A Mathematical Method to Calculate Tumor Contact Surface Area: An Effective Parameter to Predict Renal Function after Partial Nephrectomy

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Purpose: We proposed a mathematical formula to calculate contact surface area between a tumor and renal parenchyma. We examined the applicability of using contact surface area to predict renal function after partial nephrectomy.

Materials and Methods: We performed this retrospective study in patients who underwent partial nephrectomy between January 2012 and December 2014. Based on abdominopelvic computerized tomography or magnetic resonance imaging, we calculated the contact surface area using the formula ($2*\pi*$radius*depth) developed by integral calculus. We then evaluated the correlation between contact surface area and perioperative parameters, and compared contact surface area and R.E.N.A.L. (Radius/Exophytic/endophytic/Nearness to collecting system/Anterior/Location) score in predicting a reduction in renal function.

Results: Overall 35, 26 and 45 patients underwent partial nephrectomy with open, laparoscopic and robotic approaches, respectively. Mean ± SD contact surface area was 30.7 ± 26.1 cm^2 and median (IQR) R.E.N.A.L. score was 7 (2.25). Spearman correlation analysis showed that contact surface area was significantly associated with estimated blood loss ($p=0.04$), operative time ($p=0.04$) and percent change in estimated glomerular filtration rate ($p<0.001$). On multivariate analysis contact surface area and R.E.N.A.L. score independently affected percent change in estimated glomerular filtration rate ($p<0.001$ and $p=0.03$, respectively). On ROC curve analysis contact surface area was a better independent predictor of a greater than 10% change in estimated glomerular filtration rate compared to R.E.N.A.L. score (AUC 0.86 vs 0.69).

Conclusions: Using this simple mathematical method, contact surface area was associated with surgical outcomes. Compared to R.E.N.A.L. score, contact surface area was a better predictor of functional change after partial nephrectomy.

Key Words: nephrectomy, kidney function tests, treatment outcome, prognosis

Abbreviations and Acronyms

ACE = absolute change in estimated glomerular filtration rate

ASA® = American Society of Anesthesiologists®

BMI = body mass index

CCI = Charlson comorbidity index

CIT = cold ischemia time

CSA = contact surface area

CT = computerized tomography

EBL = estimated blood loss

eGFR = estimated glomerular filtration rate

LPN = laparoscopic partial nephrectomy

MRI = magnetic resonance imaging

OPN = open partial nephrectomy

PCE = percent change in eGFR

PN = partial nephrectomy

PRF = postoperative renal function

RPN = robotic assisted partial nephrectomy

WIT = warm ischemia time

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Compared with radical nephrectomy, partial nephrectomy achieves similar oncologic outcomes but better renal function preservation for patients with localized renal tumors.[1] By reducing the incidence of sequelae of chronic kidney disease and cardiovascular morbidities, PN also provides better overall survival than radical nephrectomy.[2,3] In EORTC (European Organisation for Research and Treatment of Cancer) trial 30904, although PN did not result in improved survival, it did result in a reduced incidence of at least moderate renal dysfunction (eGFR less than 60 ml/minute/1.73 m^2).[4] In recent years the indication for PN has been expanded to select patients with renal tumors larger than 4 cm.[5] In addition, several nephrometry systems have been published and compared to standardize the description of renal tumors.[1,6] For example, the R.E.N.A.L. and PADUA nephrometry systems characterize anatomical features in terms of tumor radius, endophytic component, proximity to sinus fat/collecting system and location (anterior/posterior aspect and location relative to polar lines).[7,8] The centrality index is the ratio of the distance between the tumor and renal center over the tumor radius.[9] Among the nephrometry systems the R.E.N.A.L. score was first published in 2009 and is the most well-known.[7] It has been found to be associated with perioperative outcomes of PN such as warm ischemia time and estimated blood loss.[10] However, the ability of the R.E.N.A.L. score to predict a loss in renal function is still controversial.[11,12] To date, there is no well validated method to predict postoperative renal function after PN.

The concept of renal tumor contact surface area was introduced in 2014 by Leslie et al, in that CSA was found to be correlated with perioperative outcomes and PRF.[13] However, dependence on image rendering software limits the use of CSA in clinical practice. In addition, no head-to-head comparisons of CSA and the R.E.N.A.L. score have yet been published. In this study we developed a novel equation to estimate CSA purely using a mathematical model. We then examined correlations between CSA and perioperative outcomes. Finally, we comparatively analyzed the ability of CSA and R.E.N.A.L. score to predict a reduction in renal function.

MATERIALS AND METHODS

After institutional review board approval we evaluated consecutive patients who underwent PN via OPN, LPN or RPN approaches for localized renal tumors between January 2012 and December 2014 at a tertiary referral center. The choice of surgical approach was based on cost, surgeon expertise and patient preference. Patients with multiple renal tumors, bilateral renal tumors or a solitary kidney were excluded from study. All of the patients had preoperative imaging with CT or MRI. Cold ischemia was only used for the patients undergoing OPN, with warm ischemia for those undergoing LPN and RPN. Patient demographics, clinical data and imaging studies were obtained electronically and analyzed retrospectively.

Preoperative demographics (gender, age, BMI, ASA score, CCI and R.E.N.A.L. score), perioperative outcomes (operative time, ischemia time, EBL, perioperative complications, length of hospitalization) and pathological features were recorded and evaluated. Renal function was assessed by serum creatinine and eGFR based on the MDRD (Modification of Diet in Renal Disease) equation. We obtained data on preoperative and postoperative renal function as determined by the nadir of the eGFR within 1 to 10 months after PN. Changes in renal function were presented as absolute changes in eGFR and percent changes in eGFR.

We developed a novel formula to calculate the CSA using integral calculus. We assumed that the renal tumor was a sphere so that the radius (r) could be obtained. The length of tumor invasion was measured as depth (d), and the maximal r and d were measured in cm and rounded to the nearest tenth from the coronal or transverse plane of CT or MRI. The final equation, $CSA=2*\pi*r*d$, was formulated by a urologist and a mathematician (fig. 1, *A*). The method by which we performed the measurements and calculations is shown in figure 2. Interobserver concordance to calculate the CSA was assessed between 2 observers (GHC and CPH), each of whom was blinded to the clinical outcomes.

Continuous variables are shown as mean ± SD and ordinal variables as median (IQR). Categorical variables including more than 10% change in eGFR (PCE10) and more than 20% change in eGFR (PCE20) are shown as percentages. Spearman correlation analysis was used to evaluate the relationship between CSA and R.E.N.A.L. score as well as perioperative outcomes. Univariate and multivariate analysis of various clinical variables including CSA and changes in renal function were evaluated using linear regression analysis. The abilities of CSA and R.E.N.A.L. score to predict changes in renal function were evaluated and compared using ROC curve analysis. Cutoff values of CSA were obtained by the Youden index. All analyses were performed using SPSS® version 22 with $p < 0.05$ considered statistically significant.

RESULTS

Overall 35, 26 and 45 patients underwent PN via open, laparoscopic and robotic approaches, respectively. Two patients in the OPN group were excluded from study due to bilateral renal tumors and multiple renal tumors, respectively. There was no significant difference in baseline patient demographics among the surgical approaches except for gender (table 1). The average time to nadir eGFR was 3.3 months. Mean ± SD CSA was 30.7 ± 26.1 cm^2 and median (IQR) R.E.N.A.L. score was 7 (2.25). Mean ± SD CIT and WIT were 38.6 ± 16 and 26.7 ± 25.1 minutes, respectively. Postoperative complications included grade 1-2 events in 20 (18.9%) patients (10 urinary tract infections, 5