patients. In addition,

Table 1 Demographic characteristics

Characteristic	OPN ($n = 15$)	RAPN ($n = 16$)	P value
Age (years)	64.2 ± 12.2	63.3 ± 13.2	0.85
Gender (%)			
Male	10 (66.7)	14 (87.5)	0.17
Female	5 (33.3)	2 (12.5)	
BMI (kg/m^2)	24.4 ± 5.1	24.9 ± 4.2	0.77
ASA score	1.5 ± 0.5	1.4 ± 0.5	0.58
Preoperative eGFR (ml/min/1.73 m^2)	71.1 ± 13.8	70.6 ± 14.5	0.92
Laterality (%)			
Right kidney	8 (53.3)	10 (62.5)	0.61
Left kidney	7 (46.7)	6 (37.5)	
Tumor size (cm)	3.2 ± 0.9	3.0 ± 0.9	0.54
RENAL nephrometry score (%)			
Low	1 (6.7)	1 (6.25 %)	0.64
Intermediate	9 (60.0)	12 (75.0 %)	
High	5 (33.3)	3 (18.75 %)	

OPN open partial nephrectomy, *RAPN* robot-assisted partial nephrectomy, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *eGFR* estimated glomerular filtration rate

selective clamping of branch arteries was performed for 9 cases in the RAPN group without conversion to the conventional technique with main renal artery clamping. The perioperative outcomes for the 31 patients are listed in Table 2. Operative time for the RAPN group was significantly longer than for the OPN group. Although no patient received a transfusion, estimated blood loss in the RAPN group was significantly less than in the OPN group. In addition, there was no significant difference between the ischemia times in the two groups.

Severe postoperative complications corresponding to Clavien–Dindo system ≥2 developed in 1 patient, only, in the OPN group; there was no significant difference between overall incidence of postoperative complications In the OPN and RAPN groups. Furthermore, there was no significant difference between eGFR 4 weeks after surgery in the two groups, and no significant difference between percentage eGFR decrease 4 weeks after surgery in the groups.

As shown in Table 2, variables related to postoperative recovery, i.e. time to walk, time to oral intake, and time to permission for discharge, were compared for the OPN and RAPN groups; all three factors favored the RAPN group, with significant differences compared with the OPN group. Moreover, no patient in either the OPN or RAPN group was pathologically diagnosed with a positive surgical margin. During the observation period of this study, disease recurrence was not noted for any patient.

Discussion

Renal tumors of smaller size are increasingly being detected. Accumulating evidence suggests the use of PN results in equivalent oncological and superior renal functional outcomes compared with those of radical nephrectomy. PN is, therefore, currently regarded as the new standard of care for small localized renal tumors [1]. With progress in minimally invasive renal surgery, a laparoscopic procedure has been applied to PN, and long-term results

Table 2 Perioperative outcomes

Variable	OPN ($n = 15$)	RAPN ($n = 16$)	P value
Operative time (min)	203.7 ± 55.2	263.0 ± 63.5	0.010
Estimated blood loss (ml)	653.6 ± 611.7	57.5 ± 96.9	<0.001
Transfusion (%)	0 (0)	0 (0)	NA
Ischemia time (min)	20.3 ± 9.1	23.0 ± 7.5	0.37
Conversion to			
Radical nephrectomy (%)	0 (0)	0 (0)	NA
OPN (%)	–	0 (0)	–
Postoperative eGFR (ml/min/1.73 m^2)[a]	61.1 ± 13.3	60.2 ± 11.5	0.84
Decrease in postoperative eGFR (%)[a]	10.0 ± 6.6	10.4 ± 7.0	0.87
Complications			
Overall (%)	3 (20.0)	1 (8.3)	0.25
Clavien–Dindo grade II < (%)	1 (6.7)	0 (0)	0.29
Time to walk after surgery (days)	1.4 ± 0.4	1.1 ± 0.2	0.012
Time to oral intake after surgery (days)	2.8 ± 0.6	2.1 ± 0.4	<0.001
Time until permission for discharge after surgery (days)	4.8 ± 0.8	4.2 ± 0.8	0.046
Positive surgical margins (%)	0 (0)	0 (0)	NA
Disease recurrence (%)	0 (0)	0 (0)	NA

OPN open partial nephrectomy, *RAPN* robot-assisted partial nephrectomy, *NA* not applicable, *eGFR* estimated glomerular filtration rate

[a] Evaluated 4 weeks after surgery

of LPN have been shown to be similar to those of OPN; however, the advanced skills and prolonged learning curve associated with LPN limit its dissemination as a standard surgical option [2, 14]. Despite still being an evolving procedure, RAPN, characterized by several features facilitating complex procedures during PN, for example magnified 3D visualization and articulating robotic instruments [4], could result in clinical outcomes comparable with or even superior to those of other surgical approaches [15]. This might be particularly true for renal hilar tumors [4–7], which have been regarded as a contraindication to LPN and are traditionally treated by OPN because of proximity to the main vessels and the complexity of renorrhaphy [2]. Considering these findings, we retrospectively reviewed our clinical experience with OPN and RAPN performed for renal hilar tumors at a single institution during the same period, and comprehensively compared the clinical outcomes for the two procedures.

At our institution, after introduction of a robotic system, RAPN has become the preferred approach for minimally invasive PN, particularly for technically challenging renal tumors. OPN is still an established option, depending on the surgeon's preference, and is usually applied to difficult cases, for example those with hilar tumors closely involving the major vessels. Thirty-one patients with renal hilar tumors were treated at our institution, consisting of 15 and 16 who received OPN and RAPN, respectively. There were no significant differences between demographic characteristics in the OPN and RAPN groups, indicating the recent expansion of indication for RAPN, which is now comparable with that for OPN. Furthermore, the intended surgical procedures were successfully completed for all 31 patients irrespective of surgical approach. Collectively, these findings suggest that both OPN and RAPN at our institution could be performed while maintaining surgical technique of acceptable quality.

We then compared perioperative outcomes for the OPN and RAPN groups. Although RAPN took significantly longer than OPN, there was no significant difference between ischemia time in the two groups. Although tumor excision during OPN, but not RAPN, was performed under cold ischemic conditions, no significant difference between postoperative percentage eGFR decrease was noted in the groups, suggesting, if the time is short, as in this study, a limited effect of warm ischemic conditions on postoperative change in renal function. Furthermore, ischemia time seems to be most likely to reflect the technical difficulty of PN; therefore, considering the lack of a difference between the ischemia time in the two groups, robotic assistance may have significant advantages during the complicated procedures performed during ischemia, even for challenging renal hilar tumors, resulting in a contribution to maximum preservation of the postoperative renal function.

In addition, estimated blood loss in the RAPN group was significantly less than that in the OPN group, which may be because of the presence of pneumoperitoneum and precise management of intra-renal vessels during tumor excision in the RAPN group. There were no significant differences between the incidence of postoperative complications in the OPN and RAPN groups, and no patient was pathologically diagnosed with a positive surgical margin in either group. As for issues associated with patient convalescence, all the factors examined in this series, i.e. time to walk, time to oral intake, and time until permission for discharge, significantly favored RAPN compared with OPN. Collectively, these findings suggest that outcomes from RAPN could be similar to those from OPN, with regard to safety and cancer control, and significantly superior to those from OPN as a minimally invasive approach for renal hilar tumors.

Although these findings suggest the usefulness of RAPN for renal hilar tumors, it is of interest to compare these findings with those of other studies. As shown in Table 3, which summarizes results from contemporary series of minimally invasive PN for hilar tumors [3–7, 16–20], outcomes in our series are comparable with those in previous RAPN series, or even superior to those in LPN series. In particular, our outcomes were derived on the basis of data from our initial experience with RAPN among 50 cases. This finding may be indicative of a very short learning curve for RAPN, even for hilar tumors, which could be regarded as one of the major advantages of RAPN. To further improve outcomes of RAPN for hilar tumors, particularly those associated with the warm ischemia time, several approaches have recently been reported [6, 13, 21]. For example, Abreu et al. [6] described their surgical technique of unclamped RAPN for hilar tumors, and reported perioperative outcomes comparable with those from early unclamping RAPN. We, also, have reported our experience with selective arterial clamping during RAPN for renal tumors, including those located at hilar lesions, by use of a novel image overlay navigation system, and indicated the usefulness of this procedure, which served as a helpful guide to find the target branch and optimum position for arterial clamping close to the tumor by revealing the course of segmental arteries until they reached the tumor, and therefore enabled precise dissection in a bloodless field and further improved renal function early after surgery [13].

Here, we would like to emphasize several limitations of this study. First, this was a retrospective comparative study of a small number of patients with a short follow-up period; it is, therefore, difficult to draw definitive conclusions concerning long-tern renal functional and prognostic issues. Second, despite being located in the renal hilum, renal tumors included in this series were characterized by small size; it is, therefore, necessary to consider this point when interpreting these outcomes. Third, a unified approach for

Table 3 Contemporary series of minimally invasive partial nephrectomy for hilar tumors

Ref.	Approach (no. of patients)	Tumor size (cm)	Operative time (min)	EBL (ml)	WIT (min)	Postoperative changes in eGFR (ml/min/1.73 m^2)	Postoperative complications (%)	Positive surgical margins (%)
Gill et al. [3]	LPN (25)	3.7	216	231	36	NA	5 (20.0)	0 (0)
Reisiger et al. [16]	LPN (8)	1.6	180	188	26	NA	6 (75.0)	0 (0)
Lattouf et al. [17]	LPN (18)	3.0	238	165	34	NA	3 (33.3)	1 (7.1)
Richstone et al. [18]	LPN (18)	3.2	173	394	29	NA	6 (33.3)	0 (0)
George et al. [19]	LPN (43)	3.6	129	312	19	−10.9	11 (25.6)	1 (2.3)
Di Pierro et al. [20]	LPN (11)	1.6	140	270	24	−6.0	2 (18.2)	1 (9.1)
Rogers et al. [4]	RAPN (11)	3.8	202	220	29	−8.0	NA	0 (0)
Dulabon et al. [5]	RAPN (41)	3.5	195	262	26	NA	NA	1 (2.4)
Abreu et al. [6]	RAPN (7)	3.8	237	229	0	1.3	2 (28.6)	0 (0)
Eyraud et al. [7]	RAPN (70)	3.9	210	250	27	−14.7	23 (32.9)	1 (1.4)
Present series	RAPN (16)	3.0	263	58	23	−10.4	1 (8.3)	0 (0)

EBL estimated blood loss, *WIT* warm ischemia time, *eGFR* estimated glomerular filtration rate, *LPN* laparoscopic partial nephrectomy, *NA* not available, *RAPN* robot-assisted partial nephrectomy

introducing ischemia was not used; that is, OPN and RAPN were performed under cold and warm ischemia, respectively. In addition, selective arterial clamping was applied to some of the cases receiving RAPN. These technical differences could have affected postoperative renal functional outcomes. Finally, a single well-experienced surgeon was involved with both surgical groups; hence, it may difficult to apply the findings of this study to real-world clinical practice.

In conclusion, in this study we comprehensively compared clinical outcomes for 15 and 16 patients with renal hilar tumors who underwent OPN and RAPN, respectively. On the basis of the findings obtained in this study, compared with OPN, RAPN seemed to result in favorable outcomes in terms of morbidity without sacrificing safety and cancer control for patients with hilar tumors; accordingly, it may be necessary to expand the indication for RAPN to highly challenging cases, for example patients with complicated hilar tumors.

Conflict of interest All authors have no conflict of interest.

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