Effect of Parenchymal Volume Preservation on Kidney Function After Partial Nephrectomy

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Purpose: The percent of functional volume preservation is a primary determinant of functional outcome after partial nephrectomy. We assessed what is to our knowledge a novel method to estimate the percent of functional volume preservation to assess its effect on functional outcomes.

Materials and Methods: We studied the glomerular filtration rate outcome based on the modification of diet in renal disease 2 in 39 patients with normal preoperative serum creatinine who underwent open or laparoscopic partial nephrectomy from January 2007 to December 2009. A cylindrical volume ratio method was used to estimate the percent of functional volume preservation on computerized tomography images obtained before and after partial nephrectomy. A model to predict the postoperative estimated glomerular filtration rate was based on multiplying the preoperative glomerular filtration rate by the percent of functional volume preservation, followed by adjustment for the functional contribution of the contralateral kidney. Correlation and multiple regression analysis was done to test the model.

Results: The median preoperative, nadir and late estimated glomerular filtration rate in the cohort was 104 (range 53 to 234), 75 (range 21 to 189) and 90 ml per minute/1.73 m^2 (range 45 to 228), respectively. The nadir and late estimated glomerular filtration rate was measured at a median of 2 (range 0 to 8) and 358 days (range 13 to 827), respectively. The median percent of functional volume preservation was 88% (range 50% to 100%) for the operated kidney and 94% (range 75% to 105%) when adjusted for total bilateral kidney volume. We noted a 96% correlation between the predicted and the observed late estimated glomerular filtration rate. On multivariate analysis the preoperative glomerular filtration rate ($p < 0.001$) and ischemia time ($p = 0.02$) correlated with the nadir glomerular filtration rate, and the preoperative glomerular filtration rate ($p < 0.001$) and the percent of functional volume preservation ($p = 0.04$) correlated with the late glomerular filtration rate.

Conclusions: These data support the notion that preoperative nephron endowment and the percent of functional volume preservation are the primary determinants of the long-term functional outcome after partial nephrectomy in patients with normal preoperative kidney function who have ischemia time within acceptable limits.

Key Words: kidney, organ size, nephrectomy, kidney function tests, ischemia

Abbreviations and Acronyms

CT = computerized tomography

eGFR = estimated GFR

GFR = glomerular filtration rate

PEC = percent endophytic component

PFVP = percent functional volume preservation

PN = partial nephrectomy

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Study received institutional review board approval.

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PARTIAL nephrectomy is emerging as the standard of care for anatomically amenable kidney tumors.[1] Numerous studies have confirmed the benefits of PN in terms of improved kidney function and overall survival.[2–4] The basis for these improved outcomes is preservation of functional nephron mass.

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Despite the obvious importance of this factor it has not been extensively studied due to the challenges posed by measuring the functional volume change. Radiological volumetric analysis requires sophisticated software and can be technically difficult. Intraoperative estimation of tissue preservation is subjective and tends to be inaccurate. Nuclear imaging analysis evaluates functional changes but cannot reliably provide a measure of anatomical volume.

We describe a novel method to estimate PFVP by basic geometric analysis of CT images obtained before and after PN. A theoretical model to predict postoperative GFR was devised that relies on the association of baseline GFR and PFVP. Analysis allowed model testing to study the effects of PFVP on long-term functional outcomes in patients with radiologically normal kidneys who had ischemia time within acceptable limits.

METHODS

Patient Population

Patient data were obtained from an institutional review board approved, prospectively maintained database in conformity with Health Insurance Portability and Accountability Act regulations. A total of 138 patients were identified who underwent open or laparoscopic PN, as performed by 3 surgeons at a tertiary referral center between October 2007 and October 2009. Selection of 39 patients for analysis was based on the inclusion criteria of treatment for a single unilateral kidney tumor, normal preoperative serum creatinine (range 0.5 to 1.5 mg/dl), and the availability of postoperative surveillance CT and serum creatinine. All serum creatinine measurements were made at a single clinical reference laboratory. GFR was estimated using the modification of diet in renal disease 2 equation.[5]

Analysis

Volumetric. Kidney imaging involved 3 mm step-section imaging without and with iodinated contrast medium. Volumetric measurements were made on arterial contrast phase images, on which tumors and kidney parenchyma were visualized with greatest resolution. We used syngo Studio imaging software (Siemens Medical Solutions, Erlangen, Germany) to view and analyze CT cross-sectional images.

PFVP was estimated using a cylindrical volume (V) ratio method based on the ratio of the volume of 2 cylinders that approximated the kidney volume measured on preoperative and postoperative CT images. The equation, $V = \pi r^2 h$, was used to determine preoperative (V_{pre}) and postoperative (V_{post}) cylindrical kidney volume, where r represents radius and h represents height. To measure height the number of sections between the uppermost and lowermost borders of the kidneys was multiplied by slice thickness, which was 0.3 cm in this study. The mid polar plane was identified by averaging the uppermost and lowermost image section numbers. In the mid polar plane a center point was assigned to an ellipse drawn around the kidney periphery. Kidney diameter was measured using a line passing through the center point, which symmetrically divided the medial and lateral aspect of the kidney perpendicular to the hilar axis. Another 2 diameter measurements were made that passed through the center point within 25 to 35 degrees of the primary diameter measurement line. The mean radius was then calculated.

Adjustment was made to preoperative kidney volume by subtracting the volume of nonfunctional endophytic tumor tissue within the kidney periphery. To accomplish this we measured the maximum tumor radius and calculated tumor volume (V_{tum}) using the equation, $V_{tum} = 4/3\pi r^3$. PEC was multiplied by V_{tum} to determine nonfunctional kidney volume (V_{nfk}) ($V_{nfk} = V_{tum} \times$ PEC). V_{nfk} was subtracted from V_{pre} to determine adjusted preoperative kidney volume, that is V'_{pre} ($V'_{pre} = V_{pre} - V_{nfk}$).

Operated kidney PFVP was determined by calculating the V_{post}/V'_{pre} ratio. Four patients in this study had a solitary kidney and so calculated PFVP equated to total functional volume. The remaining 35 patients required adjustment of PFVP to accommodate the functional volume from the contralateral kidney using the equation, [PFVP + 0.5(1 − PFVP)]. In these 35 patients the size and contrast enhancement appearance of the contralateral kidney were symmetrical to those of the operated kidney.

Statistical. Pearson correlation analysis was used to assess relationships between predicted and observed GFR data. Univariate and multivariate linear regression analysis was done to assess correlations of PFVP with demographic, pathological and operative data. The null hypothesis was rejected at $p < 0.05$.

RESULTS

Figure 1 shows the methodology of cylindrical volume ratio estimation of PFVC. Table 1 lists demographic, pathological and operative data. The patient population was generally healthy with a median American Society of Anesthesiologists score of 2 (range 1 to 3). Of the patients 82% had stage T1 disease. Cold ischemia was used in 18 patients (46%) with a median duration of 38.5 minutes (range 28 to 61). Warm ischemia was used in 17 patients (44%) with a median duration of 24.5 minutes (range 16 to 60).

Table 2 lists volumetric and functional data. Median tumor volume was 20 ml (range 1.3 to 126) with a median PEC of 50% (range 20% to 100%). Median PFVP in the total cohort after adjusting for the functional contribution of the contralateral kidney was 94% (range 75% to 105%). Stage 3 chronic kidney disease was present in 3 (8%) and 5 patients (13%) preoperatively and postoperatively, respectively. Median long-term eGFR preservation was 94% (range 57% to 122%).

Table 3 shows the results of univariate and multivariate linear regression analysis to identify