A Novel Mathematical Model to Predict the Severity of Postoperative Functional Reduction before Partial Nephrectomy: The Importance of Calculating Resected and Ischemic Volume

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Purpose: Preoperatively predicting postoperative kidney function is an essential step to achieve improved renal function and prevent chronic kidney disease. We introduce a novel formula especially to calculate resected and ischemic volume before partial nephrectomy. We examined whether resected and ischemic volume would have value for predicting postoperative renal function.

Materials and Methods: We performed a retrospective cohort study in 210 patients who underwent robotic partial nephrectomy between September 2006 and October 2013 at a tertiary cancer care center. Based on abdominopelvic computerized tomography and magnetic resonance imaging we calculated resected and ischemic volume by the novel mathematical formula using integral calculus. We comparatively analyzed resected and ischemic volume, and current nephrometry systems to determine the degree of association and predictability regarding the severity of the postoperative functional reduction.

Results: On multivariable analysis resected and ischemic volume showed a superior association with the absolute change in estimated glomerular filtration rate/percent change in estimated glomerular filtration rate ($B = 6.5$, $p = 0.005$/ $B = 6.35$, $p = 0.009$). The ROC AUC revealed accurate predictability of resected and ischemic volume on the stratified event of an absolute change in estimated glomerular filtration rate/event of percent change in estimated glomerular filtration rate compared to 3 representative nephrometry systems. The calibration plot of this model was excellent (close to the 45-degree line) within the whole range of predicted probabilities.

Conclusions: We report a method of preoperatively calculating resected and ischemic volume with a novel formula. This method has superior correlation with the absolute and percent change in estimated glomerular filtration rate compared to current nephrometry systems. The predictive model achieved a strong correlation for the absolute and percent change in estimated glomerular filtration rate.

Abbreviations and Acronyms

ACE = eGFR absolute change
C-index = centrality index
CKD = chronic kidney disease
D = deepest tumor involvement depth from reference line
eACE20 = 20 ml/minute/1.73 m^2 or greater ACE event
eGFR = estimated GFR
ePCE20 = 20% or greater more PCE event
GFR = glomerular filtration rate
PADUA = preoperative aspects and dimensions used for anatomical
PCE = eGFR percent change
PFV = preserved functional volume
PN = partial nephrectomy
PRF = postoperative renal function
RAIV = resected and ischemic volume
R.E.N.A.L. = radius, exophytic/endophytic, nearness of tumor to collecting system or sinus, anterior/posterior, hilar touching main renal artery or vein, location relative to polar lines
TAT = total anesthesia time
W = width of planned tumor margin and ischemic volume caused by renorrhaphy in procedure
WIT = warm ischemia time

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THE incidence of kidney cancer has increased, as detected by increased imaging use.[1] For more than 40 years surgeons have neglected the importance of nephron sparing due to the risk of cancer recurrence or metastasis.[2] However, PN is now the gold standard since it provides an equivalent oncologic outcome and better preservation of long-term renal function.[3,4] Its indications have been expanded from most T1a tumors (4 cm or less) to T1b disease (4 to 7 cm).[5]

In this era of high technology surgical improvements have appeared to be the next strategy to preserve PRF, such as various techniques to decrease WIT and maximize PFV.[6–8] However, a recent study concluded that the effect of WIT is transient, mainly affecting functional deterioration on early followup with most PRF nadirs recovering during its late followup.[9,10] Therefore, late eGFR depends primarily on PFV.[9–13] As such calculating PFV has become of paramount importance to predict PRF in the practical setting.

In the last 5 years the R.E.N.A.L., PADUA and C-index nephrometry systems were developed to objectively quantify tumor anatomical complexity. Many studies have validated these parameters externally while considering perioperative outcomes such as WIT, estimated blood loss, complications and functional outcome.[14–16] Despite intense debates on this issue uncertain conclusions make clinicians hesitant to apply these systems in the practical setting. To bring about a positive paradigm shift from radical nephrectomy to PN preoperatively predicting postoperative kidney function is an essential step to achieve improved function and prevent CKD. The only requirement is the refinement of a predictable indicator concentrating on a specific goal.

In this study we introduce a novel formula especially to calculate RAIV before PN. We also examined whether RAIV has value for predicting PRF and we considered its clinical application.

MATERIALS AND METHODS

A total of 217 consecutive patients who underwent robotic PN were identified in our institutional review board approved database between September 2006 and October 2013, and their records were retrospectively analyzed. Of these patients 210 with conventional abdominopelvic computerized tomography and magnetic resonance imaging available were included in the cohort. Preoperative demographic information (age, gender, body mass index, tumor size, R.E.N.A.L. nephrometry,[14] PADUA classification[15] and C-index[16]), perioperative outcomes (TAT, WIT, estimated blood loss and hospital stay) and histological characteristics (malignant vs benign) were evaluated. RAIV was calculated by the novel formula described. Absolute and percent changes in creatinine and eGFR from baseline were assessed 6 months postoperatively using the MDRD (Modification of Diet in Renal Disease) formula.[17]

Novel Formula Concept

The novel formula for nephron loss volume was inspired by the geometric characteristic of a round renal mass. It follows the concept of RAIV and its calculation process (figs. 1 and 2). Figure 2 shows the tumor involvement space mathematically expressed on the quadrant. It geometrically reconstructs the concept that the small inner sphere represents the tumor and the space between the red and blue lines represents a cross-sectional RAIV image. During tumor resection and renorrhaphy the 3-dimensional space between the red and blue lines indicates the substantial volume of nephron loss that could be mathematically calculated by integral calculus. The novel integral formula comprises 3 parameters, including W, D and tumor radius. The formula was devised by a urologist and mathematically authenticated by an integral geometry specialist.

Statistical Analysis

Continuous variables are shown as the mean ± SD. Categorical variables are shown as the frequency and percent. Univariable linear regression was performed to identify association between ACE/PCE with ACE and PCE as continuous variables, and various clinical variables, RAIV and current nephrometry systems that may

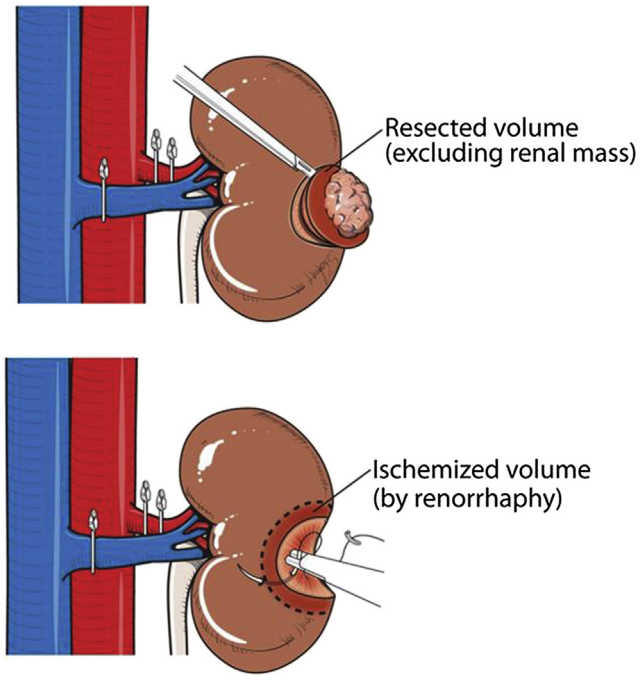

Figure 1. RAIV concept and calculation process. Tumor involvement is mathematically expressed on quadrant.