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Learning curve in robot-assisted partial nephrectomy: comparison between an expert surgeon and a team in training in single-center experiences

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Introduction An important issue in robotic surgery is the training of urologists and the learning curve to perform a robot-assisted partial nephrectomy (RAPN), especially for those procedures that require vascular clamping.

Material and methods We retrospectively enrolled 333 patients, undergoing RAPN in the period between 01/2014 and 12/2020. Surgical complexity, surgery duration, perioperative complications, and clamping were evaluated for each patient. Comparisons were made between an experienced surgeon and 3 urologists with initial experience in robotic surgery.

Results Total number of RAPN was 333, of wich 172 were performed by the chief and 142 by the team. Analyzing the data, after an initial training in robotic surgery, it's possible to perform surgery of medium complexity (RENAL score 6-7) after 15 procedures performed in total independence. To proceed to high complexity tumors (RENAL score 8-9) with possible vascular clamping and warm ischemia time <25 minutes at least 25 completely independent procedures are required. There were no significant differences in the comparisons regarding the duration of the procedures (p = 0.19), complications (p = 0.44) and positive margins (p = 0.96).

Conclusions Robotic training for complex procedures, with low intra and postoperative complication rates, acceptable positive margin rates and sustainable cost-effective durations, requires a minimum number of medium complexity procedures, which in our study we have identified as 25 procedures, considering the initial ability in simple procedures of our 3 surgeons in training.

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INTRODUCTION

Renal cell carcinoma (RCC) is the 9th most common cancer in men and 14th most common cancer in women worldwide [1]. The widespread use of abdominal imaging has affected the epidemiology of RCC [2]. The incidence of kidney cancer rises globally with the highest rates in developed countries. This demonstrates the impact of advanced diagnostic imaging but also the rising prevalence of modifiable risk factors such as smoking, obesity and hypertension [3].

Since the introduction of the da Vinci surgical platform, robotic technology has been increasingly utilized as the preferred surgical approach for several urological operations including prostatectomy, partial nephrectomy and cystectomy [4]. There are currently several nephrometric scores (the most used are RENAL and Padua Prediction Score) which are used to predict any post-operative complications, and therefore, to preoperatively plan the clamping of the vascular pedicle. Other scores are available today, such as the Arterial Based Complexity (ABC) score that can be used to evaluate the complexity

of a renal tumor and predict how difficult the tumor resection (partial nephrectomy) may be [5].

RENAL score consists of Radius (tumour size as maximal diameter), Exophytic/endophytic properties of the tumour, Nearness of tumour's deepest portion to the collecting system or sinus, Anterior (a)/posterior (p) descriptor and the Location relative to the polar line [6]. Padua and RENAL scores were significantly associated with predicting prolonged warm ischaemia time and high-grade postoperative complications after robot-assisted partial nephrectomy (RAPN) [7].

Another important issue is the training of urologists and the learning curve to perform a RAPN, especially for those procedures that require vascular clamping.

MATERIAL AND METHODS

We have retrospectively enrolled 333 patients, undergoing RAPN in the period between 01/2014 and 12/2020.

Age, performance status through the Charlson score, surgical complexity through the RENAL score, surgery duration, intra and postoperative complications (classified through Clavien), possible clamping and its duration, histology, positivity of the margins and TNM staging were considered for each patient. The comparison was made between an experienced surgeon (at least 150 robotic procedures performed, 80 robot-assisted radical prostatectomy [RARP] and 50 RAPN) and 3 assistant urologists with initial experience in robotic surgery (at least 30 robotic procedures performed, 15 RAPN and 15 RARP).

Level of experience in laparoscopic renal surgery were, respectively, excellent for the chief (>100 laparoscopic nephrectomies, >50 partial nephrectomies) and good for the team (>0 laparoscopic nephrectomies, >15 partial nephrectomies).

We compared the performance of each surgery, considering those performed in total independence. Surgical approach was, in all procedures, 2 arms and transperitoneal. The technique consisted of using the Veress needle (except in patients with previous abdominal surgery, where the Hasson technique is preferred), inserted perpendicularly into the fascia while pulling up on the fascia in the upper quadrant of the affected side. The tumor removal technique can be performed with enucleation or enucleoresection (with a small part of healthy parenchyma). The split and roll technique can ease the removal of the tumor. In our center, for vascular clamping, we isolate the vein and renal artery separately, and use the bulldog clamp. When satisfactory haemostasis is obtained, the bulldog is removed. Nephrorrhaphy is performed by replacing the scissors with a needle

driver on the first arm and is double: a deep hemostatic suture involving the medullary layer, and the other on the cortical layer. Other hemostatic agents such as Floseal© or Tachosil© can be used to improve hemostasis.

Surgical complexity was divided into low complexity (RENAL score 4–5), intermediate (RENAL score 6–7), high (RENAL score 8–9). Scoring 9 corresponds to the maximum score in our series. The performances were evaluated throughout the period, retrospectively observing the progression over time, until obtaining a satisfactory performance in tumors with high complexity and independence to perform vascular clamping.

The percentage of positive margins and post-operative complications was analyzed, correlating it with the pTNM and the kind of complications respectively. The learning curve for achieving desirable perioperative outcomes have been studied regarding outcomes of no complications, no positive margins, and warm ischemia time (WIT) ≤25 minutes. For any level of complexity, the differences between the team and the chief were analyzed using t-Student test.

RESULTS

Total number of RAPN was 333, 172 performed by the chief and 142 by the team (44 + 55 + 45 respectively). 17 were made in mixed form (not to be allocated to a single surgeon). The median value for the performance status of patients, assessed according to the Charlson score, was 4 (range 1–8) and 65 for age (range 19–87, (σ): 11.95). Histology showed 165 clear cell RCC, 49 oncocytoma, 36 papillary RCC type 1, 20 papillary RCC type 2, 29 Chromophobe, 13 angiomiolipoma, 1 follicular carcinoma 'thyroid-like', 1 paraganglioma, 1 non-Hodgkin lymphoma. The remainder were rarer benign lesions or chronic inflammations.

Pathological staging (pTNM) showed 80 T0 (for benign neoplasm or chronic inflammations), 175 T1a, 60 T1b, 3 T1b + T1a (for bilateral RAPN), 7 T2a and 8 T3 (tumors classified in clinical staging as T1 lesions but with perirenal fat infiltration on histology). The number of surgeries performed by the team has grown over the years to the point of achieving good independence, surpassing those made by the experienced surgeon (Figure 1).

The median value for duration of surgery for the experienced surgeon was 80 minutes (range 30–210, σ: 24.23), and for surgeon 1, 2 and 3 was 87,5 minutes (range 50–160; σ: 23.81), 90 minutes (range 40–165, σ: 22.91), and 100 minutes (40–150, σ: 21.89) respectively (Figure 2). Obviously, this data must be analyzed also taking into account the surgical complexity, which in the early years was much greater for

procedures performed by the experienced surgeon. Although the duration was slightly shorter for the procedures performed by the experienced surgeon there were no statistically significant differences (p = 0.19)

Previous surgeries did not lead to differences in surgical and post-operative outcomes but did cause an average increase in the duration of port placement (using the Hasson technique) and surgery duration (average duration greater than 11 minutes).

Intraoperative complications occurred in 3 patients: one case for the experienced surgeon with perforation of the ileum, which required OPEN conversion, with admission to intensive care and subsequent death of the patient, one case of splenic injury for surgeon 2, resolved with the application of Tachosil© and subsequent regular course until discharge, and one case of colon injury for surgeon 3, resolved with intracorporeal suture and subsequent regular course until discharge.

The progression of highly complex surgeries was gradual over the years for the team, until satisfactory independence was achieved between 2018 and 2019. Positive margins were not significantly different between the experienced surgeon and the team: 14 for chief (8.13%), and 12 for the team: 4 (9.5%), 6 (10.9%); and 2 (4.4%) respectively.

Postoperative complications occurred in 14 patients: twelve for the experienced surgeon (6.9%) of which eight patients were Clavien 1 and two patients Clavien 3 (one patient had a pulmonary embolism, treated with medical therapy and admission to intensive care and another patient had extravasation of urine, treated with DJ ureteral catheter placement); one patient for surgeon 1 (2.3%) (anemia, treated with blood transfusion [Clavien 2]), and one for surgeon 3 (2.2%) (Clavien 1).

Comparing the complications, differentiating minor complications (Clavien 1-2) and major complications (Clavien 3–5), no statistically significant differences were found between the experienced surgeon and the team (p = 0.44).

Median value for length of stay was 3 days (range 2–25, σ: 0.29).

Another comparison was made of the presence of positive margins, without finding statistically significant differences (p = 0.96).

Finally, we also compared the time of warm ischemia, which for the experienced surgeon was 10 minutes (median value, σ: 4.91) and 12 minutes (σ: 3.41), 18 minutes (σ: 4.07) and 13 minutes (σ: 4.18) for surgeon 1, 2 and 3 respectively. The differences were not statistically significant (p = 0.32).

Analyzing the data, we can say, in our experience, that after an initial training in robotic surgery,

which allows the approach to low complexity tumors (RENAL score 4–5), it is possible to perform surgeries of medium complexity (RENAL socre 6–7) after 15 procedures performed in total independence. To proceed with complex tumors (RENAL score 8–9) with possible vascular clamping and WIT <25 minutes, at least 25 completely independent procedures are required.

The pedicle clamp was performed not only in tumors of high complexity, but also in those of low and intermediate complexity. The percentage of total pedicle clamps for low, intermediate and high complexity was respectively 25%, 52%, 23% .However, it is necessary to highlight that the percentage of tumors requiring clamp in low, intermediate and high complexity tumors were respectively 6%, 31%, 50%

DISCUSSION

Defining the exact number of operations required to proceed to the next step in the RAPN is very difficult. The impact of surgical training on health care costs and clinical outcomes should be a priority for future studies [8]. In a study of Omidele et al. the learning curve for achieving positive outcomes for a single, fellowship-trained surgeon from October 2007 through June 2015, was noted in 61–90 cases after 66–80 months of performing minimally invasive partial nephrectomy surgeries at a rate of 20 cases per year [9].

There are some limitations in our study: it is a retrospective study, the surgeons involved in the study had an initial robotic experience and this does not allow to evaluate the initial progression to surgical ability, but only to evaluate the progression between those of low complexity and high complexity with clamping. Furthermore, we used the RENAL score to stratify the anatomical complexity, but this does not necessarily reflect the complexity of the intervention (for example patients exposed to previous surgery can make the procedure difficult but it is not considered in the RENAL score).

Data in the literature vary greatly on this surgical progression.

A study of David J. Paulucci et al. shows that although RAPN can consistently be performed safely with acceptable outcomes after a small number of cases, improvement in trifecta achievement, warm ischaemia time, estimated blood loss, blood transfusions and a shorter hospitalization continues to occur up to 300 procedures [10].

Another limitation is that in our study we consider the progression and the minimum limit to be able to perform complex procedures, but an experienced surgeon is still present to interact in case of need.

The possibility of performing RAPN with the help of an expert surgeon in case of need allows the surgeon in training to be able to work in less stressful conditions. Another consideration in our study is emulation, as we believe that observing (even without performing) procedures by surgeons at the same level allows for improvement within subsequent procedures. The comparable learning curves are only those of the 3 assistants, as they learned through the same surgical training. Therefore, this surgical training and the learning curve are not comparable with that of the experienced surgeon. However, oncological findings are comparable, as are surgical margins and complications.

The positive margins, as described in Table 1, were distinguished in the procedures with subsequent advanced pTNM (pT3), therefore difficult to obtain even with a well-performed procedure. However, even making an adequate distinction between positive margins pT1 and pT3, the overall comparison does not affect the outcome.

However, highly complex procedures do not only concern vascular clamping, but also the anatomical features (analyzed well but not perfectly by the RENAL score) and the comorbidities of the patients (high Charlson score and with anticoagulant therapies).

Another limitation of the study concerns the randomization of complex cases. They were often performed by the experienced surgeon. Effectively, in the study we talk about the learning curve to perform highly complex cases, but this is different from having excellent surgical skills, often required for highly complex cases. The total number of pro-
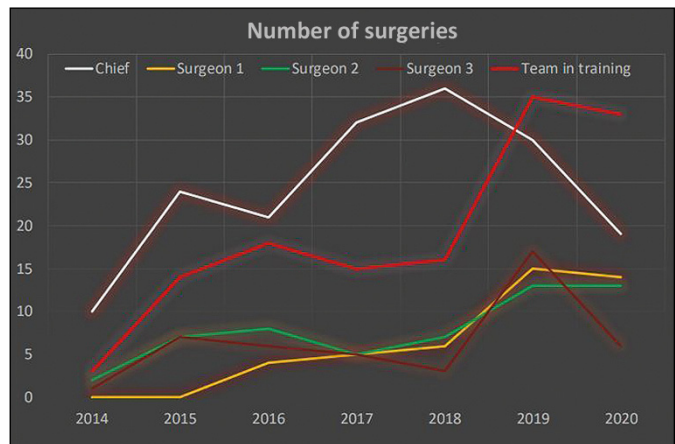

Figure 1. *Graph showing the progression of surgery over the years, by single operator and in team.*

cedures with clamping was 50 (15%). However, the preparation of the pedicle with a loop does not only concern highly complex cases, this step is sometimes necessary even for cases of low and intermediate complexity. Thus, the total number of procedures with pedicle preparation is certainly higher.

Four surgeons, 1 expert and 3 with initial robotic experience were considered in our study. This is a small group but still presents difficulties in assessing interindividual variables. There is significant between-surgeon variability in outcomes after partial nephrectomy, even after adjusting for patient characteristics. Measured and unmeasured surgeon factors account for 18–100% of variability of the remaining peri- and postoperative variables [11].

Table 1. *Summary table about complications, positive margins, surgical complexity, hilar tumors, bilateral procedures, number of procedures with vascular clamping and the median value of their duration. The fields with duration have, in brackets, their range and the others fields the percentage of the total number of procedures performed*

|	Chief	Surgeon 1	Surgeon 2	Surgeon 3
Duration (median value, minutes)	80 ±24.23	87.5 ±23.81	90 ±22.91	100 ±21.89
Minor Complications (Clavien 1–2)	8 (4.6%)	1 (2.2%)	0	1 (2.2%)
Major Complications (Clavien 3–5)	3 (1.7%)	0	0	0
Positive margins (pT1)	13 (7.5%)	3 (7.1%)	3 (5.4%)	0
Positive margins (pT3)	1 (0.5%)	1 (2.3%)	3 (5.4%)	2 (4.4%)
Low complexity (RENAL score 4–5)	110 (63,9%)	30 (68 %)	37 (67.2%)	30 (66%)
Intermediate complexity (RENAL score 6–7)	47 (27.3%)	11 (25%)	13 (23.6%)	13 (28.8%)
High Complexity (RENAL score 8–9)	15 (8.7%)	3 (6.8%)	5 (9%)	2 (4.4%)
Hilar Tumors (H)	3 (1.7%)	1 (2.2%)	1 (1.8%)	1 (2.2%)
Bilateral RAPN	2 (1.1%)	1 (2.2%)	0	1 (2.2%)
Number of procedures with vascular clamping	30 (17%)	6 (13%)	11 (20 %)	3 (6.6%)
Duration of Vascular clamping (median value, minutes)	10 ±4.91	12 ±3.41	18 ±4.07	13 ±4.18

RAPN – robotic-assisted partial nephrectomy
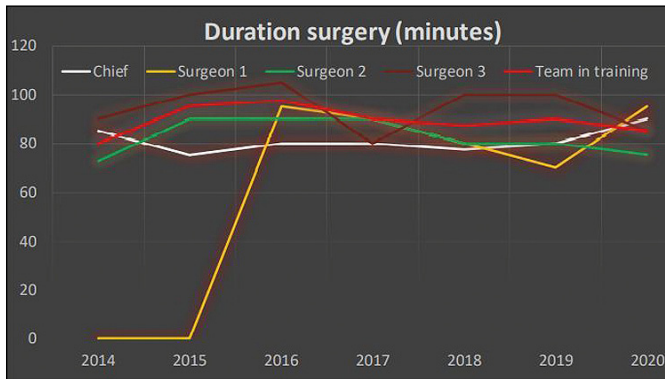
Figure 2. *Graph showing the median value of surgery duration over the years, by single operator and in team.*

Currently there is a great need for a standardized curriculum for training of robotic surgeons [12]. The training of future generations will also be able to rely on simulators because there are many ben-

efits to utilizing virtual reality simulation for robotic skills acquisition, including advanced procedural-based training [13].

CONCLUSIONS

Robotic training for complex procedures in safety, with low intra and postoperative complication rates, acceptable positive margin rates and sustainable cost-effective durations , requires a minimum number of medium complexity procedures, which in our study we have identified as 25 procedures, considering the initial ability in simple procedures of our 3 surgeons in training. Probably in the future this learning curve will be reduced due to the advent of simulators available to residents, already available in many centers (including ours).

CONFLICTS OF INTEREST
The authors declare no conflicts of interest.

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