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# Nomogram for predicting the likelihood of postoperative surgical complications in patients treated with partial nephrectomy: a prospective multicenter observational study (the RECORd 2 project)

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## Abstract

**Purpose:** To identify the meaningful predictors and to develop a nomogram of postoperative surgical complications in patients treated with partial nephrectomy.

**Materials and Methods:** We prospectively evaluated 4308 consecutive patients who had surgical treatment for renal tumors between 2013 and 2016 at 26 urological Italian centers (RECORd 2 project). A multivariable logistic regression for surgical complication was performed. A nomogram was created from the multivariable model. Internal validation processes were performed using bootstrapping with 1000 repetitions.

**Results:** Overall, 2584 patients undergone PN were evaluated for the final analyses. The median American Society of Anaesthesiologists (ASA) score was 2 (IQR 2-3). Patients had a cT1a stage in 72.4% of the cases. Median PADUA score was 7 (IQR 6-8). Overall, 34.3%, 27.7%, 38% of patients underwent open, laparoscopic and robotic PN. Overall and major postoperative surgical complications were recorded in 10.2% and 2.5% of patients.

At multivariable analysis, age, ASA score, clinical T2 versus T1a stage, PADUA score, preoperative anaemia, open, and laparoscopic versus robotic approach were significant predictive factors of postoperative surgical complications. We used these variables to construct a nomogram for predicting the risk of postoperative surgical complications. At decision curve analysis, the nomogram led to superior outcomes for any decision associated with a threshold probability of above 5%.

**Conclusion:** Several clinical predictors have been associated with postoperative surgical complications. We used this information to develop and internally validate a nomogram to predict such risk.

**Introduction**

According to the latest American Urological Association guideline, partial nephrectomy (PN) should be preferred over radical nephrectomy (RN) for localized tumors, regardless of the surgical approach [1]. In fact, PN has comparable oncological outcomes with a better preservation of renal function and a lower rate of long-term cardiovascular events compared to RN [2,3]. Nevertheless, PN is a technical challenging procedure. Surgical complications are a prominent concern of PN as they have been reported in up to 30% of cases [4,5]. Major surgical complications are also frequent (3-6% of cases) and can be potentially life-threatening [6].

Although the urologic community expresses a general consensus that the perioperative surgical risks are justified by the theoretical long-term favourable outcome compared to RN, the risk/benefit ratio of PN is strictly related to the patients' and tumor's clinical characteristics, but also with the surgeon experience with different approaches [7]. A careful assessment of these features is paramount and should drive the treatment-decision making for patients with renal tumors. A personalised counselling tool predicting surgical complications in patients suitable for PN has not been developed yet.

The aims of the present study are: 1) to define the incidence, severity and predictors of postoperative surgical complications after PN relying on a rigorous prospectively recorded web-based database from a national collaborative project; 2) to generate a surgical nomogram to predict the likelihood of postoperative surgical complications after PN.

## Materials and methods

The Italian REgistry of COnservative and Radical Surgery for cortical renal tumor Disease (RECORD 2 Project) is a prospective observational multicentre project promoted by the Italian Society of Urology (SIU). Overall 4325 consecutive patients undergone renal surgery for cortical renal tumors at 26 urological Italian centres between January 1st, 2013 and December 31st, 2016 were included. Of these, 2584 patients underwent PN and 1712 RN, while 29 patients had missing data. Only the 2584 patients undergone PN were included in the study and formed the analytic cohort.

An online central data server was generated and centrally controlled to limit missing or wrong data inputs. All data of patients undergoing surgery were prospectively recorded by medical doctors. The database involves 6 main folders: 1) anthropometric and preoperative data; 2) imaging, indications (elective, relative and absolute) and co-morbidities; 3) intra-operative data; 4) post-operative data; 5) histological analysis 6) follow-up. Comorbidity status was evaluated by Charlson comorbidity index (CCI), physical status by the American Society of Anesthesiologists (ASA) classification system and performance status by the Eastern Cooperative Oncology Group (ECOG) score. Surgical indications were defined as elective (unilateral lesion with healthy contralateral kidney), relative (presence of diabetes, hypertension or lithiasis that could potentially affect kidney function in the future) and absolute (bilateral tumors, multiple tumors, moderate to severe CKD or tumors involving an anatomically or functionally solitary kidney). The Preoperative Aspects and Dimensions Used for an Anatomical (PADUA) score was calculated to assess the nephrometric complexity of each case [8]. Centre caseload was defined as number of PNs per year.

Surgical postoperative complications were defined as any postoperative event caused by surgery until the 30th postoperative day (POD), altering the normal postoperative course and/or delaying discharge. The severity of complications was graded according to the modified Clavien classification [9]. Acute kidney injury (AKI) was defined as an increase in serum creatinine to ≥1.5 times from the baseline. The recommendations for the development and implementation of reporting and grading of complications after PN of the EAU panel were applied [10].

*Statistical Analysis*

A univariate and multivariable logistic regression for postoperative surgical complication was performed. The area under the receiving operator characteristic (ROC) curves (AUC) was used to quantify predictive discrimination. Different ROC curves using the same set of observations were compared to assess how comorbidities, nephrometric and surgical parameters could affect the outcome within the multivariable model (*roccomp* function) [11]. A nomogram was generated from the statistically significant variables at multivariable logistic regression. Internal validation processes were performed using bootstrapping with 1000 repetitions. Calibration was assessed by comparing the predicted probabilities with the actual observed proportions on 1000 bootstrap resamples. A decision curve analysis was applied to determine whether the clinical value of the newly derived model increased the net benefit over a realistic range of threshold probabilities [12]. Statistical significance was set as $p < 0.05$. All tests were two-sided. Analyses were carried out using STATA v.14.1 (StataCorp LP, College Station, TX).

## Results

*Patients characteristics and surgical features*

The preoperative clinical characteristics and the univariate analysis for postoperative surgical complication are summarised in table 1. Male patients were 64.7%. Median age was 64.6 (IQR 55-72) years. Median CCI score was 1 (IQR 0-2). A cT1a, cT1b and cT2 stage was reported in 72.4%, 24.3% and 3.3% of the patients, respectively. Median PADUA score was 7 (IQR 6-8) and scores ≥10 were registered in 15.9% of cases. Patients had relative and absolute indication to surgery in 12.1% and 3.4% of patients. The surgical features are summarised in table 2. Patients were treated in centres performing a median of 63 (IQR 41-84) PNs/year: 1876 (72.6%), 468 (18.1%) and 240 (9.3%) patients were treated in centres performing >50, 25-50 and <25 PNs/year, respectively. Open, laparoscopic and robotic approaches were planned in 886 (34.3%), 717 (27.7%) and 981 (38%) cases. Off-clamp procedures were performed in 47.6% of the cases, an enucleative strategy of resection technique was adopted in 36.1% of cases. Conversion to open approach was registered in 7/717 (0.9%) laparoscopic and 3/981 (0.3%) robotic PNs.

*Postoperative surgical complications*

Postoperative surgical complications were reported in 264 (10.2%) of cases. Of these, 1.9% were Clavien 1, 5.9% were Clavien 2, 1.1% Clavien 3a, 1.2% Clavien 3b and 0.2% Clavien 4a. Overall, 8.5% of patients required postoperative treatment for bleeding: 7.1% were treated with transfusions (median units transfused 2 [IQR 1-2]), 0.9% with superselective embolization and 0.5% with surgical reintervention.

Persistent urinary leakage was diagnosed in 1.1% of cases requiring prolonged maintenance of the drain and its manipulation in 0.2%, while 0.9% required urinary stenting or nephrostomy tube insertion. Two (0.1%) cases of open PN required reintervention for bowel obstruction. Four (0.2%) cases of open PN required drain position for postoperative pneumothorax. Postoperative AKI managed with pharmacological treatment was recorded in 2.2% of cases.

*Multivariable models for postoperative surgical complications*

At the full multivariable model, age (OR 1.01, 95% CI 1.00-1.03, p=0.03), ASA score (OR 1.281, 95% CI 1.00-1.62, p=0.046), clinical T2 versus T1a stage (OR 2.03, 95% CI 1.13-3.67, p=0.01), PADUA score (OR 1.16, 95% CI 1.05-1.25, p=0.001), preoperative anaemia (OR 2.20, 95% CI 1.58-3.05, p<0.001), open (OR 2.87, 95% CI 1.94-4.27, p<0.001), and laparoscopic (OR 1.73, 95% CI 1.13-2.64, p=0.01) versus robotic approach were significant predictive factors of postoperative surgical complications, while CCI and ECOG scores, surgical indication, baseline creatinine, centre caseload and enucleoresective strategy were not. The full model had an area under the ROC curve of 73.1%.

The area under the ROC curve slightly decreased if the comorbidity and performance status scores (72.4%, p=0.15) and if the cT stage and PADUA score (71.1%, p=0.09) were removed from the full model (Figure 1 a-b). In comparison to the full model, a reduced model without surgical approach and resection strategy reduced the area under the ROC curve to 69.6% (p<0.001) and decreased to 68.7% (p<0.001) if also centre caseload was removed (Figure 1 c-d).

*Surgical nomogram*

The final nomogram included age, ASA score, preoperative anaemia, surgical indication, Clinical T stage, PADUA score, surgical approach (Figure 2a). The area under the ROC curve of the model was 72.4%. After a bootstrapping with 1000 repetitions, the model reported a bias of -0.05 and a standard error of 0.607 (95% CI -7.13, -4.75). Calibration plot focusing on nomogram performance characteristics exhibited a slight underestimation when predicted postoperative surgical complication risk was compared to >50% observed events (Figure 2b). At the decision curve analysis, the nomogram led to superior outcomes for any decision associated with a threshold probability of above 5% and showed a meaningful net benefit of the model compared to PADUA score in threshold probabilities between 5% and 30% (Figure 2c).

## Discussion

PN is a complex surgical intervention and the prediction of surgical complications rate, in addition to the oncologic and functional outcomes, is paramount to assess the risk/benefit ratio of PN compared to the radical treatment [13,14]. In our study, the overall postoperative surgical complication rate was 10.2% and the major surgical postoperative complication rate was 2.5%. These results represent a further demonstration of the increasing safety of this procedure over time and slightly exceed the perioperative results of the Italian registry of conservative surgery for renal tumors (RECORd 1 project) from 2008 to 2012, which reported an overall and major complication rate of 13.1% and 3.5%, respectively [4]. The overall and Clavien 3 complication rate reported in this study were also lower compared to those of the national database of the British Association of Urological Surgeons (BAUS) reporting an overall complication rate of 17.8% and Clavien ≥3A complication rate of 5% in 1044 patients treated with PN at ten institutions from 2001 to 2012 [15]. Indeed, the higher rate of complications in this series could be related to the different era of patients' accrual and to the lower rate of minimally-invasive PNs compared to our study (41.5% vs 65.7%). Larcher and co-authors reported from the Surveillance, Epidemiology, and End Results (SEER) Medicare registry an overall complication rate of 37%, a transfusion rate of 11% and AKI in 5.8% of the cases in almost two-thousands patients treated with PN [5]. The older age and the higher rate of comorbidities of Medicare beneficiaries, together with the different characteristics of the health-care providers tracked in a population-based dataset and the different surgical era can explain such discrepancy.

We constructed a multivariable model to predict the risk of development of postoperative surgical complications after PN. Age, baseline haemoglobin, cT stage, PADUA score and planned surgical approach were significant predictive factors of postoperative surgical complications and therefore included in the model. As about patients performance status and its impact on the safety of partial nephrectomy, three different scores were included in the full multivariable model, but, interestingly, there was a trend towards significance only for two of them (ASA score [p=0.046] and ECOG score [p=0.07], while the most accurate CCI failed to reach significance at the multivariable analysis. Indeed, the development of a new proper comorbidity scale to specifically predict the outcomes after renal surgery would be helpful for patients counselling.

Patients with tumors clinically staged T2 had over a double risk of developing surgical complications compared to those with T1a tumors, while T1a and T1b tumors had a comparable rate of surgical complications (p=0.76). Indeed, the surgical feasibility of PN in patients with cT1b disease has been reported by several authors [16,17]. A recent report suggests that PN should not compromise the oncological outcome in patients with a >7 cm renal tumors even when performed with a robotic approach [18]. However, most of the surgical series comparing PN with RN reported a significantly higher blood loss and complication rates in patients treated by PN [19–22]. cT stage should be carefully considered together with the nephrometry features of the tumor: in our study, each point increase of PADUA score determined a significant increase risk of 13% of developing surgical postoperative complications. The PADUA score has been demonstrated to predict the risk of perioperative complications in patients who underwent open PN in series including mostly patients with <4 cm renal tumors [8,23]. This was confirmed also in this more comprehensive study including patients treated with minimally invasive approaches and for cT1b-T2 renal tumors.

As about centre expertise and the ways in which surgery can be performed, it was not the centre caseload, but the surgical approach that independently correlated with a reduction of surgical complications. In fact, open and laparoscopic surgery compared to robotic were the most meaningful surgical predictors of postoperative surgical complications. However, centre expertise and surgical approach are tightly interconnected in our study: among the 16/26 centres where the robotic system was available, 12 had >50 PNs per year. Conversely, the surgical technique of tumor resection lost significance at multivariable analysis. Nevertheless, the surgical variables had the strongest impact on postoperative surgical complications in our multivariable model. Their exclusion led to a loss of clinical significance of the model (AUC 73.1% vs 68.7%, $p<0.001$). A possible explanations of these results are attributable to the benefits of minimally invasive surgery and to the improved dexterity and vision of robotic system, that allows a more precise dissection, a careful haemostasis and renal reconstruction with a shorter learning curve compared to laparoscopy [24]. Therefore, surgical approach might have a higher impact on predicting the likelihood of surgical complications compared to the surgical technique and centre caseload.

Interestingly, the absolute indication was not a significant predictor of postoperative surgical complications in the full model. This finding is consistent also with other multicentre [4] and high-volume-centre [25] series. Indeed, surgeons are often enticed to treat also complex renal masses with a conservative strategy in patients with imperative indication. However, this highly challenging procedure is often performed in high-volume centres by very experienced surgeons: this might explain why the surgical indication was not a significant predictor of surgical complications at multivariable analysis in our series. However, surgical indication did not reach the significance even in the multivariable reduced model n. 4 which excludes the surgical parameters and the volume centre, but it did in the multivariable model n. 2 which excluded comorbidity and performance status scores. This could be related to the not uncommon presence of comorbidities in patients with impaired renal function due to medical reasons. Indeed, further studies are needed to better address this point and PN in patients with absolute indication remains an extremely challenging procedure.

Nomograms provide a numerical estimation of risk in the form of a probability on the basis of several patient, tumor and surgical characteristics and they are currently considered the most accurate tool to predict outcomes after surgical treatment. Numerous similar models have been published for urologic malignancies to predict oncologic outcomes [26–28], for specific treatment-decision making [24,29] and to assess the risk of surgical complications [30,31]. The internal bootstrapping was then performed to assess if the observed probability in 1000 resamples of the cohort was consistent with the prediction of the nomogram constructed using the entire cohort. The calibration plot showed an overlap of the predicted and observed probability of the surgical nomogram revealing a clinical meaningfulness of the nomogram when the observed/predicted risk was <50%. Furthermore, the decision curve analysis showed that the statistical model would improve the clinical decision-making when the predicted risk was >5%.

Despite a nomogram has been previously developed to assess the risk of complications after PN [5], this study adds a nephrometric score to the model and describes carefully all postoperative complications including their grade. A predictive tool, such this, can enable clinicians to evaluate the risk of postoperative surgical complications and might allow more accurate risk stratification on each individual case before treatment.

Despite the strengths, this study is not devoid of limitations. First, we could not determine the experience and the learning curve of each surgeon therefore the centre caseload of PN per year, was chosen as a surgical experience surrogate. Thus, our nomogram should be interpreted in light of the lack of specific knowledge on the treating surgeon's experience and skills in PN and future studies considering this variable as a predictor of surgical complications are warranted to confirm its impact on key PN outcomes. A conservative vs radical treatment and an enucleative vs standard PN resection were performed according to the surgeons' preference. Minimally invasive approaches were performed according to the centre availability and to the preference of the surgeons that might prefer an open approach for the management of complex renal masses despite the availability of a robotic platform. Another potential drawback of the study is the lack of external validity of the constructed nomogram. The nomogram should be tested also on other multicentre international cohorts as our findings might not be entirely generalizable to all patients undergoing PN. However, the internal validation was performed on the largest nation-based prospective database on PN available so far. Indeed, the high-quality report of outcomes was guaranteed by the rigorous control of data prospectively inserted on the internet-based platform only by medical doctors from the participating centres. Finally, this nomogram is not meant to guide the decision to perform PN vs RN in individual patients with localized renal masses but rather to provide an estimate of the likelihood of postoperative surgical complications according to specific patient-, tumor- and surgery-related variables to assist clinical decision making in everyday practice.

This study offers several opportunities for future research in this field. Indeed, multicentre prospective studies should 1) provide external validation of our nomogram in different clinical scenario; 2) develop a novel physical status score specific for PN to assess the real impact of those comorbidities that affect perioperative outcome in patients treated with conservative surgery; 3) integrate our nomogram in a more comprehensive decision-making tool to individualise selection strategy of PN vs RN in patients eligible for surgical treatment of PN.

## Conclusions

Surgical complications are a not-negligible aspect to consider for the treatment-decision making for patients with localized renal tumors with a 10.2% and 2.5% rate of overall and major postoperative surgical complications. We developed a surgical nomogram including age, ASA score, ECOG score, preoperative anaemia and creatinine, surgical indication, clinical T stage, PADUA score, surgical approach, to accurately predict the risk of surgical complications in patients with localized renal tumors.

## Ethical approval

The study was first approved by the Ethical Committee of the leading Centre of the RECORd project (Department of Urology, University of Florence, Careggi Hospital, Florence, Italy) and then by all Ethical Committees of all Centres participating in the project.

**Conflict of Interest:** None

**Funding:** None

## Table and Figure legends

**Table 1:** Preoperative characteristics of 2584 patients treated with partial nephrectomy for renal tumors and univariate analysis for postoperative surgical complications.

**Table 2:** Intraoperative characteristics of 2584 patients treated with partial nephrectomy for renal tumors and univariable analysis for postoperative surgical complications.

**Table 3:** Multivariable logistic regression analyses of postoperative surgical complications adjusting for preoperative and surgical variables in 2584 patients treated with PN for renal tumors. The reduced model n. 1 exclude the comorbidity and physical status scores from the regression analysis. The reduced model n. 2 exclude the PADUA score and clinical T stage from the regression analysis. The reduced model n. 3 exclude the surgical approach and technique from the regression analysis. The reduced model n. 4 exclude the surgical approach from the regression analysis.

Legend: ASA, American Society of Anesthesiologists; CCI, Charlson comorbidity index; ECOG, eastern cooperative oncology group; LPN, laparoscopic partial nephrectomy; OPN, open partial nephrectomy; PN, partial nephrectomy; RAPN, robot-assisted partial nephrectomy; SE, simple enucleation.

**Figure 1 a-d.** Comparison of ROC areas of full versus reduced logistic regression models. A) Comparison of the full model versus the reduced model n. 1 excluding the Charlson, ASA and ECOG scores from the regression analysis. B) Comparison of the full model versus the reduced model n. 2 excluding the PADUA score and clinical T stage from the regression analysis. C) Comparison of the full model versus the reduced model n. 3 exclude the surgical approach from the regression analysis.

D) Comparison of the full model versus the reduced model n. 4 exclude the surgical approach and technique from the regression analysis.

**Figure 2:** A) Surgical nomogram for predicting postoperative surgical complications in patients undergoing partial nephrectomy for renal tumors. B) Calibration plot of the actual versus predicted probability of the surgical nomogram for predicting postoperative surgical complications evaluated by 1000 bootstrap resamples. C) Decision curve analysis for the evaluation of the clinical net benefit using the surgical nomogram and PADUA score for detecting postoperative surgical complications.

**Conflicts of interest**

None declared

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| **Preoperative characteristics (n=2584)** | | **Descriptive analysis** | | **Univariate analysis for postoperative complications** | |
|---|---|---|---|---|---|
| | | No. of patients* | | Odd ratio (95% CI) | **p** |
| Gender | Male | 1671 | 64.7% | 1.27 (0.97-1.65) | 0.08 |
| | Female | 913 | 35.3% | 1.00 (reference) | - |
| Age (years) | | 64.6 | 54.9-72.2 | 1.03 (1.02-1.04) | **<0.001** |
| BMI (kg/m^2) | | 25.8 | 23.7-28.7 | 0.98 (0.95-1.01) | 0.19 |
| ECOG | median IQR | 0 | 0-1 | 1.14 (1.08-1.13) | **<0.001** |
| Score | • ≥1 | 737 | 28.5% | 1.73 (1.33-2.27) | **<0.001** |
| ASA | median IQR | 2 | 2-3 | 1.97 (1.61-2.42) | **<0.001** |
| Score | • ≥3 | 700 | 27.1% | | |
| CCI score | | 1 | 0-2 | 1.19 (1.10-1.29) | **<0.001** |
| AA-CCI score | | 4 | 2.5-5 | 1.18 (1.11-1.26) | **<0.001** |
| Surgical indication | | | | | **0.02** |
| | • Elective | 2122 | 82.1% | 1.00 (reference) | |
| | • Relative | 372 | 14.4% | 1.12 (0.78-1.60) | 0.55 |
| | • Imperative | 90 | 3.5% | 2.27 (1.27-4.07) | **0.006** |
| Tumor side, n. % | • Right | 1316 | 50.9% | 1.12 (0.87-1.45) | 0.39 |
| | • Left | 1268 | 49.1% | 1.00 (reference) | |
| Clinical T, n. % | | | | | **0.001** |
| | • T1a | 1872 | 72.4% | 1.00 (reference) | |
| | • T1b | 628 | 24.3% | 1.17 (0.87-1.58) | 0.29 |
| | • T2 | 84 | 3.3% | 2.78 (1.61-4.81) | **<0.001** |
| Multiple ipsilateral lesion n. % | | 152 | 5.9% | 1.61 (0.94-2.73) | 0.08 |
| Tumor growth pattern | | | | | 0.54 |
| | • ≥50% Exophytic | 1444 | 55.9% | 1.00 (reference) | |
| | • <50% Exophytic | 933 | 36.1% | 1.14 (0.87-1.50) | 0.34 |
| | • Entirely endophytic | 207 | 8.0% | 1.21 (0.76-1.94) | 0.42 |
| Tumor location relative to the polar line (PL) | | | | | **0.009** |
| | • Entirely above PL | 1505 | 58.2% | 1.00 (reference) | |
| | • ≤50% crosses PL | 616 | 23.8% | 1.32 (0.90-1.95) | 0.15 |
| | • >50% crosses PL | 463 | 17.9% | 1.55 (1.17-2.05) | **0.002** |
| Nearingness to the collecting system | | | | | **<0.0001** |
| | • ≥7 | 1332 | 51.5% | 1.00 (reference) | |
| | • >4 but <7 | 884 | 34.2% | 2.16 (1.57-2.96) | **<0.0001** |
| | • ≤4 | 368 | 14.2% | 1.58 (1.10-2.27) | **0.01** |
| PADUA score, median IQR | | 7.0 | 6.0-8.0 | 1.16 (1.07-1.26) | **<0.0001** |
| RENAL score, median IQR | | 6.0 | 5.0-7.0 | 1.18 (1.09-1.26) | **<0.0001** |
| PADUA score complexity index | | | | | **0,001** |
| | • 6-7 | 1274 | 49.3% | 1.00 (reference) | |
| | • 8-9 | 900 | 34.8% | 1.37 (1.02-1.84) | **0.035** |
| | • ≥10 | 410 | 15.9% | 1.91 (1.35-2.69) | **<0.0001** |
| Baseline hemoglobin (g/dL), median (IQR) | | 14.2 | 13.2-15.1 | 0.72 (0.66-0.78) | **<0.0001** |

| | | | | |
|---|---|---|---|---|
| Preoperative anaemia ^ n. % | 326 | 12.0% | 3.06 (2.28-4.13) | **<0.0001** |
| Baseline creatinine (mg/dL), median (IQR) | 0.9 | 0.8-1.0 | 1.81 (1.39-2.39) | **<0.0001** |
| Baseline eGFR (mL/min), median IQR | 85.8 | 69.9-100.4 | 0.99 (0.98-0.99) | **<0.0001** |

*Number and percentage, and median and interquartile range are reported for nominal and continuous variables.
^Anaemia was defined as haemoglobin under the threshold of 12 g/dL and 13 g/dL in women and men, respectively.

**Table 1:** Preoperative characteristics of 2584 patients treated with partial nephrectomy for renal tumors and univariate analysis for postoperative surgical complications.

| Intraoperative characteristics (n=2584) | Descriptive analysis | | Univariate analysis for postoperative complications | |
|---|---|---|---|---|
| | No. of patients* | | Odd ratio (95% CI) | p |
| **Open approach** | **886** | **34.3%** | 3.74 (2.67-5.23) | **<0.0001** |
| • Transperitoneal | 146 | 16.5% | | |
| • Retroperitoneal | 740 | 83.5% | | |
| **Laparoscopic approach** | **717** | **27.7%** | 1.71 (1.16-2.52) | **0.01** |
| • Transperitoneal | 443 | 61.8% | | |
| • Retroperitoneal | 274 | 38.2% | | |
| **Robotic approach** | **981** | **38.0%** | 1.0 (reference) | |
| • Transperitoneal | 847 | 86.3% | | |
| • Retroperitoneal | 134 | 13.7% | | |
| Centre caseload | 63 | 41-84 | 1.02 (1.01-1.03) | **<0.0001** |
| Type of resection | | | | |
| • Enucleation | 934 | 36.1% | 1.00 (reference) | |
| • Standard PN | 1650 | 63.9% | 1.95 (1.45-2.64) | **<0.0001** |
| Haemostatics on tumor renal bed | | | | |
| • Application | 2176 | 84.2% | 1.00 (reference) | 0.55 |
| • No application | 408 | 15.8% | 1.10 (0.79-1.56) | |
| Renorraphy on tumor renal bed | | | | |
| • Used | 2191 | 84.8% | 1.00 (reference) | 0.09 |
| • Not used | 393 | 15.2% | 1.39 (0.94-2.06) | |
| Pedicle clamping, n. % | | | | |
| • On-clamp | 1353 | 52.4% | 1.00 (reference) | |
|     • En bloc | 301 | 22.2% | | |
|     • Arterial | 1052 | 87.8% | | |
| • Off-clamp | 1231 | 47.6% | 1.11 (0.85-1.43) | 0.45 |

*Number and percentage, and median and interquartile range are reported for nominal and continuous variables.

**Table 2:** Intraoperative characteristics of 2584 patients treated with partial nephrectomy for renal tumors and univariable analysis for postoperative surgical complications.

| | Multivariate logistic regression analysis for postoperative surgical complications | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Full model | | | Reduced model n. 1 | | | Reduced model n. 2 | | | Reduced model n. 3 | | | Reduced model n. 4 | | |
| | OR | 95%CI | p-value | OR | 95%CI | p-value | OR | 95%CI | p-value | OR | 95%CI | p-value | OR | 95%CI | p-value |
| Age (continuous) | 1.01 | 1.00-1.03 | 0.034 | 1.02 | 1.01-1.03 | 0.001 | 1.01 | 0.99-1.02 | 0.11 | 1.01 | 1.00-1.02 | 0.02 | 1.01 | 1.00-1.03 | 0.02 |
| ASA score (continuous) | 1.28 | 1.00-1.62 | 0.046 | | | | 1.28 | 1.00-1.62 | 0.04 | 1.48 | 1.17-1.86 | <0.001 | 1.44 | 1.13-1.81 | 0.002 |
| ECOG score (continuous) | 1.21 | 0.98-1.47 | 0.071 | | | | 1.21 | 0.99-1.47 | 0.07 | 1.13 | 0.93-1.38 | 0.19 | 1.15 | 0.94-1.41 | 0.15 |
| CCI score (continuous) | 1.01 | 0.92-1.12 | 0.733 | | | | 1.02 | 0.92-1.11 | 0.80 | 1.03 | 0.93-1.14 | 0.59 | 1.03 | 0.93-1.13 | 0.56 |
| Surgical Indication | | | 0.66 | | | | | | 0.68 | | | 0.47 | | | 0.36 |
| Elective | 1.00 (ref.) | | | 1.00 (ref.) | | | 1.00 (ref.) | | | 1.00 (ref.) | | | 1.00 (ref.) | | |
| Relative | 0.79 | 0.51-1.21 | 0.28 | 0.82 | 0.54-1.25 | 0.36 | 0.87 | 0.57-1.32 | 0.52 | 0.70 | 0.47-1.07 | 0.11 | 0.74 | 0.52-1.14 | 0.17 |
| Absolute | 1.48 | 0.80-2.73 | 0.22 | 2.11 | 1.18-3.78 | 0.01 | 1.49 | 0.81-2.75 | 0.19 | 1.56 | 0.85-2.87 | 0.15 | 1.59 | 0.86-2.93 | 0.13 |
| Clinical T | | | 0.04 | | | 0.03 | | | | | | 0.04 | | | 0.02 |
| T1a | 1.00 (ref.) | | | 1.00 (ref.) | | | | | | 1.00 (ref.) | | | 1.00 (ref.) | | |
| T1b | 1.17 | 0.85-1.58 | 0.33 | 1.18 | 0.86-1.60 | 0.30 | | | | 1.16 | 0.85-1.58 | 0.76 | 1.17 | 0.86-1.60 | 0.30 |
| T2 | 2.03 | 1.13-3.67 | 0.01 | 2.12 | 1.18-3.79 | 0.01 | | | | 2.23 | 1.24-4.00 | 0.01 | 2.22 | 1.24-3.98 | 0.01 |
| PADUA Score (continuous) | 1.16 | 1.05-1.25 | 0.001 | 1.15 | 1.03-1.25 | 0.002 | | | | 1.18 | 1.08-1.28 | <0.001 | 1.17 | 1.07-1.27 | <0.001 |
| Preoperative anaemia | 2.20 | 1.58-3.05 | <0.001 | 2.34 | 1.69-3.24 | <0.001 | 2.29 | 1.66-3.16 | <0.001 | 2.29 | 1.66-3.16 | <0.001 | 2.27 | 1.64-3.14 | <0.001 |
| Baseline Creatinine (continuous) | 1.26 | 0.92-1.72 | 0.14 | 1.36 | 1.00-1.83 | 0.04 | 1.23 | 0.90-1.67 | 0.19 | 1.19 | 0.87-1.61 | 0.27 | 1.28 | 0.87-1.75 | 0.12 |
| Centre caseload (PN/year) | 0.993 | 0.98-0.997 | 0.278 | 0.99 | 0.99-1.00 | 0.27 | 0.99 | 0.99-1.00 | 0.57 | 0.99 | 0.99-1.00 | 0.001 | | | |
| Surgical approach | | | <0.001 | | | <0.001 | | | <0.001 | | | | | | |
| OPN | 2.87 | 1.94-4.27 | <0.001 | 3.10 | 1.20-2.76 | <0.001 | 3.08 | 2.07-4.58 | <0.001 | | | | | | |
| LPN | 1.73 | 1.13-2.64 | 0.011 | 1.81 | 1.20-2.75 | 0.005 | 1.72 | 1.12-2.63 | 0.01 | | | | | | |
| RAPN | 1.00 (ref.) | | | 1.00 (ref.) | | | 1.00 (ref.) | | | | | | | | |
| Standard PN vs SE | 1.02 | 0.72-1.45 | 0.91 | 1.04 | 0.73-1.47 | 0.53 | 1.12 | 0.79-1.60 | 0.52 | | | | | | |

**Table 3:** Multivariable logistic regression analyses of postoperative surgical complications adjusting for preoperative and surgical variables in 2584 patients treated with PN for renal tumors. The reduced model n. 1 exclude the comorbidity and physical status scores from the regression analysis. The reduced model n. 2 exclude the PADUA score and clinical T stage from the regression analysis. The reduced model n. 3 exclude the surgical approach and technique from the regression analysis. The reduced model n. 4 exclude the surgical approach from the regression analysis.

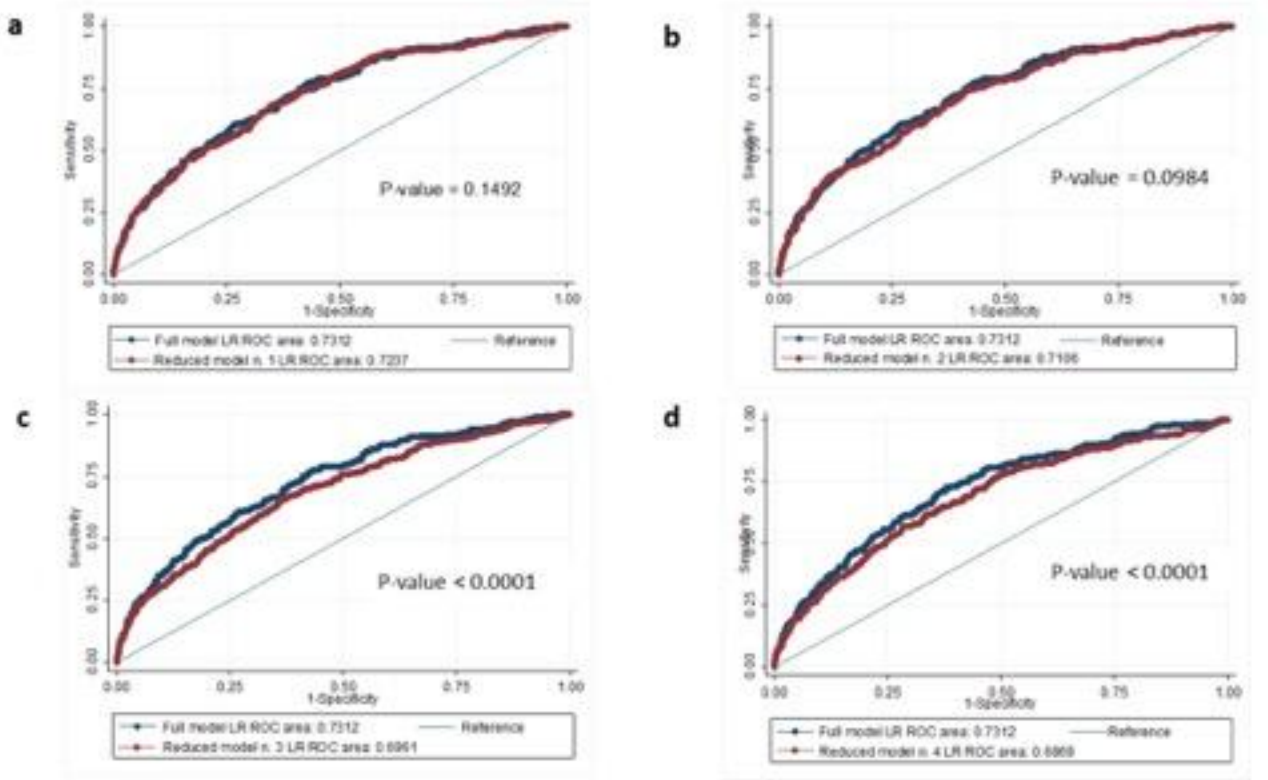
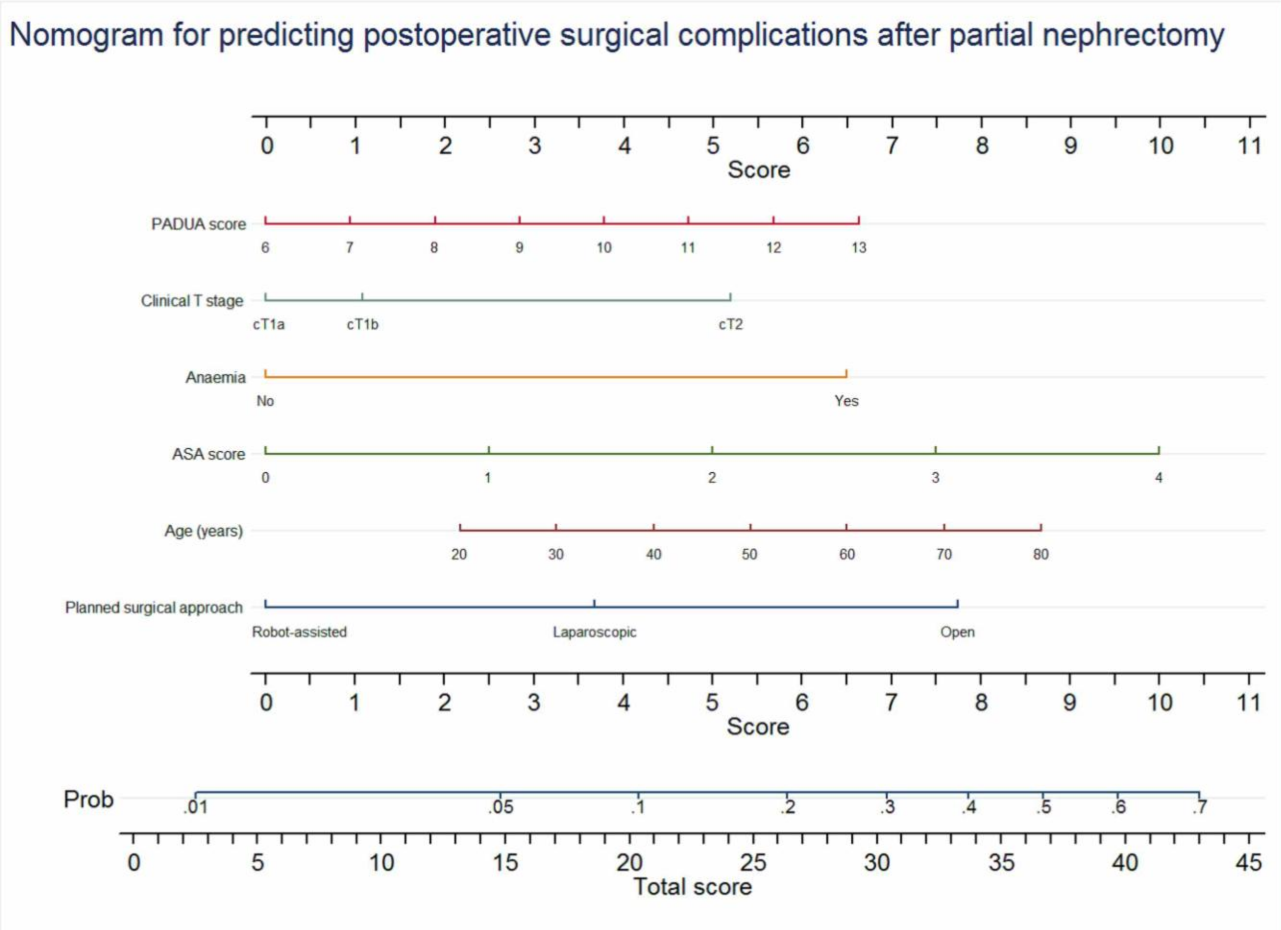
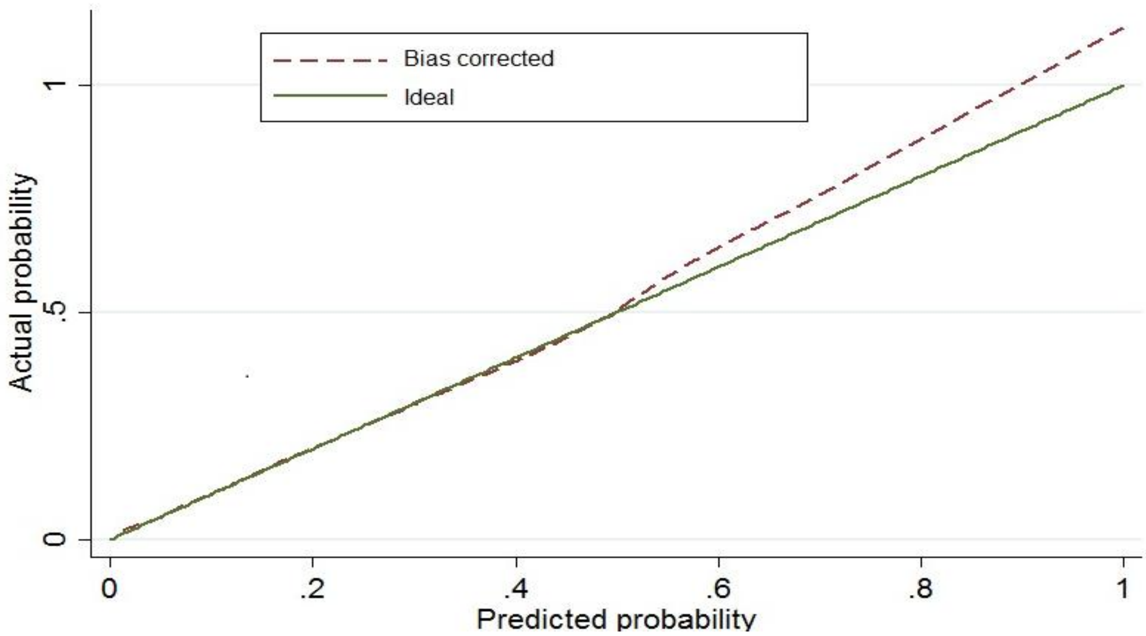



**Figure 1 a-d.** Comparison of ROC areas of full versus reduced logistic regression models. A) Comparison of the full model versus the reduced model n. 1 excluding the Charlson, ASA and ECOG scores from the regression analysis. B) Comparison of the full model versus the reduced model n. 2 excluding the PADUA score and clinical T stage from the regression analysis. C) Comparison of the full model versus the reduced model n. 3 exclude the surgical approach from the regression analysis. D) Comparison of the full model versus the reduced model n. 4 exclude the surgical approach and technique from the regression analysis.


Nomogram for predicting postoperative surgical complications after partial nephrectomy
Score
0 1 2 3 4 5 6 7 8 9 10 11
PADUA score
6 7 8 9 10 11 12 13
Clinical T stage
cT1a cT1b cT2
Anaemia
No Yes
ASA score
0 1 2 3 4
Age (years)
20 30 40 50 60 70 80
Planned surgical approach
Robot-assisted Laparoscopic Open
Prob
.01 .05 .1 .2 .3 .4 .5 .6 .7
Total score
0 5 10 15 20 25 30 35 40 45


Bias corrected
Ideal
Actual probability
0 .5 1
Predicted probability
0 .2 .4 .6 .8 1

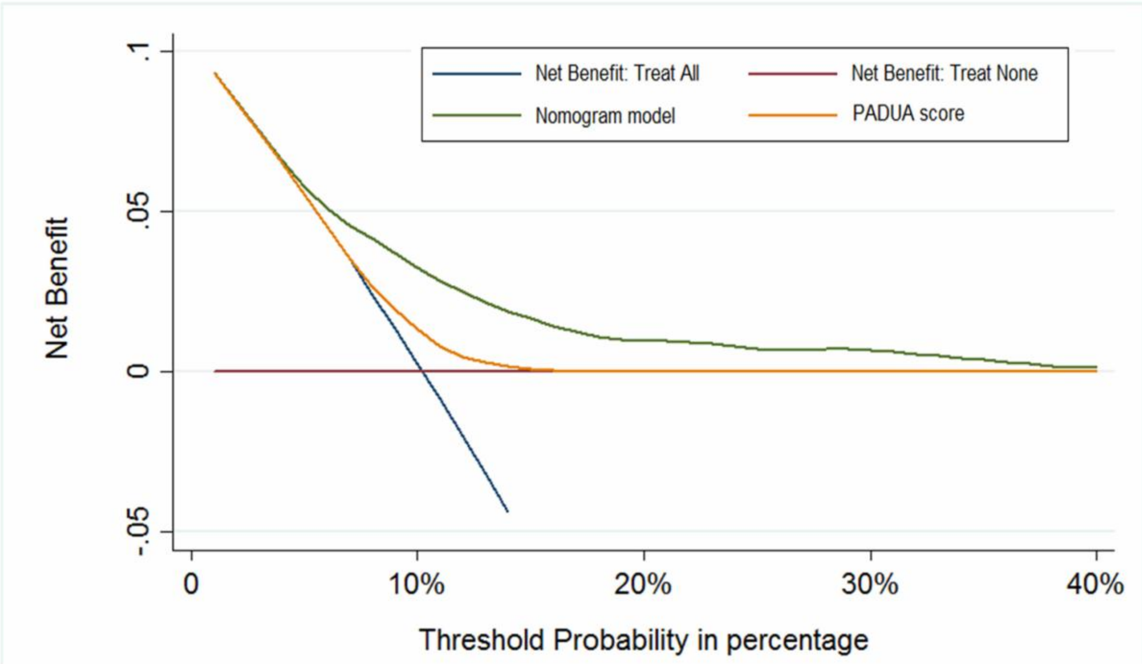



**Figure 2:** A) Surgical nomogram for predicting postoperative surgical complications in patients undergoing partial nephrectomy for renal tumors. B) Calibration plot of the actual versus predicted probability of the surgical nomogram for predicting postoperative surgical complications evaluated by 1000 bootstrap resamples. C) Decision curve analysis for the evaluation of the clinical net benefit using the surgical nomogram and PADUA score for detecting postop
erative surgical complications.