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ORIGINAL RESEARCH ARTICLE

Minimising warm ischaemia time during robot-assisted partial nephrectomy. A video-based assessment of tumour excision, kidney reconstruction and intermediate time

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ABSTRACT

Introduction: Surgical video review is an emerging tool for assessing patient outcomes, especially in complex surgeries such as robot-assisted partial nephrectomy (RAPN). Assessing and measuring warm ischaemia time (WIT) during RAPN by dividing it into the time used for tumour excision time (ExcT), time used for kidney reconstruction time (RecT) and intermediate time (IntT) has not been performed before. This study aimed to analyse the factors that can influence all surgical times and assess their impact on positive surgical margins (PSMs) and complication rates.
Methods: We evaluated 32 surgical video recordings from patients undergoing RAPN and measured WIT, ExcT, RecT and IntT with a stopwatch. Factors such as tumour characteristics and surgeon experience were also recorded. SPSS software was used to identify the predictors for all surgical times and to correlate ExcT with PSM and RecT with complication rate.
Results: We recorded a median WIT of 1,048 s (17 min and 28 s). The median of ExcT, RecT and IntT was 398 s (37.1% of WIT), 518 s (46.7% of WIT) and 180 s (16.2% of WIT), respectively. We found a significant correlation ($P < 0.001$) between R.E.N.A.L. score and all surgical times. No correlation was found between ExcT and PSM ($P = 0.488$) and between RecT and the probability of developing complications ($P = 0.544$).
Conclusion: Tumour morphology influences all surgical times, and surgeon experience influences only ExcT. We observed a short RecT during RAPN though at the cost of increased ExcT, and we believe that improving surgical experience, especially for the excision of more complex tumours, can reduce WIT during RAPN.

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Introduction

Minimally invasive nephron-sparing surgery, whenever feasible, is the standard of care for patients diagnosed with T1a and T1b kidney cancer [1]. However, this approach is technically challenging and should not compromise oncological, functional or perioperative outcomes. Vascular clamping during partial nephrectomy (PN) is associated with kidney function impairment, and attempts should be made to limit warm ischaemia time (WIT) to 20 min [2]. Efforts to reduce WIT should not compromise surgical margins or the potential rate of complications resulting from the excessive reduction of necessary resection and suturing time.

Surgical video review (SVR) is an emerging tool for assessing patient outcomes [3], especially in complex surgeries such as robot-assisted partial nephrectomy (RAPN). Robotic surgery platforms enable high-quality video recordings, providing greater magnification and closer views of anatomical details. We have previously assessed WIT by reviewing surgical video recordings of a series of laparoscopic partial nephrectomy (LPN) operations and divided it into tumour excision time (ExcT), kidney reconstruction time (RecT) and intermediate time (IntT). We found that surgeon experience influences WIT, ExcT and RecT but not IntT, which depends more on tumour complexity [4].

With this new study, we reviewed surgical video recordings of RAPN to assess and measure these surgical times as parts of the total WIT, and to analyse the factors that can influence them. A secondary aim was to assess the impact of the ExcT on surgical margins and the impact of the RecT on the complications' rate.

Materials and methods

The storage of recorded surgical videos for a period of time is mandatory in Norway to ensure quality and provide medicolegal evidence. This requirement allowed us to retrospectively review surgical video recordings of 32 consecutive patients undergoing RAPN at our institution between January 2023 and January 2024. All procedures were performed on T1a tumours using Intuitive Xi robotic systems (Intuitive™, Sunnyvale, CA, USA). As part of the kidney cancer surgical team, one surgeon

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(O.B.) reviewed the video recordings and measured WIT, ExcT, RecT and IntT in seconds using a digital stopwatch. We defined exact visual cues as starting and ending points for each surgical time.

WIT is the time between the clamping and unclamping of the renal artery. We defined the WIT starting point as the positioning of bulldog clamp on the renal artery and the WIT ending point as the opening of the bulldog clamp. In cases of bleeding that required reclamping, additional time was added to the initial measured time. If several arteries were involved, the time between the clamping and the unclamping of the main renaly artery was measured. At our institution, it is a common practice to clamp only the artery during hilar compression and to clamp the vein only for tumours situated centrally in the kidney, especially on the right side and always after the artery is clamped. We performed an enucleoresection technique in all cases, using one suture (two in cases of wide resection surface) of V-loc™ 3/0 barbed suture for inner renorrhaphy. This suture included all bleeding vessels and collecting system. For ExcT, we defined the starting point as when the monopolar-curved scissors' cut function is used in the renal parenchyma, either for resection or enucleation, and the ending point as when the tumour base is completely free from the kidney. For RecT, we defined the starting point as when the needle first enters the parenchyma and the ending point as when the Hem-o-lock® clip is applied to the loose end of the inner-layer suture. Early unclamping was attempted routinely, and if haemostasis was achieved, the surgeon proceeded to complete outer-layer renorrhaphy using the sliding-clip technique. To minimise WIT, our routine strategy is to take a short time-out before clamping, involving all team members (assistant, nurse and anaesthesiologist) in specifying their roles during the WIT. We defined IntT as the time elapsing between the clamping and the unclamping of the artery not used for tumour excision (ExcT) or for renorrhaphy (RecT); this time includes several manoeuvres like clamping and unclamping the kidney vein, when needed, or switching from scissors to needle driver.

Anatomical aspects of a tumour may influence WIT [5], and nephrometry scoring systems are widely used in surgical practice. In our unit, we used the radius, exophytic/endophytic, nearness, anterior/posterior and location (R.E.N.A.L.) score to assess tumour complexity and plan the RAPN, as described by Kutikov [6]. Of the three members of the surgical team, two (operators 2 and 3) had high expertise in LPN(over 300 procedures) but less in robotic surgery (less than 50 procedures), and one (operator 1) had high experience in robotic surgery (over 200 robotic procedures for prostate and kidney cancer) but less experience in LPN (less than 50 procedures).

Positive surgical margins (PSMs) were registered by a pathologist using microscopic examination, and perioperative complications such as bleeding or urinary fistulas were recorded in the patient's journal according to the Clavien-Dindo classification [7]. PSMs can be caused by inappropriate excision technique, whilst postoperative complications may be due to inappropriate suturing technique.

Demographic information (including age, gender, tumour type and side, tumour size at CT scan, RENAL score and grade, and surgeon expertise), surgical features (bleeding amount, WIT, ExcT, Rect and IntT) and clinical outcomes (surgical margins and postoperative complications) were collected from patients' medical records and analysed using descriptive statistics. The Kruskal-Wallis *U* test and Spearman's test were used to compare means and proportions, respectively. Stepwise multivariable regression models were used to assess predictors for all surgical times. Statistical significance was set at $P < 0.05$.

Results

Demographics, surgical features and clinical outcomes

Population and tumour characteristics are summarised in Table 1. The cohort comprised 87% males (28 patients) with a median age of 64 years and an interquartile range (IQR) of 56–72 years. Most of the tumours were solid (84%) with a median [IQR] tumour diameter of 2.9 cm (1.8, 3.2 cm) and a median [IQR] R.E.N.A.L. score of 6.5 points (5.0, 8.0 points). Half of the patients had low-complexity tumours, 34% had medium-complexity tumours and 16% had high-complexity tumours. All three surgeons operated similarly on low-, medium- and high-complexity tumours.

The surgical features included median [IQR] bleeding of 100 mL (50, 300 mL) and median [IQR] WIT of 1,048 s (876, 1,395 s). The ExcT for tumour resection was measured at a median [IQR] of 398 s (268, 581 s) or 37.1% of the total WIT. The median [IQR] RecT was 518 s (412, 670 s), representing 46.7% of the WIT. The median [IQR] IntT was 160 s (131, 213 s), representing 16.2% of the WIT.

Table 1. Population demographics.

Variable	Overall (*n* = 32)			
	Median	IQR	*n*	%
Age (years)				
Median [IQR]	66.5	56.2–72.0		
Gender				
Male			28	87.5
Female			4	12.5
Tumour type				
Solid			27	84.4
Cystic			5	15.6
Side				
Right			14	43.8
Left			18	56.3
Tumour size (cm)				
Median [IQR]	2.9	2.0–3.7		
R.E.N.A.L. score				
Median [IQR]	6.5	5.0–8.0		
RENAL score grade				
Low (4–6)			16	50
Medium (7–9)			11	34.4
High (10–12)			5	15.6

n: number of patients; IQR: interquartile range.

Two (6%) positive margins were recorded, and Clavien-Dindo ≥2 complications occurred in one patient (3%) with bleeding and A–V fistulae. No patients registered urinary fistulae.

Predictive factors for WIT, ExcT, RecT and IntT

We found a significant correlation between the WIT and tumour size (*P* = 0.001, mean 0.657), RENAL score (*P* = 0.001, mean 0.792) and RENAL complexity (*P* = 0.001, correlation estimate 894.3, 1349.1 and 1181.7 for low, medium and high grade, respectively), with a longer WIT for a higher tumour size, RENAL score and more complex tumour. No significant difference was found between the WIT and surgeon's expertise (*P* = 0.422). Similarly, a significant correlation was found between the ExcT and tumour size (*P* = 0.001, mean 0.595), RENAL score (*P* = 0.001, mean 0.792) and complexity (*P* = 0.001, correlation estimate 306.6, 550.7 and 679.4 for low, medium and high grade, respectively) but also surgeon's experience with a significantly longer ExcT (mean 583 s, *P* = 0.029) for the surgeon with fewer than 50 RAPN. Similar to WIT, a correlation was found between the RecT and tumour size (*P* = 0.001, mean 0.6), RENAL score (*P* = 0.001, mean 0.735) and complexity (*P* = 0.001, correlation estimate 413.9, 613.4 and 859.4 for low, medium and high grade, respectively) but not surgeon's experience. We found a correlation between IntT and RENAL score (*P* = 0.001), with a longer IntT for a higher RENAL score and tumours on the right side (*P* = 0.020). No significant difference was found between the IntT and tumour size (*P* = 0.832, mean 0.039) or complexity (*P* = 0.672, correlation estimate 173.7, 183.1 and 193.8 for low, medium and high grade, respectively), although the mean IntT was higher in medium and high complexity cases.

After stepwise regression, two models were found to predict the WIT and ExcT, as presented in Table 2.The model including RENAL complexity and tumour size had better accuracy (*R* = 0.833) for WIT and the model including RENAL complexity and surgeon had better accuracy (*R* = 0.772) for ExcT. Only one model could predict the RecT and IntT, depending on the RENAL score variable (*R* square = 0.616 and 0.398, respectively) as 61.6% of the RecT and 39.8% of the IntT were determined by tumour complexity.

Correlation between ExcT with PSM and RecT with complication rates

No correlation was found between ExcT, either as a continuous variable (*P* = 0.488) or as a percentage of WIT (*P* = 0.580), and the probability of PSM. Likewise, no correlation was found between RecT, as a continuous variable (*P* = 0.544) or as a percentage of WIT (*P* = 0.468), and the probability of developing complications.

Table 2. Surgical features and clinical outcomes.

Variable	Overall (*n* = 32)			
	Median	IQR	*n*	%
Bleeding (mL)				
Median [IQR]	100	50–300		
Surgical margins				
Negative			30	93.8
Positive			2	6.3
Postoperative complications				
< Clavien Dindo grade 2			31	96.9
≥ Clavien Dindo grade 2			1	3.1
WIT (seconds)				
Median [IQR]	1048.5	876.2–1395.0		
Excision time (sec)				
Median [IQR]	398.0	268.7–581.7		
Percent of WIT				37.1
Reconstruction time (sec)				
Median [IQR]	518.5	412.7–670.0		
Percent of WIT				46.7
Intermediate time (sec)				
Median [IQR]	160.0	131.7–213.7		
Percent of WIT				16.2
Operator				
1			7	21.9
2			14	43.8
3			11	34.4

n: number of patients; IQR: interquartile range; WIT: warm ischaemia time; sec: seconds.

Discussion

To the best of our knowledge, no data are available on intraoperative video documentation review for WIT assessment in RAPN. We found tumour morphology to influence all the surgical times and surgeon's experience influenced only the ExcT. We observed a short RecT although at the cost of increased ExcT. No correlation was found between the surgical times and postoperative outcomes.

Previous studies have assessed the importance of SVR as De Backer et al. [3] did for 100 RPNs and showed that surgical phase duration can be correlated with certain clinical outcomes. They found BMI and the duration of renal tumour identification to positively correlate, as higher BMI involves often more intraabdominal fatty tissue. Also tumour complexity correlated with both tumour excision and renorrhaphy duration, in their series. A SVR was also used to assess the impact of adherent perinephritic fat on perioperative outcomes of RAPN by Kim et al. [8].

Our earlier publication on surgical video assessment of LPN showed how much of the total WIT the surgeon uses to excise the tumour or to reconstruct the kidney and how much time is used for other manoeuvers, such as instrument transfer or any other 'dead' time [4]. We suggested that for LPN, efforts to reduce WIT should focus on reducing IntT, especially for more complex tumours, by improving surgical planning and teamwork.

Our present study yielded several important findings. First, tumour characteristics significantly influenced all surgical times.

The time taken to excise the tumour, reconstruct the kidney, and IntT accounted 37%, 47% and 16% of the total WIT, respectively. This finding is consistent with Ficarra et al. [9] that found tumour morphology as an independent predictor of WIT, adjusting for the effects of surgeon experience and clinical tumour size. We found that only ExcT, as part of the WIT,

Table 3. Stepwise regression analyse for warm ischaemia time, excision time, reconstruction time and intermediate time.

Model	Total ischaemia time			Excision time			Reconstruction time			Intermediate time		
	R	*R* square	Sig. *F* change	*R*	*R* square	Sig. *F* change	*R*	*R* square	Sig. *F* change	*R*	*R* square	Sig. *F* change
1	0.800[a]	0.641	*0.001*	0.712[a]	0.507	*0.001*	0.785[a]	0.616	*0.001*	0.631[a]	0.398	*0.001*
2	0.833[b]	0.693	*0.034*	0.772	0.595	0.018						
Predictors	a. RENAL complexity (correlation estimates 894.3, 1349.1 and 1181.7 for low, medium and high grade, respectively) b. RENAL complexity, Tumour Size (mean 0.657)			a. RENAL complexity (correlation estimates 306.6, 550.7 and 679.4 for low, medium and high grade, respectively) b. RENAL complexity, operator (correlation estimates 337.2, 398.3 and 583.9 for operator 1, 2 and 3, respectively)			a. RENAL score (mean 0.735)			a. RENAL score (mean 0.050)		

depended on tumour complexity and surgeon experience, whereas ResT and IntT depended only on tumour morphology. Ten per cent more ExcT is used during RAPN compared with LPN (27% in our previous study) and only 6% shorter RecT. The surgeon uses less time for renorrhaphy using a robotic surgical platform and articulated arms, but more time to excise the tumour than with standard laparoscopy. As the monopolar curved robotic scissors (10 mm, where 2 mm is covered with isolating MCS plastic tip) are shorter than standard laparoscopic scissors (15 mm), we believe the use of enucleation rather than resection could help shorten ExcT, in order to minimise WIT during RAPN.

Second, our study revealed that the most experienced robotic surgeon, despite having limited LPN experience, had shorter ExcT compared to other surgeons with more LPN experience but less robotic experience. This aligns with the findings of Larcher et al. [10] showing that RAPN outcomes might be affected by surgeon experience, shortening WIT and lowering the complication rate but not the PSMs. Additionally, Motoyama et al. [11] showed that an experienced robotic surgeon can perform RAPN using da Vinci Xi with acceptable perioperative outcomes after a small number of procedures, regardless of their prior experience in LPN. This is a probable explanation for the operator with more robotic experience having better excisional times, though no difference was found in the time needed to reconstruct the kidney after tumour excision.

Third, in our RAPN series, nearly 7 min was used to excise the tumour, more than 8 min to reconstruct the kidney and 3 min for other manoeuvers, out of a median WIT of 17 min and 28 s.

In conclusion, we believe that efforts should be taken to reduce ExcT in order to minimise WIT during RAPN. During LPN, reducing IntT by improving teamwork and surgical planning allowed WIT reduction independently of the surgeon experience [4]; for RAPN, the surgeon's robotic experience was important to reduce ExcT and consequently WIT. Using more enucleation than resection during tumour excision or developing longer curved scissors for robot platforms could be a solution for reducing ExcT.

IntT was correlated with RENAL score and was significantly higher on the right side. This could be explained by the need for additional time in cases of kidney vein clamping, which was performed only on the right side in our series. Another explanation for longer 'dead' time in the right-sided procedures could be the need to switch robot arms 3 and 4 with the left hand for a RAPN performed on the right side, as all three surgeons were right-handed.

To the best of our knowledge, no data are available to evaluate the time used to excise the tumour, to reconstruct the kidney or for other manoeuvers during WIT for RAPN or their clinical impacts on surgical outcomes. Our study found correlation neither between ExcT and PSM nor between RecT and postoperative complications. The small sample size and low rate of PSM and complications for this study could have biased our findings. For the LPN series, we observed that the longer the time taken to reconstruct the resection surface, the higher the probability of developing a complication. Guerrrero et al. [12] showed similar complication rates for RAPN versus LPN in a recent systematic review, and we believe that a better kidney reconstruction was achieved using a robotic platform, although without any correlation with the rate of complications.

The main limitation of this study is its small sample size and inhomogeneous surgical experience amongst the surgical team members, which made it impossible to objectively measure. The tumours we operated on were over 2 cm and of intermediate- to high-complexity, which we believe represents the pattern of tumour treated with RAPN in many robotic centres. This study was not blinded because SVR requires a trained kidney surgeon to identify the specific steps of the procedure. Timing is not in itself important but the consequences over patient's safety and outcome. Some patient characteristics and comorbidities were not recorded owing to the retrospective design of this study. We believe that larger cohorts are needed to investigate the impact of these surgical times on perioperative outcomes, like PSMs and postoperative complications. The use of robotic platforms allows for easy recording of procedures and storage of media for collaboration at the multi-institutional level.

Conclusions

We divided WIT during RAPN into excision, reconstruction and IntT using SVR. ExcT represents more than a third of WIT without affecting PSMs. RecT represents less than half of the WIT and does not affect the probability of developing post-operative complications. Tumour morphology influences all surgical times, whilst surgeon experience influences only ExcT. We observed a short RecT for RAPN though at the cost of increased ExcT, and we believe that improving surgical experience, especially for the excision technique (enucleation/resection) of more complex tumours, can reduce WIT during RAPN.

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This study was approved by the Institutional Review Board of our institution. The use of surgical video content for extracting quality improvement and educational material was subject to written approval by the patient, and all the patients in our study signed an informed consent form.

Conflicts of interest

The authors report no conflicts of interest.

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