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Kidney Cancer

Impact of Surgical Experience Before Robot-assisted Partial Nephrectomy on Surgical Outcomes: A Multicenter Analysis of 2500 Patients

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Abstract

Background: Robot-assisted partial nephrectomy (RAPN) is a challenging procedure that is influenced by a multitude of factors.
Objective: To assess the impact of prior surgical experience on perioperative outcomes in RAPN.
Design, setting, and participants: In this retrospective multicenter study, results for 2548 RAPNs performed by 25 surgeons at eight robotic referral centers were analyzed. Perioperative data for all consecutive RAPNs from the start of each individual surgeon's experience were collected, as well as the number of prior open or laparoscopic kidney surgeries, pelvic surgeries (open, laparoscopic, robotic), and other robotic interventions.
Intervention: Transperitoneal or retroperitoneal RAPN.
Outcome measurements and statistical analysis: The impact of prior surgical experience on operative time, warm ischemia time (WIT), major complications, and margin, ischemia, complication (MIC) score (negative surgical margins, WIT ≤20 min, no major complications) was assessed via univariate and multivariable regression analyses accounting for age, gender, body mass index (BMI), American Society of Anesthesiologists score, PADUA score, and RAPN experience.
Results and limitations: BMI, PADUA score, and surgical experience in RAPN had a strong impact on perioperative outcomes. A plateau effect for the learning curve

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was not observed. Prior laparoscopic kidney surgery significantly reduced the operative time ($p < 0.001$) and WIT ($p < 0.001$) and improved the MIC rate ($p = 0.022$). A greater number of prior robotic pelvic interventions decreased WIT ($p = 0.011$) and the rate of major complications ($p < 0.001$) and increased the MIC rate ($p = 0.011$), while prior experience in open kidney surgery did not. One limitation is the short-term follow-up.

Conclusions: Mastering of RAPN is an ongoing learning process. However, prior experience in laparoscopic kidney and robot-assisted pelvic surgery seems to improve perioperative outcomes for surgeons when starting with RAPN, while experience in open surgery might not be crucial.

Patient summary: In this multicenter analysis, we found that a high degree of experience in keyhole kidney surgery and robot-assisted pelvic surgery helps surgeons in achieving good initial outcomes when starting robot-assisted kidney surgery.

1. Introduction

Robot-assisted partial nephrectomy (RAPN) has become a widely accepted alternative to the open and conventional laparoscopic techniques for nephron-sparing surgery. To date, the individual approach is based on the surgeon's skill and expertise [1]. However, surgeon expertise is not well defined: multiple studies have investigated learning curves in robotic surgery with diverging results [2]. A multitude of data is available on single-surgeon and low-volume series, but this does not reflect intersurgeon variability [3]. While learning curves are often described as an improvement in one or multiple outcomes over time as the number of procedures and experience increase, important patient- and surgeon-dependent variables are lacking in many reports [4]. In this regard, one possible confounder might be the surgeon's surgical experience before adoption of a new technique. For the transition from laparoscopic to robotic colorectal surgery, a shorter learning curve has been postulated for experienced laparoscopic surgeons, as the anatomic landmarks are already well known [5]. However, this effect has not been confirmed consistently [6,7]. Moreover, Vickers et al. [8] described inferior outcomes for laparoscopic radical prostatectomy performed by experienced open surgeons and, according to Bravi et al. [9] the risk of positive surgical margins with the robotic approach was not affected by the number of previous open procedures.

In comparison to radical prostatectomy, procedural standardization is even more challenging in RAPN because of the significant variations in patient- and tumor-related factors [10]. This might be one reason why the impact of surgical experience on RAPN outcomes has not been investigated so far. Therefore, we performed a multicenter learning curve analysis of 25 robotic surgeons to assess the impact of prior experience with open, laparoscopic, and robotic urological procedures on surgical outcomes of RAPN.

2. Patients and methods

In this multicenter retrospective analysis, consecutive RAPNs from each individual surgeon's first case were included from eight teaching robotic departments. Procedures were performed by 25 robotic surgeons between 2007 and 2021. The interventions were performed via a transperitoneal or retroperitoneal approach, depending on surgical and center expertise. All RAPNs were performed using a da Vinci surgical Si, Xi, or X system. According to surgical need, intraoperative ultrasound was applied, occasionally after prior use of digital three-dimensional (3D) reconstruction models. Printed 3D models were not available.

Patient age, gender, body mass index (BMI), American Society of Anesthesiologists (ASA) score, histology results, and PADUA score were obtained as patient- and tumor-related factors. Operative time, estimated blood loss, warm ischemia time (WIT), postoperative complications according to the Clavien-Dindo classification [11], and positive surgical margins (PSMs) served as surgical factors. The margin, ischemia, complication (MIC) rate was defined as the absence of PSMs, WIT $\leq$20 min, and the absence of major complications [12].

To assess the influence of prior surgical experience on the learning curve, the individual numbers of open kidney, laparoscopic kidney, open pelvic, laparoscopic pelvic, robotic pelvic, and other robotic interventions before the first RAPN were obtained for each surgeon. The consecutive number RAPNs performed by the individual surgeon was defined as experience (EXP).

The primary outcome was defined as the impact of EXP and prior surgical experience on operative time, WIT, major complications, and the MIC rate. Comparative analysis of the effect of tumor- and patient-related factors (age, gender, BMI, ASA score, PADUA score) was carried out. In linear and logistic univariate and multivariable regression analyses, operative time, WIT, the absence of major complications, and MIC fulfillment served as the dependent variables. Surgeon EXP, individual prior surgical experience, and tumor- and patient-related factors were defined as independent variables. Surgeon EXP was defined as the absolute number of interventions, and an individual's prior surgical experience was measured per 100 interventions (both as continuous variables). To account for a potential interaction between PADUA score and EXP, an interaction term was added. An independent variable was only included in the multivariable regression if its effect was significant on univariate analysis.

Secondary outcomes were the learning curves for operative time, WIT, a major complication-free postoperative course, and fulfillment of MIC criteria. MIC fulfillment was estimated as the predicted value or probability as a function of EXP including 95% confidence intervals (CIs). The learning curves for WIT and MIC were further stratified by PADUA score and prior laparoscopic kidney and robotic pelvic interventions.

Results are reported as the median and range for continuous variables and the absolute frequency and percentage for categorical variables [13]. Logistic and linear regression analyses were performed using SPSS version 23 (IBM, Armonk, NY, USA). All tests were two-sided, p-values <0.05 were considered significant. This study was approved by the ethical review boards of Hannover Medical School (reference 9812_BO_K_2021) and Saarland (reference 180/21).

3. Results

3.1. Patient characteristics and overall outcome

Overall, 2548 RAPNs were included from eight departments at a median caseload of 180 procedures (range 101–772). A total of 1868 tumors (73%) were malignant, of which 65% had clear cell morphology (Table 1). Most tumors were pT1 stage, with 1350 (72%) pT1a and 362 (19%) pT1b tumors. The PADUA score was evenly distributed, with 29% low-risk (PADUA 6–7), 33% intermediate-risk (PADUA 8–9), and 32% high-risk (PADUA $\geq$10) tumors. The median operative time was 152 min and 84% of the RAPNs were performed transperitoneally. Some 88% of the tumors were excised on-clamp within 13 min. Major complications occurred in 8% of cases, and MIC was achieved in 1907 RAPNs (75%).

3.2. Influence of EXP on surgical outcomes

The 25 surgeons had a median caseload of 52 RAPNs (range 18–524); eight (32%) had performed more than 100 RAPNs, and two (8%) had performed more than 200 (Supplementary Fig. 1). Increasing EXP had a strong effect not only on operative time, WIT, and major complications but also on MIC fulfillment on multiple regression analysis (all $p < 0.001$; Table 2, Supplementary Tables 1–3). The corresponding predicted learning curves illustrate an estimated decreases of 17 min (95% CI 19–16) in operative time and 2.0 min (95% CI 1.8–2.2 min) in WIT per 100 RAPN cases (Fig. 1). At EXP of 300 RAPN, the predicted learning curve for a major complication-free course exceeded 95% and the MIC rate reached 90%. However, none of the learning curves appeared to reach a plateau (Fig. 1).

Table 1 – Patient characteristics and perioperative outcomes for 2548 robot-assisted partial nephrectomies

Parameter	Result
Median age, yr (range)	64 (20–93)
Male, *n* (%)	1645 (65)
Median body mass index, kg/m^2 (range)	27 (15–60)
Median American Society of Anesthesiologists score (range)	2 (1–4)
Median PADUA score (range)	8 (6–14)
Low risk (score 6–7), *n* (%)	726 (29)
Intermediate risk (score 8–9), *n* (%)	833 (33)
High risk (score $\geq$10), *n* (%)	802 (32)
Risk not defined, *n* (%)	187 (7)
Malignant histology, *n* (%)	1868 (73)
Clear cell	1219 (48)
Papillary (type I and II)	449 (18)
Chromophobe	152 (6.0)
T stage, *n* (%)	
pT1	1712 (92)
pT2	44 (5.3)
pT3	90 (4.8)
pT4	3 (0.2)
Surgical access, *n* (%)	
Transperitoneal	2252 (88)
Retroperitoneal	296 (12)
Median operating time, min (range)	152 (35–585)
Off-clamp resections, *n* (%)	295 (12)
Median warm ischemia time, min (range)	13 (1–60)
Postoperative complications, *n* (%)	
None	1984 (78)
Minor (Clavien-Dindo grade 1–2)	356 (14)
Major (Clavien-Dindo grade 3–5)	206 (8.1)
Positive surgical margins, *n* (%)	80 (3.1)
Margin, ischemia, complication outcome achieved, *n* (%)	1907 (75)
Median length of stay, d (range)	7 (2–65)

3.3. Impact of patient- and tumor-related factors on outcomes

On multivariable regression analysis, BMI was associated with longer operative time, while older patient age was associated with a higher major complication rate and a lower MIC rate (all $p < 0.05$; Table 2, Supplementary Tables 1 and 3). PADUA score had a significant impact on all perioperative outcomes (all $p < 0.001$): each 1-point increment in PADUA score increased the operative time by 7.2 min (95% CI 6.0–8.4), WIT by 1.0 min (95% CI 0.9–1.2), and the odds ratio (OR) for major complications by 1.17 (95% CI 1.01–1.28), while the OR for MIC fulfillment decreased by 0.74 (95% CI 0.69–0.79). When stratifying predicted learning curves for WIT by PADUA score, the estimated WIT fell below 15 min with EXP of 100 cases for PADUA 9 tumors, but required EXP of 200 cases for PADUA 11 tumors (Fig. 2). Correspondingly, the estimated MIC rate was 90% for PADUA 8 tumors, but only 80% for PADUA 11 tumors at EXP of 200 cases (Fig. 2). There was no statistically significant interaction between surgical experience and PADUA score in all multivariable analyses.

3.4. Impact of prior surgical experience

Each of the 25 surgeons had undergone different surgical training (Table 3). Fifteen (60%) had some training and experience in conventional laparoscopy. All of the surgeons had performed open kidney surgery and other robotic interventions before their first RAPN.

On multivariable regression analysis, all prior surgical intervention categories had a significant effect on perioperative outcomes. Prior laparoscopic kidney surgery significantly reduced the operative time for RAPN (17 min per 100 interventions; $p < 0.001$), but the decrease was not as great with prior laparoscopic pelvic surgery (7.6 min per 100 interventions; $p < 0.001$; Supplementary Table 1). Experience with prior laparoscopic kidney surgery decreased WIT and increased the MIC rate ($p \leq 0.022$). Prior robotic pelvic surgery experience decreased WIT, lowered the risk of major complications, and increased the MIC rate (all $p < 0.05$). Prior experience in open kidney surgery was not beneficial in our cohort and even negatively impacted the MIC rates (OR 0.82; $p < 0.001$; Table 2).

When stratifying the predicted learning curve for WIT by the number of prior laparoscopic kidney interventions, the predicted WIT was <15 min from the very first RAPN for surgeons with $\geq$200 prior laparoscopic kidney interventions (Fig. 2). By contrast, WIT fell below 15 min after reaching EXP of 80 cases for surgeons with 100–199 prior laparoscopic kidney interventions (Fig. 2). Correspondingly, the

Table 2 – Logistic regression to assess the impact of patient- and tumor-related factors, surgical experience in RAPN, and prior surgical experience on the MIC score

	Univariate		Multivariable	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Age	0.99 (0.98–1.0)	0.042	0.99 (0.98–1.00)	0.036
Gender (reference: male)	1.08 (0.89–1.32)	0.5	–	–
Body mass index	0.98 (0.96–1.0)	0.037	0.98 (0.96–1.00)	0.059
ASA score	0.81 (0.69–0.95)	0.009	0.96 (0.79–1.16)	0.4
PADUA score	0.82 (0.78–0.87)	<0.001	0.74 (0.69–0.79)	<0.001
Surgical experience				
RAPN	1.005 (1.004–1.008)	<0.001	1.005 (1.003–1.006)	<0.001
Prior open kidney surgery	1.04 (1.02–1.07)	0.002	0.82 (0.77–0.88)	<0.001
Prior laparoscopic kidney surgery	1.3 (1.1–1.4)	<0.001	1.2 (1.0–1.3)	0.022
Prior open pelvic surgery	1.04 (1.03–1.06)	<0.001	1.07 (1.03–1.10)	<0.001
Prior laparoscopic pelvic surgery	1.02 (0.95–1.09)	0.7	–	–
Prior robotic pelvic surgery	1.2 (1.1–1.3)	<0.001	1.2 (1.1–1.3)	0.003
Prior other robotic surgery	1.14 (0.99–1.31)	0.073	–	–
PADUA-RAPN interaction	1.0 (1.0–1.001)	<0.001	1.0 (1.0–1.001)	0.223

ASA = American Society of Anesthesiologists; CI = confidence interval; MIC = margin, ischemia, complication; RAPN = robot-assisted partial nephrectomy.

predicted probability of MIC fulfillment was higher for robotic surgeons with a greater experience in robotic pelvic interventions (Fig. 2).

4. Discussion

Within the past two decades, it has been proven that RAPN is a valid alternative to the open and laparoscopic approaches with at least equivalent outcomes [14]. However, especially for surgeons at the beginning of their career in robotic surgery, RAPN may lead to suboptimal outcomes [15]. Therefore, the European Association of Urology Robotic Urology Section (ERUS) recently developed a training curriculum for RAPN that includes strategies to foster standardization of surgical steps and quality [15]. In the present study we analyzed the learning curves of 25 surgeons from their first RAPN to assess the impact of prior surgical experience on perioperative outcomes. In brief, prior laparoscopic kidney and robot-assisted pelvic surgeries appeared to improve RAPN results, while prior open kidney surgery did not.

When comparing fellows with expert surgeons in RAPN, Khene et al. [16] found longer operative time (by 60 min) and WIT (18 vs 14 min) and lower MIC scores for surgeries performed by the nonexperts. An increase in operative time by 1 h by an inexperienced surgeon was confirmed in the ERUS RAPN curriculum study [15].

In a single-surgeon analysis in 2010, Mottrie et al. [17] observed significant decreases in console time (from 125 to 68 min) and WIT (from 28 to 16 min) after 50 patients. The authors hypothesized that 30–40 cases are needed to master RAPN, which is in line with Zeuschner et al. [18], who considered a console surgeon to be experienced after 35 RAPN cases. Our present results validate a significant impact of EXP on operative times and WIT, but none of these outcomes reached a plateau. While this is in contrast to the plateau in WIT after 150 cases defined by Larcher et al. [19], it underlines the possibly infinite learning process described by Paulucci et al. [20], who analyzed the learning curves of four surgeons with an individual caseload higher than 300 RAPNs. The authors demonstrated a persistent influence of EXP after the initial learning curve of 50 cases on WIT, a trifecta outcome (WIT ≤25 min, no complications, no PSMs), blood loss, and length of hospital stay up to 300 cases per surgeon. In accordance with their data, our study also illustrates the effect of EXP on complication rates and the MIC score: again, despite improving results over time, the curves do not appear to reach a plateau.

One potential reason for this infinite learning process might be growing self-confidence and a shift towards more challenging cases. Whereas patient-related factors such as age and BMI had a rather heterogeneous impact in our multivariable analyses, the PADUA score, one of the major surrogates for tumor complexity, had a significant effect on all perioperative outcomes: a higher PADUA score resulted in longer operative time and WIT, a higher number of major complications, and a lower MIC rate. Therefore, for cases with higher PADUA scores, higher levels of experience were required to achieve comparable WIT and MIC scores. Roman et al. [10] evaluated the impact of case mix on the RAPN learning curve and found an increase in tumor complexity throughout the first 100 cases of a single surgeon. Likewise, Xie et al. [21] observed significant evolution of tumor complexity over 144 RAPN cases combined with shorter WIT (from 20 to 16 min) and an improvement in MIC rate (from 40% to 86%). Although tumor complexity and EXP had a significant effect on the WIT and MIC score individually, the difference was not significant when both variables were considered simultaneously [22]. One reason may be that the number of cases in this study is much higher (2500 cases performed by 25 surgeons).

While Xie et al. [21] summarized RAPN results for a single surgeon with experience of >1000 laparoscopic partial nephrectomies before the first robotic case, the influence of prior surgical experience has seldom been analyzed in the literature. Castilho et al. [23] demonstrated the learning curve of a single surgeon after direct transition from open to RAPN by comparing the first 50 and subsequent 50 cases: WIT significantly decreased and achievement of a trifecta of outcomes increased. Likewise, Motoyama et al. [24] reported on the learning curve for 65 RAPNs performed by a surgeon with 300 prior robot-assisted radical prostatectomies, but only 15 laparoscopic partial nephrectomies. The median WIT was 15 min, with a significant reduction

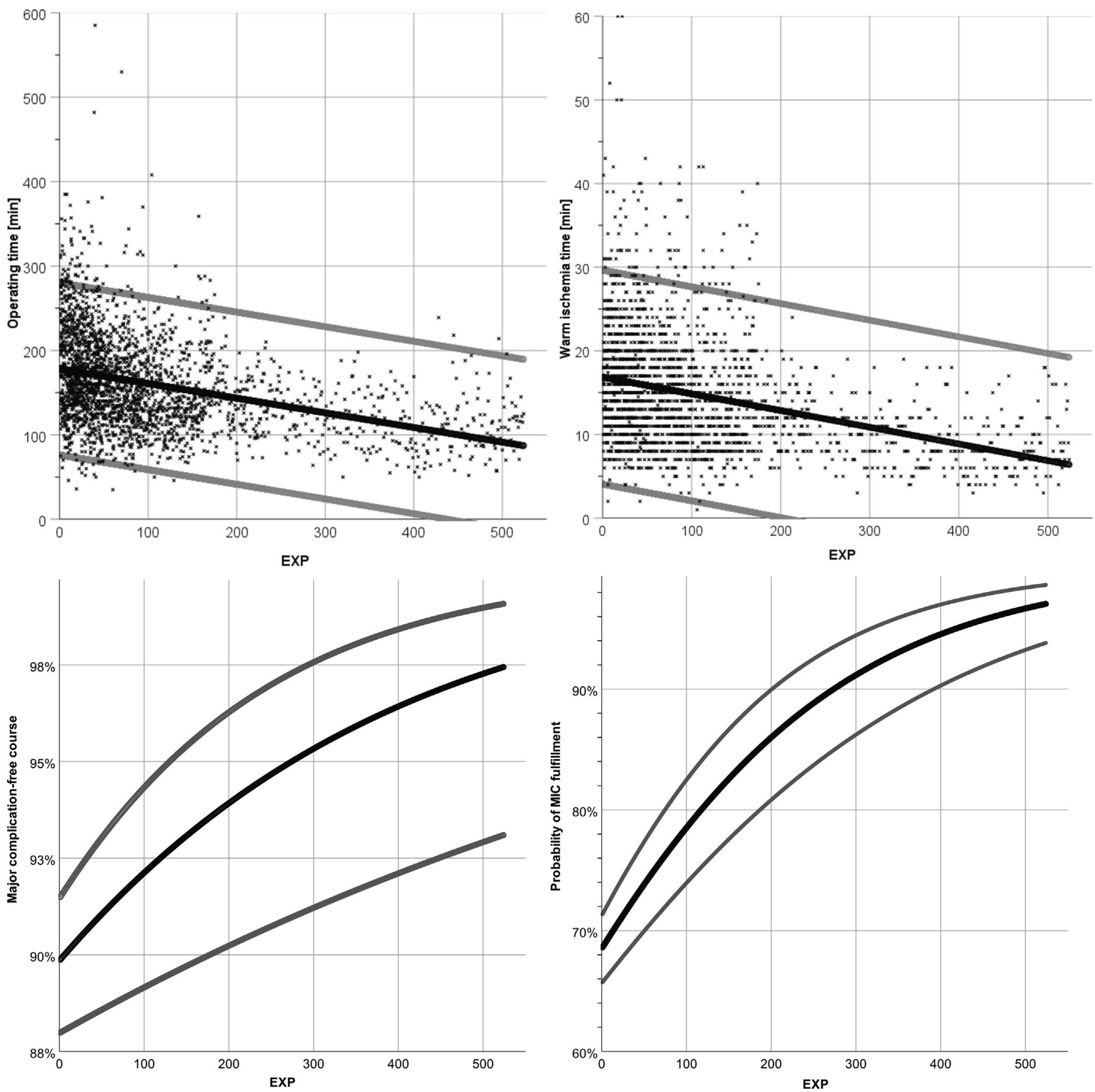

Fig. 1 – Learning curves for the surgeons in terms of operating time, warm ischemia time, and the probability of a major complication-free postoperative course and MIC fulfillment. Predicted values were calculated as a function of surgical experience in robot-assisted partial nephrectomy (EXP) via univariate regression analyses. Gray lines indicate the corresponding 95% confidence intervals. The actual operating time and warm ischemia time for each case are denoted by small crosses. MIC = margin, ischemia, complication rate.

over time. The cutoff of 20 min was achieved after four cases. By contrast, Dias et al. [25] analyzed the learning curve of a laparoscopic surgeon without previous robotic experience who had to complete 44 cases before achieving tumor resection (and defect closure) within a WIT of <20 min. One potential explanation for the shorter WIT of a surgeon experienced in robotic radical prostatectomy might be the suturing skills acquired during vesicourethral anastomosis. However, the question of whether the learning curve can be improved by prior surgical experience and if laparoscopic, open, or robotic training is necessary for faster development cannot be answered with single-surgeon series. Dagenais et al. [3] analyzed data for 1461 patients undergoing RAPN performed by 19 surgeons and observed significant intersurgeon variance. Some of the differences in perioperative outcomes could be explained by tumor and patient characteristics, but surgeon variability had a significant impact on critical variables including operative time and WIT.

With the condensed results for 25 surgeons from eight institutions, the present study emphasizes the different starting points for novices in RAPN: six (24%) surgeons

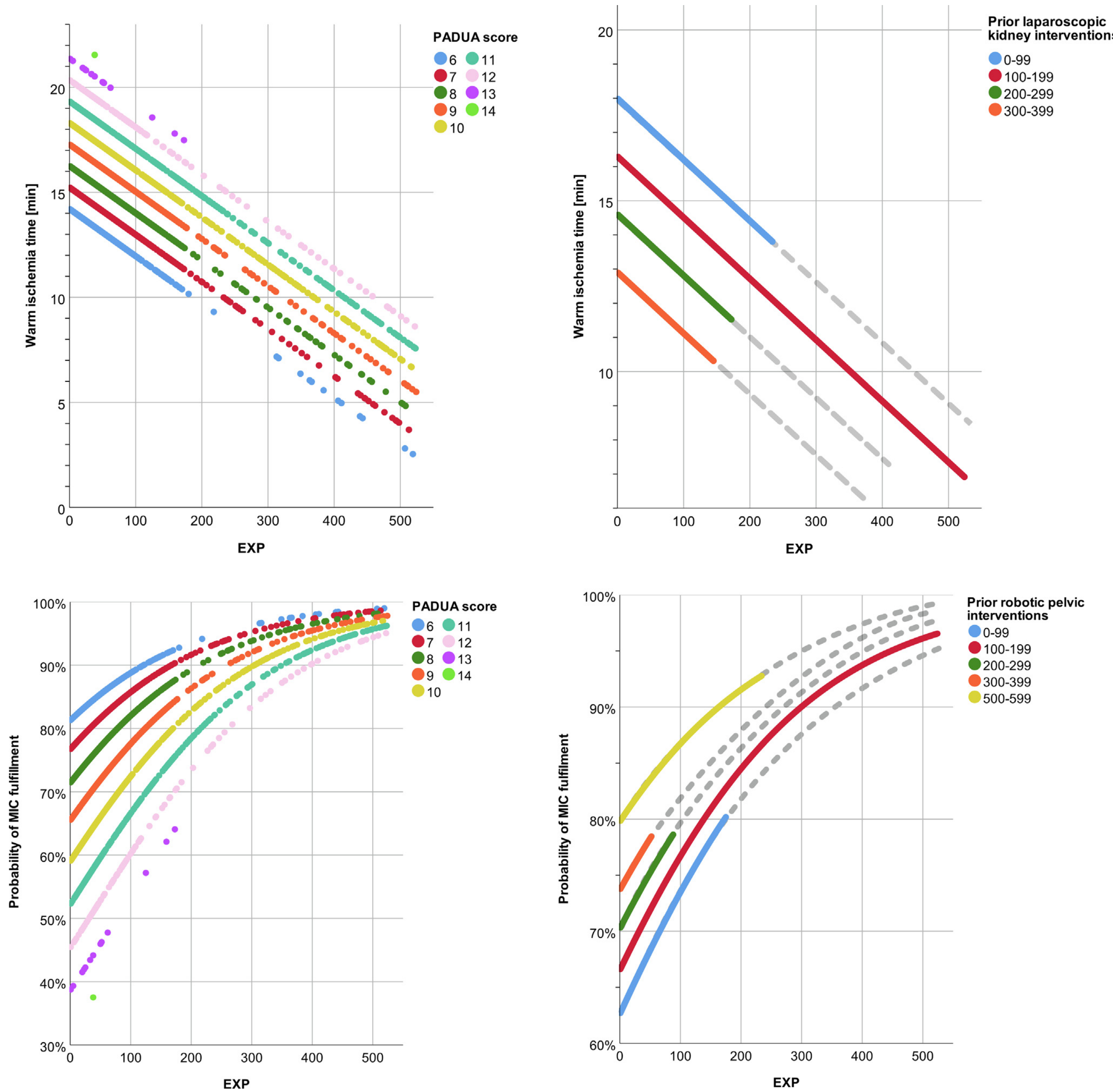

Fig. 2 – Learning curves for the surgeons in terms of predicted warm ischemia time and the probability of MIC fulfillment as a function of surgical experience in robot-assisted radical nephrectomy (EXP) on univariate regression analysis. The learning curves are stratified by PADUA score and the number of prior laparoscopic kidney interventions and robotic pelvic interventions. Dots represent individual cases and lines are only apparent because of overlap. Gray dashed lines indicate the most probable graphical trend. MIC = margin, ischemia, complication rate.

had performed fewer than 25 open partial nephrectomies before, while others had performed more than 500. Likewise, experience in conventional laparoscopic surgery varied considerably, with 40% of urologists inexperienced in this approach. However, the benefits of prior surgical experience for perioperative outcomes were heterogeneous: extensive expertise in open kidney surgery might not be crucial for improving RAPN outcomes. On the contrary, prior experience in laparoscopic renal interventions appeared to be beneficial for all the quality criteria measured. Shorter WIT without a decrease in operative time was achieved by robotic pelvic surgeons. These findings support the theory that familiarity with the anatomic landmarks and access to the hilum after previous laparoscopic experience, as well as laparoscopic and robotic suturing skills, has a positive impact on RAPN.

While this multicenter study involving more than 2500 RAPN procedures illuminates important aspects of the learning curve, some limitations must be mentioned. First, the study period covered a time span of more than 10 yr in which a multitude of changes in surgical techniques and robotic systems occurred. Several authors have highlighted the importance of hospital case volume, the institutional learning curve, and the impact of the bedside

Table 3 – Number of prior surgeries performed by the robotic surgeons before their first robot-assisted partial nephrectomy

Procedure	Median number performed (range)	Surgeons with <25 cases, *n* (%)
Open kidney surgery	145 (3–1500)	6 (24)
Laparoscopic kidney surgery	5 (0–300)	14 (56)
Open pelvic surgery	500 (0–3500)	6 (24)
Laparoscopic pelvic surgery	3 (0–510)	17 (68)
Robotic pelvic surgery	100 (0–550)	8 (32)
Other robotic surgery	23 (0–250)	13 (52)

assistant or the presence of a fellow in training or a proctor during surgery; however, these data were not available [18,26,27]. Moreover, not all the surgeons were performing a robotic procedure for the first time and had undergone different forms of "training" before and during their first RAPN cases, which was not evaluated; access to a simulator and proctoring might also have impacted the initial results [28,29]. Finally, only short-term perioperative outcomes were analyzed. However, the current study addresses most of the points of criticism in previous learning curve analyses and includes patient- and tumor-related factors, prior surgical experience, and the individual development of multiple surgeons in a large cohort [4].

5. Conclusions

RAPN is a challenging procedure with an ongoing learning process that is influenced by multiple patient-, tumor-, and surgeon-related factors. Besides tumor complexity and an increasing surgeon caseload, prior surgical experience also has a major impact on perioperative outcomes. In particular, prior laparoscopic kidney and robot-assisted interventions appear to improve the results of RAPN. Future training concepts might incorporate these findings for prospective validation.

Author contributions: Nina N. Harke had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Harke, Zeuschner.
Acquisition of data: Harke, Zeuschner, Huusmann, Schiefelbein, Schneller, Schoen, Wiesinger, Pfuner, Ubrig, Gloger, Osmonov, Eraky, Witt, Liakos, Wagner, Radtke, Al Nader, Imkamp, Siemer, Stöckle.
Analysis and interpretation of data: Harke, Zeuschner.
Drafting of the manuscript: Harke, Zeuschner.
Critical revision of the manuscript for important intellectual content: Witt, Hadaschik, Kuczyk, Radtke, Schiefelbein, Schoen, Wiesinger, Ubrig, Osmonov, Wagner, Imkamp, Siemer, Stöckle.
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Appendix A. Supplementary data

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