



Development of a simple nomogram to estimate risk for intraoperative complications before partial nephrectomy based on the Mayo Adhesive Probability score combined with the RENAL nephrometry score

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Purpose: This study aimed to develop a simple nomogram based on the Mayo Adhesive Probability (MAP) score combined with the RENAL nephrometry score (RNS) to predict intraoperative complications before partial nephrectomy (PN) in Asian populations.

Materials and Methods: This study retrospectively collected patients undergoing PN at three medical centers. Each component of the MAP score and the RNS (6 variables) was evaluated to assess its association with intraoperative complications by multivariable logistic regression with backward elimination.

Results: A total of 46 cases (7.2%) with intraoperative complications were identified among 637 patients. After backward elimination, three variables, including tumor diameter (4–7 cm vs. ≤4 cm: odds ratio [OR], 4.339; 95% confidence interval [CI], 1.943–9.692; ≥7 cm vs. ≤4 cm: OR, 8.434; 95% CI, 1.225–58.090), nearness to the collecting system (4–7 mm vs. ≥7 mm: OR, 2.988; 95% CI, 1.293–6.907; ≤4 mm vs. ≥7 mm: OR, 21.394; 95% CI, 6.122–74.756), and perirenal fat stranding type (type 1 vs. no stranding: OR, 3.119; 95% CI, 1.079–9.017; type 2 vs. no stranding: OR, 18.722; 95% CI, 6.757–51.868), were retained. The predictive power (measured by area under the curve [AUC]) of the nomogram was observed to be superior to the RNS or MAP score alone (RNS: 0.686, MAP score: 0.729, the nomogram: 0.837), but comparable to their combination (0.813).

Conclusions: The simple nomogram contains fewer components than the combination of the RNS and MAP scores yet demonstrates equivalent predictive power for intraoperative complications.

Keywords: Intraoperative complication; Laparoscopic surgery; Nephrectomy; Predictive value of tests

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INTRODUCTION

Minimally invasive surgical approaches are the standard option for treating renal masses whenever possible. Minimally invasive approaches have the advantages of less blood loss, faster recovery times, and comparable oncologic outcomes to those of open surgery, but they demand much more surgical technique [1].

Dozens of scoring systems have been developed to assess the complexity of partial nephrectomy (PN) [2]. Of these, the RENAL nephrometry score (RNS), a simple scoring system consisting of four variables (diameter, endo/exophytic growth, nearness to the collecting system, and tumor location), is predominant nowadays [3]. Apart from focusing on tumor-specific characteristics, another unique scoring system known as the Mayo Adhesive Probability (MAP) score, which concentrates on tumor-environment information, has also been introduced [4]. Both of these scoring systems have been shown to be potentially important for perioperative outcomes ranging from operation time, warm ischemia time, estimated blood loss, and surgical conversion to even pathologic malignancy [5-10].

Intraoperative complications are rare during surgery in experienced hands, with a reported incidence rate of 5.0% to 13.5% [8,11-14]. Typically, conversion to radical surgery and local regional injury are commonly seen. Numerous factors are involved in surgical conversion, including the surgeon's experience, renal characteristics, and even team cooperation [8]. In this regard, an increasing number of clinical parameters and tumor-related features are further included to improve the predictive ability of different models [15]. However, regardless of their improved predictive accuracy, these new models may be too complex for clinical practice, and some of their components may be less important, which can in turn diminish their actual predictive power [2]. Both the RNS and the MAP score have been identified as independent risk factors for surgical conversion [8,14,16]. These two scoring systems focus on different courses of PN, and their combination may theoretically be more comprehensive than the use of either one along for assessing surgical complexity. However, the relationship between their combination and intraoperative complications has rarely been illustrated.

In the present study, we aimed to establish a nomogram to evaluate the RNS and MAP scores alone and in combination so as to better understand their roles in intraoperative complications before laparoscopic PN.

MATERIALS AND METHODS

Our study protocol was approved by the Institutional Review Board of the Chongqing Medical University (approval number: Keyan 2020002) and was registered on the Chinese Clinical Trial Registry (registration number: ChiCTR2000030970). Informed consent was waived owing to the study's retrospective nature. This study abided by the TRIPOD statement [17].

1. Patient selection

Prospectively maintained electronic databases were first established at all three high-volume hospitals in January 2014. From January 2014 to May 2020, patients with single-sided ipsilateral renal lesions who underwent retroperitoneal laparoscopic PN were retrospectively reviewed. Meanwhile, patients with multiple masses on the same side or those who underwent surgery via a transperitoneal approach were excluded from this study. All procedures were completed by senior urologists with at least 3 years of experience in laparoscopic PN.

2. Data collection and outcomes

Demographic characteristics, intraoperative information, and surgical outcomes were collected from the electronic databases. The surgical records along with the anesthesia records for each patient were reviewed to identify intraoperative complications. Intraoperative complications were defined as unplanned transfer to open surgery or radical nephrectomy or both, local main organ injury (such as liver, pancreas, intestines, or diaphragm), or vessel damage requiring immediate repair (main renal vein or artery or postcava). Two urologists (XT and DJ) who were masked to the clinical outcomes independently rated the RNS and the MAP score according to preoperative computed tomography scans.

3. Statistical analysis

Data are expressed as mean±standard deviation or as median with interquartile range for continuous variables and as percentage frequencies for categorical variables, respectively. Chi-squared and Wilcoxon signed rank tests were used to compare the differences between categorical and continuous variables, respectively. Multivariable logistic regression with backward elimination of variables was done to assess the components associated with intraoperative complications. Variables with the least significant effect not meeting the level of staying in the model were removed and this process was repeated until there was no more significant change available. A final nomogram was established based

Table 1. Demographic information and tumor features of 637 consecutive patients who underwent laparoscopic PN (including 32 conversions and 14 local injuries)

Variable	Overall (n=637)	Intraoperative complications (n=46)	No intraoperative complications (n=591)	p-value
Patient-related factors				
Age (y)	55.1±11.3	56.2±9.2	55.0±11.4	0.696
Female	231 (36.3)	18 (39.1)	213 (36.0)	0.750
Male	406 (63.7)	28 (60.9)	378 (64.0)	
Body mass index (kg/m ²)	25.2±4.4	26.8±5.4	25.1±4.3	0.012*
Right lesion	285 (44.7)	25 (54.3)	260 (44.0)	0.218
Left lesion	352 (55.3)	21 (45.7)	331 (56.0)	
ASA classification				
1–2	420 (65.9)	16 (34.8)	404 (68.4)	<0.001*
3–4	217 (34.1)	30 (65.2)	187 (31.6)	
Surgery-related factors				
Warm ischemia time (min)	15.3±6.1	17.2±4.3	15.1±6.2	0.025*
Surgery time (min)	111.3±38.7	152.5±55.6	108.1±35.2	<0.001*
Length of hospital stay (d)	5.1±2.8	5.5±2.1	5.1±2.8	0.344
Transfusion	42 (6.6)	9 (19.6)	33 (5.6)	<0.001*
Estimated blood loss (mL)	157.6±63.2	255±88	150±54	<0.001*
Postoperative complications	61 (9.6)	6 (13.0)	55 (9.3)	0.431
Tumor-related factors				
Malignancy	554 (87.0)	42 (91.3)	512 (86.6)	0.496
Benign	83 (13.0)	4 (8.7)	79 (13.4)	
T stage 1a	454 (71.3)	28 (60.9)	426 (72.1)	0.064
T stage 1b	175 (27.4)	16 (34.8)	159 (26.9)	
T stage 2	8 (1.3)	2 (4.3)	6 (1.0)	
RNS	6.15 (IQR, 5–8)	6.94 (IQR, 6–8)	6.11 (IQR, 5–8)	<0.001*
Tumor size (cm)	3.4±1.5	4.9±1.8	3.3±1.4	<0.001*
MAP score	2.04 (IQR, 0–3)	3.00 (IQR, 1–3)	2.01 (IQR, 0–3)	<0.001*
No stranding	320	8	312	<0.001*
Stranding type 1	177	12	165	
Stranding type 2	140	26	114	

Values are presented as mean±standard deviation, number (%), median (IQR), or number only.

PN, partial nephrectomy; ASA, American Society of Anesthesiologists; RNS, RENAL nephrometry score; MAP score, Mayo Adhesive Probability score; IQR, interquartile range.

*p<0.05.

on a multivariable logistic regression model. Thereafter, the nomogram was evaluated through both discrimination (area under the curve [AUC]) and calibration (locally weighted scatterplot smoothing [LOWESS] between the observed and the predicted probability of intraoperative complications). STATA version 15.1 software (Stata Corp., College Station, TX, USA) was used for data analysis. A difference of p<0.05 indicated statistical significance.

RESULTS

Demographic information and tumor features of 637 consecutive patients undergoing laparoscopic PN are presented in Table 1. Overall, intraoperative complications occurred in

Table 2. Reasons for conversions in 32 of 637 consecutive patients

Reasons for conversion	Case
Tumor invasion to collecting system	11
Technique limits	10
Poor blood control	7
Surgical margin positive	2
Rupture of main renal artery	2

PN, partial nephrectomy.

46 patients, including 32 in patients undergoing conversions and 14 due to local injuries. Two patients experienced open and radical surgeries. The reasons for conversions to open or radical surgery or both are listed in Table 2. Among them, the most frequent was invasion of the collecting system.

Table 3. Univariable and multivariable logistic regression analysis with backward elimination of risk factors for intraoperative complications in 637 patients

Variable	Univariable logistic analysis			Multivariable logistic analysis		
	Odds ratio	95% confidence interval	p-value	Odds ratio	95% confidence interval	p-value
RNS						
Tumor diameter (cm)						
≤4	Ref.	Ref.		Ref.	Ref.	
4–7	6.329	3.254–12.307	<0.001	4.339	1.943–9.692	<0.001
≥7	18.857	4.095–86.829	<0.001	8.434	1.225–58.090	0.031
Endophytic percent (%)						
≥50	Ref.	Ref.		Eliminated		
50–100	1.388	0.732–2.632	0.314			
100	10.843	0.914–39.71	0.059			
Nearness to the collecting system (mm)						
≥7	Ref.	Ref.		Ref.	Ref.	
4–7	4.424	2.100–9.319	<0.001	2.988	1.293–6.907	0.011
≤4	33.428	12.751–87.633	<0.001	21.394	6.122–74.756	<0.001
Tumor location						
Polar ^a	Ref.	Ref.		Eliminated		
Half middle ^b	0.474	0.190–1.183	0.110			
Total middle ^c	1.481	0.909–2.872	0.071			
MAP score						
Perirenal fat stranding type						
No stranding	Ref.	Ref.		Ref.	Ref.	
Type 1	3.154	1.219–8.163	0.018	3.119	1.079–9.017	0.036
Type 2	11.005	4.659–25.992	<0.001	18.722	6.757–51.868	<0.001
Posterior perinephric fat thickness (cm)						
<1.0	Ref.	Ref.		Eliminated		
1.0–1.9	1.573	0.720–3.435	0.255			
≥2.0	3.242	0.926–6.887	0.062			

PN, partial nephrectomy; RNS, RENAL nephrometry score; MAP score, Mayo Adhesive Probability score.

^a:Tumor entirely above the upper or below the lower polar line. ^b:Lesion crosses the polar line. ^c:>50% of mass is across the polar line or the mass crosses the axial renal midline or the mass is entirely between the polar lines.

All variables given in the table are consistent with the original RNS and MAP score.

Two patients were transferred to radical nephrectomy owing to injury to the main renal artery.

After multivariable logistic regression analyses (Table 3) of the risk factors for intraoperative complications, three variables were identified: tumor diameter (4–7 cm vs. ≤4 cm: odds ratio [OR], 4.339; 95% confidence interval [CI], 1.943–9.692; p<0.001; ≥7 cm vs. ≤4 cm: OR, 8.434; 95% CI, 1.225–58.090; p=0.031), nearness to the collecting system (4–7 mm vs. ≥7 mm: OR, 2.988; 95% CI, 1.293–6.907; p=0.011; ≤4 mm vs. ≥7 mm: OR, 21.394; 95% CI, 6.122–74.756; p<0.001), and perirenal fat stranding type (type 1 vs. no stranding: OR, 3.119; 95% CI, 1.079–9.017; p=0.036; type 2 vs. no stranding: OR, 18.722; 95% CI, 6.757–51.868; p<0.001). These three factors were then incorporated to establish a simple nomogram for intuitive presentation (Fig. 1).

The AUC comparisons with single RNS or MAP scores and their components are summarized in Table 4. Accord-

ing to our results, the predictive value of the nomogram was superior to that of the RNS or MAP score alone (RNS: 0.686, MAP score: 0.729, the nomogram: 0.837), but was equivalent to their combination (RNS+MAP scores: 0.813; p=0.271).

Furthermore, the observed probability of intraoperative complications was plotted based on the probability predicted by the nomogram (Fig. 2). A predicted probability of less than 40% might be an overestimate compared with actual probability, and this should be considered in clinical practice.

DISCUSSION

Intraoperative complications are important considerations during surgery, since they are associated with adverse outcomes, such as greater blood loss, longer operative time, and even conversion to radical nephrectomy [11,14,18]. Few previous studies have focused on the importance of intra-

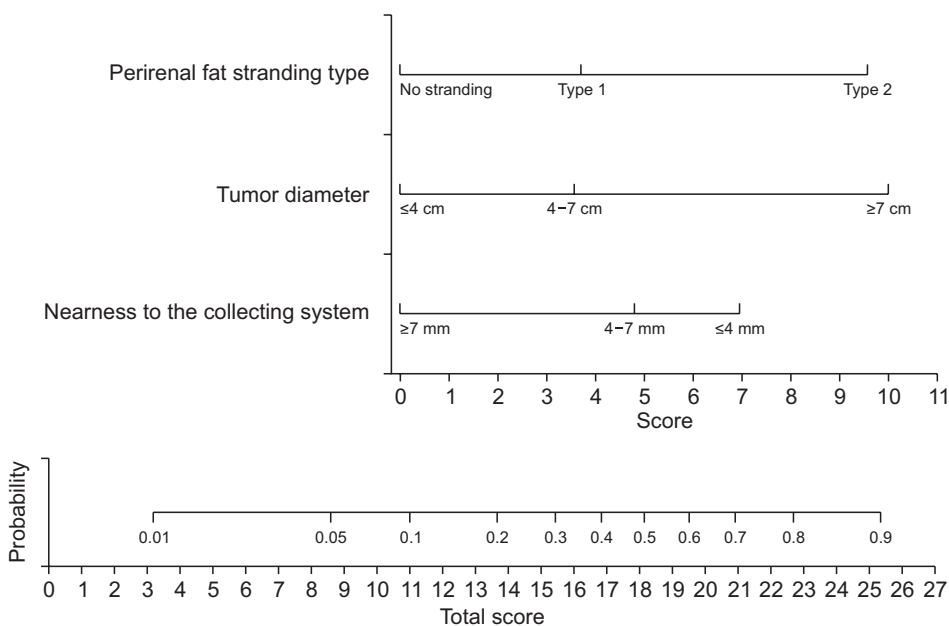


Fig. 1. A new nomogram to estimate risk for intraoperative complications during partial nephrectomy based on the Mayo Adhesive Probability score combined with the RENAL nephrometry score after multivariable logistic regression with backward elimination.

Table 4. AUC of predictors for intraoperative complications in 637 consecutive patients who underwent laparoscopic PN at 3 high-volume medical centrals in China between January 2014 and May 2020

Covariates	AUC	95% confidence interval	p-value (compared with the nomogram)
R score	0.672	0.595–0.749	<0.001*
N score	0.701	0.617–0.785	<0.001*
Stranding type	0.741	0.671–0.812	0.005*
MAP score	0.729	0.658–0.801	<0.001*
RNS	0.686	0.593–0.778	<0.001*
RNS+MAP scores	0.813	0.746–0.881	0.271
The nomogram	0.837	0.783–0.891	-

AUC, area under the curve; PN, partial nephrectomy; R, tumor radius; N, nearness to the collecting system; RNS, RENAL nephrometry score; MAP score, Mayo Adhesive Probability score; -, not available.

*p<0.05.

operative complications, which may be partly due to their rarity. In our study, the incidence rate of intraoperative complications was 7.2%, which is comparable to the rates reported in other studies [8,11-14]. The ideal model for prediction of intraoperative complications in PN would include as few components as possible without compromising accuracy.

In the literature, several factors have been identified as predictors of risk for surgical conversion. Our results were similar to those reported by Petros et al. [18], a retrospective study with the largest cohorts so far. In that study, among 1,857 patients undergoing PN, 90 (5%) were converted to radical surgery, and the risk factors were identified as larger tumor size (OR, 1.20; p=0.040), higher RNS (OR, 1.41; p=0.001), hilar tumor or renal sinus invasion (OR, 2.80; p=0.004), intra-

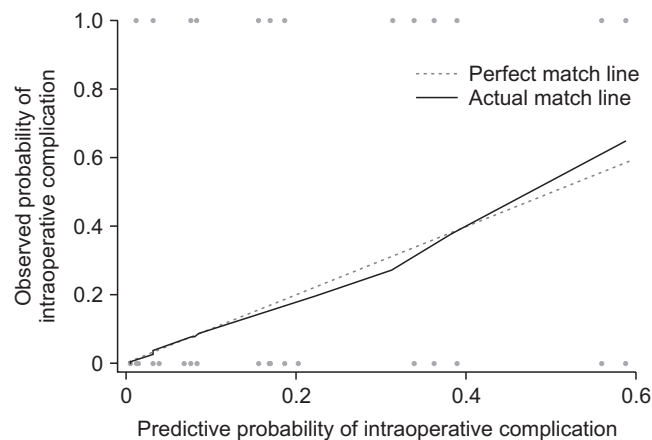


Fig. 2. The predictive probability of intraoperative complications of the nomogram and the observed probability of intraoperative complications were plotted by the locally weighted scatterplot smoothing (LOWESS) method. The ideal relationship between these two would be a one-to-one correspondence, which is plotted as a 45° segment line (dotted line), whereas the actual relationship is presented as a solid line.

operative bleeding (OR, 19.62; p<0.001), and positive surgical margin (OR, 31.85; p<0.001). Similarly, in a recent meta-analysis, both the MAP score (OR, 7.66; 95% CI, 3.10–18.94; p<0.001) and the RNS (OR, 1.40; 95% CI, 1.14–1.73; p=0.001) were recognized as risk factors for conversion to radical nephrectomy [2]. Such results are understandable. In our cohort, the causes of conversions were tumor invasion to the collecting system, limitations of the technique, positive surgical margin, poor blood control, and renal artery injury. Both the RNS and the MAP score were closely correlated with these factors. The MAP score, for instance, is a scoring system that represents

the probability of adhesive perirenal fat. Such “sticky” fat makes it difficult to dissect tissues and vessels and to identify local surgical markers, resulting in high risk for incident injury or unplanned conversion.

Laparoscopic PN is a technique-demanding surgery, in which local injury can be encountered even in the hands of experienced urologists; however, reports are sparse. During the process of renal dissection and isolation, the toxic sticky fat is identified as a risk factor for injury to local organs or vessels [14,19]. In general, sticky fat is associated with a high body mass index (BMI), which can be more accurately estimated by the MAP score in retroperitoneal PN. Besides, the toxic sticky fat is also associated with more blood loss and further contributes to a fuzzy surgical field, which may also play a role in surgical conversions.

The roles of the RNS and the MAP score have been well illustrated for some perioperative outcomes, whereas little is known about the role of their combination for predicting intraoperative complications [8,10,14]. Jin et al. [14] combined these two scoring systems by logistic regression analysis and found that the combination was superior to either of the single scores, and the AUC value was improved to 0.847 for intraoperative complications, which is consistent with our results. However, in their study, there were up to six actual variables, making the model complex for actual clinical practice. Similarly, Yang et al. [16] also assessed these two different algorithms in a retrospective study recruiting 159 patients who underwent laparoscopic PN. Each of their variables was evaluated to predict the margin, ischemia time, and complication achievement rate. Eventually, three factors, namely, tumor diameter, nearness to the renal sinus or collecting system, and posterior perinephric fat thickness, were incorporated to create a less complicated scoring system. But the actual predictive ability of this novel system and the association with intraoperative complications were not accessible.

After multivariable regression analysis with backward elimination in our study, only three factors, namely, tumor diameter, nearness to the collecting system, and adhesive perirenal fat stranding type, were retained to construct a nomogram. Each of them was assigned different scores to reach a final possibility of intraoperative complications. The internal validation using AUC showed that the predictive value of the nomogram was comparable to the direct combination of the RNS and the MAP score ($p=0.271$) and superior to the single scores and each component. Besides, the nomogram was further evaluated by LOWESS between the observed and the predicted probabilities of intraoperative complications. When the predicted probability of intraoperative

complications was low (<40%), the actual probability was lower than estimated, which should be taken into consideration in practical use. We also assessed the interobserver agreement of both the nomogram and the direct combination of the RNS and the MAP score. According to our results, the nomogram was more reliable (kappa test: 0.901 vs. 0.685, respectively).

Nonetheless, several limitations should be noted in this study. First, some specific intraoperative complications might have been missed owing to the retrospective design of the study. Second, the BMI in our cohort was much smaller than in American or European populations; thus, this population might not be representative of populations outside Asia. Nevertheless, the applicability of this study is to develop a simple nomogram for consideration before PN and to warn surgeons that patients with a high chance of getting intraoperative complications should not be ignored.

CONCLUSIONS

In conclusion, the combination of tumor diameter, nearness to the collecting system, and perirenal fat stranding type, which represents the RNS and the MAP score, can accurately predict intraoperative complications during laparoscopic PN, with fewer components than the combination of the RNS and MAP scores, yet with equivalent predictive power. These findings prove that a better predictive model can be created by not only addition but also subtraction. Moreover, this nomogram can be considered preoperatively.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Xiaojun Tan, Dachun Jin, and Yu Zhou. Data acquisition: Xiaojun Tan, Dachun

Jin, and Jian Hu. Statistical analysis: Xiaojun Tan, Dachun Jin, and Jian Hu. Data analysis and interpretation: Xiaojun Tan, Dachun Jin, and Jian Hu. Drafting of the manuscript: Xiaojun Tan, Dachun Jin, and Yunxiang Li. Critical revision of the manuscript: Weili Zhang, Yuanfeng Zhang, and Ji Wu. Obtaining funding: Xiaojun Tan and Yuanfeng Zhang. Administrative, technical, or material support: Weili Zhang and Ji Wu. Supervision: Yuanfeng Zhang and Ji Wu. Approval of the final manuscript: Yuanfeng Zhang and Ji Wu.

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