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The Learning Curve for Robot-assisted Partial Nephrectomy: Impact of Surgical Experience on Perioperative Outcomes

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Abstract

Robot-assisted partial nephrectomy (RAPN) outcomes might be importantly affected by increasing surgical experience (EXP). The aim of the study is to investigate the effect of EXP on warm ischemia time (WIT), presence of at least one Clavien-Dindo $\geq$2 postoperative complication (CD $\geq$ 2), and positive surgical margins (PSMs) to define the learning curve for RAPN. We evaluated 457 consecutive patients diagnosed with a cT1-T2 renal mass were evaluated. EXP was defined as the total number of RAPNs performed by each surgeon before each patient's operation. Median WIT was 14 min and the rate of CD $\geq$ 2 and PSMs was 15% and 4%, respectively. At multivariable regression analyses adjusted for case mix, EXP resulted associated with shorter WIT ($p < 0.0001$) and higher probability of CD $\geq$ 2–free postoperative course ($p = 0.001$), but not with PSMs ($p = 0.7$). The relationship between EXP and WIT emerged as nonlinear, with a steep slope reduction within the first 100 cases and a plateau observed after 150 cases. Conversely, the relationship between EXP and CD $\geq$ 2–free course resulted linear, without reaching a plateau, even after 300 cases.

Patient summary: Perioperative outcomes after robot-assisted partial nephrectomy (RAPN) are importantly and individually affected by surgeon's experience. After 150 RAPNs, no further improvement is observed with respect to ischemia time, but the learning curve appears endless with respect to complications.

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In surgery, the learning curve (LC) depicts the relationship between surgeon's experience (EXP) and patient's outcomes [1] and is key to estimate the number of patients at risk of suboptimal outcomes due to the learning process, to aid clinical decision making in complex cases, and to develop surgical training programs.

Current guidelines state that robot-assisted partial nephrectomy (RAPN) adoption is subjected to surgeon's

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expertise and skills [2]; however, data in this regard are scarce. Specifically, despite previous reports demonstrated a link between EXP and patients' outcomes [3–6], an actual curve is seldom depicted [7]. To address this issue, the aim of the current study was to define the surgical LC for RAPN. Our hypothesis postulated an initial learning phase, where clinical outcomes are heavily affected by surgical experience followed by a later plateau phase, where the impact of experience is negligible.

A prospectively maintained database of patients diagnosed with a cT1-T2 renal mass and treated with RAPN with a standardised technique [8,9] between 2006 and 2017 at two tertiary care referral European centres was assessed. Surgeons with extensive experience (≥200 total procedures) and high annual volume (median, ≥30 procedures/yr) were evaluated. For each individual patient, EXP was defined as the total number of RAPNs performed by each surgeon before the patient's operation [1]. Multivariable linear and logistic regression models were fitted to evaluate the effect of EXP on duration of warm ischemia time [WIT], the probability of at least one Clavien-Dindo [10] grade ≥2 postoperative complication [CD ≥ 2], and positive surgical margins [PSMs]. Covariates consisted of tumour clinical size, anatomical complexity classified with R.E.N.A.L. nephrometry score [11], and Charlson comorbidity index. Given the hypothesis that the effect of EXP on the outcomes is nonlinear as result of a learning process, EXP was modelled using restricted cubic splines where significant. Model-derived coefficients were used to compute estimated WIT and estimated probability of CD ≥ 2–free postoperative course, and local polynomial smoother weighted function was used to depict an actual curve by graphically exploring the effect of EXP on the outcomes, after accounting for clinical size, R.E.N.A.L. nephrometry score, and Charlson comorbidity index to adjust for case mix. A sensitivity analysis testing the hypothesis that the impact of surgical experience was different by different individual surgeons was conducted using an interaction term. Analyses were performed using R software v.3.0.2 [12], and all tests were two-sided with significance level set at $p < 0.05$.

457 patients were evaluated (Supplementary Table 1). Median WIT was 14 min, whereas the rate of CD ≥ 2 and PSM was 15 and 4%, respectively. Haemorrhage resulted the most common individual CD ≥ 2 (Supplementary Table 2). Increasing experience was associated with variations in case mix (Supplementary Fig. 1). At multivariable regression (Table 1), EXP resulted associated with lower WIT and the relationship resulted nonlinear (simultaneous test for all splines terms, $p < 0.0001$). EXP resulted associated with higher probability of CD ≥ 2–free postoperative course (odds ratio: 1.03 per 50 cases; confidence interval [CI], 1.01–1.04; $p = 0.001$). Conversely, EXP was not associated with the risk of PSMs ($p = 0.7$). The relationship between EXP and WIT emerged as nonlinear, with a steep reduction in WIT from case 1 to case 150 and a plateau observed after 150 cases (Fig. 1A). Conversely, the relationship between EXP and CD ≥ 2–free postoperative course resulted linear without reaching a plateau, even after 300 cases (Fig. 1B). Finally, no interaction between EXP and individual surgeon was recorded (all $p > 0.05$).

RAPN consists of technically challenging steps and, owing to such intrinsic complexity, our hypothesis stated that clinical outcomes might be heavily affected by increasing EXP during an initial learning phase, whereas the impact of EXP progressively dilutes in a later plateau phase. The results of the study confirmed our hypothesis and several relevant observations deserve further discussion.

First, our findings support a nonlinear inverse relationship between EXP and WIT. Specifically, after accounting for case complexity, estimated WIT was 20, 13, and 11 min after 10, 150, and 300 procedures, respectively (Fig. 1A). The steep decrease (−7 min) observed between case 10 and case 150 defines the learning phase; conversely, the negligible variation (−2 min) observed between case 150 and case 300 defines the plateau phase.

Second, our findings support a linear direct relationship between EXP and probability of CD ≥ 2–free postoperative course. Specifically, after accounting for case complexity, estimated probability of CD ≥ 2–free postoperative course was 77, 87, and 96% after 10, 150, and 300 procedures, respectively (Fig. 1B). The constant decrease in the CD ≥ 2 risk does not allow the distinction of a plateau phase from a learning phase, suggesting that the LC with respect to complications might be endless, albeit after extensive

Table 1 – Study outcomes and linear and logistic regression analyses predicting warm ischemia time, Clavien-Dindo ≥2 postoperative complication-free course, and positive surgical margins in 457 patients diagnosed with a cT1-T2 renal mass and treated with robot-assisted partial nephrectomy at two (262 and 195 cases, respectively) tertiary care European centres, 2006–2017

Warm ischemia time		
Median (interquartile range)	14 (10–19) min	
Multivariable linear regression analysis	Estimate (95% CI)	*p* value
Experience, per 50 procedures[a]	–	<0.0001
Clinical tumour size	0.05 (0.01–0.08)	0.02
R.E.N.A.L. score	0.95 (0.61–1.28)	<0.0001
Charlson comorbidity index	−0.23 (−0.63 to 0.16)	0.2
Clavien-Dindo ≥2 complication-free postoperative course		
Rate (frequency)	85% (*n* = 389)	
Multivariable logistic regression analysis	Odds ratio (95% CI)	*p* value
Experience, per 50 procedures[b]	1.03 (1.01–1.04)	0.001
Clinical tumour size	0.99 (0.99–0.99)	0.03
R.E.N.A.L. score	0.99 (0.98–1.01)	0.9
Charlson comorbidity index	0.94 (0.95–0.98)	<0.001
Positive surgical margins		
Rate (frequency)	4% (*n* = 19)	
Multivariable logistic regression analysis	Odds ratio (95% CI)	*p* value
Experience, per 50 procedures[b]	0.99 (0.99–1.01)	0.7
Clinical tumour size[c]	–	–
R.E.N.A.L. score	1.01 (0.99–1.01)	0.5
Charlson comorbidity index[c]	–	–

CI = confidence interval.
[a] Modelled as restricted cubic spline, *p* value computed using simultaneous test for all splines terms.
[b] Modelled as linear predictor.
[c] Not included in the model due to the number of events.

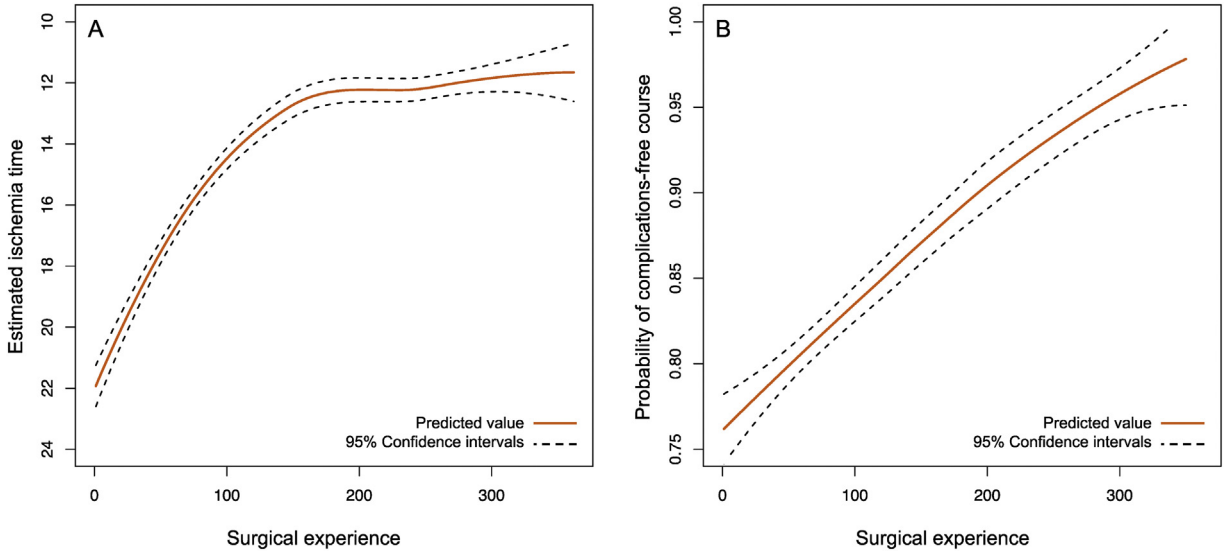

Figure 1 – Surgical learning curve for robot-assisted partial nephrectomy: effect of increasing surgical experience on estimated warm ischemia time (A) and estimated probability of Clavien-Dindo ≥2 complication-free postoperative course (B). Estimate is adjusted for case mix accounting for clinical tumour size, R.E.N.A.L. nephrometry score, and Charlson comorbidity index. For instance, after ten cases, the estimated warm ischemia time is 20 min and the probability of Clavien-Dindo ≥2 complication-free postoperative course is 77%. After 150 cases, the estimated warm ischemia time is 13 min and probability of Clavien-Dindo ≥2 complication-free postoperative course is 87%. After 300 cases, the estimated warm ischemia time is 11 min and the probability of Clavien-Dindo ≥2 complication-free postoperative course is 96%.

experience a very low risk of CD ≥ 2 complications can be achieved.

Third, our findings do not support a relationship between EXP and the risk of PSMs (Table 1). Despite surgical experience might affect the resection quality and ultimately the risk of PSMs, the limited number of events recorded (4%; n = 19) qualifies the PSM as a useless metric for LC definition.

Remarkably, this study represents the first description of the RAPN LC based on extensive surgical experience. A preliminary report from the early phase of RAPN adoption demonstrated lower WIT and console time after 30 procedures [3]. However, the limited extent of the RAPN program (62 cases) did not allow for any learning-effect assessment. Similar limitation affects other investigations that evaluated series shorter than 150 cases [5–7]. Interestingly, analyses based on longer experiences demonstrated that clinical outcomes continue to improve after 50 procedures. An increasing optimal outcomes rate was observed up to 300 procedures, suggesting that the learning process for RAPN might be longer and more complex than expected [4].

Taken together with the results of the current study, these observations suggest that RAPN must be regarded as a complex surgical procedure with a relatively long LC and indicate that special consideration should be given to dedicated training programs aimed at the improvement of patient's outcome during the learning process. Moreover, our findings, together with the results of studies reporting improved outcomes in high-volume RAPN centres [13], are a strong argument supporting the utmost importance of kidney cancer treatment centralisation. It is noteworthy that the LC analysis is also important to compare different surgical strategies. For instance, relative to laparoscopic partial nephrectomy [5,14], superior outcomes can be achieved earlier.

The current study is strengthened by the extensive experience of the surgeons involved, by the precise consideration of the key predictors [11,15] of perioperative outcomes after RAPN, and by the methodology used. However, despite its novelty and uniqueness, the current study is not devoid of limitations, including the inability of accounting for any modification over time in the technique used or in the surgical equipment. Moreover, our analysis was primarily focused on the LC of the first surgeon only, and its interaction with the entire team was not assessable, as well as the role of his or her previous experience in laparoscopic or other robot-assisted surgery. Finally, the generalisability of the study results to providers with different characteristics is limited by the potential presence of individual surgeon-related bias and by the high volume of the centres evaluated.

In conclusion, perioperative outcomes after RAPN are importantly and individually affected by surgeon's experience. After 150 RAPNs, no further improvement is observed with respect to ischemia time, but the LC appears endless with respect to complications.

Author contributions: Alessandro Larcher 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 conception and design: Larcher, Peyronnet, Bensalah, Mottrie.
Acquisition of data: Larcher, Muttin, Peyronnet, De Naeyer, Khene, Dell'Oglio, Ferreiro, Schatteman, Capitanio, D'Hondt, Montorsi, Bensalah, Mottrie.
Analysis and interpretation of data: Larcher, Muttin, Peyronnet, Dell'Oglio, Bensalah, Mottrie.
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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.eururo.2018.08.042.

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