Differentiating reconstructive techniques in partial nephrectomy: a propensity score analysis

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Introduction: *To assess whether volumetric measurements can differentiate functional changes between reconstructive techniques after partial nephrectomy.*
Materials and methods: *One hundred and fifty-six patients undergoing partial nephrectomy for a single renal mass were retrospectively studied between 2008 and 2012. Computed tomography scans were available for volume calculations on 56 (18 non-renorrhaphy and 38 renorrhaphy). Institutional review board approval was obtained. The primary outcome was %volume loss in the operated kidney, which was calculated from three-dimensional reconstructions using a semiautomatic segmentation algorithm. Multivariable regression and propensity score analysis was performed.*
Results: *Volumetric analysis detected a difference in mean %volume loss between two-layer reconstruction (cortical renorrhaphy and base-layer) and base-layer only (15.6% versus 3.8%, $p < 0.001$). The mean %glomerular filtration rate (GFR) loss was also greater in the two-layer group (8.9% versus 2.4%, $p = 0.03$). Demographics were similar between groups except the two-layer group was older, had more males, and increased ischemia time. On multivariable regression the presence of two-layer closure (β = -15.2%, $p < 0.001$) and tumor diameter (β = -7.4, $p = 0.004$) were significant predictors of %volume loss while ischemia time ($p = 0.88$) was not. Two-layer closure remained a predictor on propensity-adjusted analysis (β = -14.3, $p = 0.004$). The base-layer only group had two (5.3%) urine leaks and two (5.3%) bleeding complications. The two-layer group had two (1.7%) urine leaks and three (2.5%) bleeding complications (p = 0.23, 0.41).*
Conclusions: *Volume loss calculated from CT scans can be used to monitor postoperative renal function. Techniques for renal reconstruction and tumor diameter are associated with volume and functional loss after partial nephrectomy and should be controlled for in future studies.*

Key Words: volumetric computed tomography, carcinoma, renal cell, partial nephrectomy, kidney function test, robotics

Introduction

Partial nephrectomy is becoming increasingly popular for the treatment of small renal masses, and recent guidelines identify it as the reference standard for clinical T1a renal tumors.[1] Nephron sparing surgery for clinical T1a renal masses increased from 10% to 81% between 1998 and 2010.[2,3] Increased utilization of partial nephrectomy is partly in response to data showing chronic kidney disease (CKD) is an independent risk factor for cardiovascular events and overall survival in the general population.[4] Risk factors for CKD are seen in up to 66% of patients treated for renal cell carcinoma.[4,5]

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CT scans have been utilized to calculate volume changes after partial nephrectomy for the past decade to better understand renal volume and functional loss.[6] Despite removing primarily non-functional tumor tissue and short ischemia times (< 25 minutes), there is a significant loss of ipsilateral renal volume (12%-20%) and overall renal function (8%-13%) associated with partial nephrectomy.[7-11] Studies in renal donor and chronic urinary obstruction populations show strong correlation between nuclear renal scans and CT-based volume measurements for determining split renal function.[12,13] Furthermore, CT-based volume measurements correlated better with 24 hour urinary creatinine clearance than did serum-based estimated glomerular filtration rate (GFR) methods such as the Modification of Diet in Renal Disease 2 equation (MDRD).[14] Recent studies have demonstrated volume loss and not ischemia time to be the primary determinant of post partial nephrectomy renal function.[7,10,15] However, modifiable factors of renal loss have remained hypothetical. Three factors of renal loss associated with renal reconstruction that are felt to be non-modifiable are: segmental artery devascularization, tissue strangulation at the renorrhaphy site, and calyceal ligation with pyramidal atrophy.

Cortical renorrhaphy (outer layer parenchymal closure) is thought to contribute to the above factors, but it has never been questioned, as the prevailing opinion has been that renorrhaphy is necessary to prevent urine leaks and postoperative bleeding. Figure 1b demonstrates base-layer sutures, and Figure 1c demonstrates cortical renorrhaphy. We had a unique opportunity to study the effects of renorrhaphy as two of the surgeons at our institution omitted cortical renorrhaphy in every case. The design of this study was based on preliminary data at our institution showing that renorrhaphy caused an increased loss in estimated GFR. Our objective was to measure volume loss associated with renorrhaphy (two-layer) compared with non-renorrhaphy (base-layer sutures only) patients and to examine associated complications between the groups. Our hypothesis was that renorrhaphy will correlate with a greater volume loss after partial nephrectomy and omission of renorrhaphy will lead to acceptable complication rates.

Materials and methods

Population and surgical technique

For this retrospective study, the billing database was queried using the CPT code for open (50240) or robotic (51543) partial nephrectomy. Institutional review board permission for waiver of patient consent was obtained. Between 2008 and 2012, 156 consecutive adult cases were identified with follow up data and the indication of renal mass suspicious for localized renal cell carcinoma after excluding for multiple masses and concomitant procedures. Retrievable contrasted pre and postoperative CT scans were available for volume analysis in 56 patients (38 renorrhaphy, 18 non-renorrhaphy). Those excluded due to absence of a CT scan were analyzed and there were no differences between the renorrhaphy and non-renorrhaphy groups for tumor diameter (p = 0.92), Charlson score (p = 0.2), or nephrometry score (p = 0.69) where available.

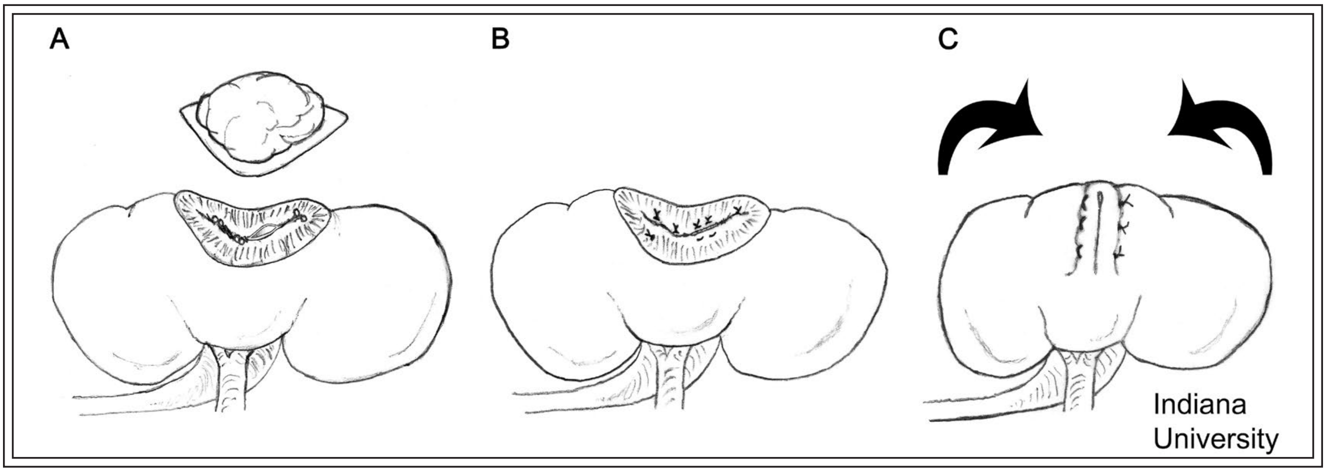

Figure 1. A) The tumor is resected with a minimal margin of healthy kidney parenchyma. **B)** Base-layer sutures are applied to close the collecting system and ligate any transected blood vessels. **C)** Cortical renorrhaphy is performed to close the parenchymal defect. Courtesy of Indiana University.

Surgical technique varied as four surgeons contributed two-layer cases (renorrhaphy) and two contributed base-layer only cases (non-renorrhaphy). See Figure 1. Non-renorrhaphy cases that were performed by surgeons who otherwise always performed the renorrhaphy technique were excluded from the analysis (n = 2). An open surgical technique was performed for all non-renorrhaphy cases and 31% of renorrhaphy cases. Both groups utilized a healthy margin technique for resection. The non-renorrhaphy cases included the following steps: 1) the renal hilum was clamped, 2) the tumor was resected with scissors or a scalpel, 3) a base layer of hemostatic sutures were placed to close the collecting system or visible openings into vessels, 4) the vascular clamp was removed, 5) additional interrupted sutures and energy devices were used for hemostasis on the base layer as needed, 6) hemostatic agents were used along with 5 minutes of manual pressure, 7) the tumor fossa was observed for at least 10-20 minutes to allow for resolution of vasospasms, and 8) the renal cortex and capsule were not reapproximated.

Volumetric measurements and other variables

The primary outcome was percent volume (%volume) loss between the preoperative and postoperative CT scans. Those calculating volume loss were blinded from the renorrhaphy status, and a board-certified radiologist with more than 15 years of experience reviewed the results for each patient. The postoperative CT scan was limited to ≥ 4 months in order to allow time for ischemic atrophy, and non-contrast scans were excluded from analysis. A semiautomatic segmentation algorithm (IntelliSpace Portal 6 software, Philips HealthCare, Cleveland, OH, USA) was used under the direction of a board-certified radiologist. The algorithm weighting parameters were set to detect enhancing renal parenchyma in order to exclude postoperative scarring at the resection site and also to avoid manual calculation of the outer boundary of the kidney. Enhancing parenchyma was defined as a Hounsfield unit (HU) of 50 as it represented an increase of 20 HU from the non-contrast renal parenchyma, which had a baseline near 30 HU. Tumor volume was excluded from the preoperative renal volume. Figure 2 demonstrates details of volume calculation. Occasionally parts of adjacent organs also had to be manually subtracted from the segmentation algorithm. One of two investigators performed the volume calculations, and the interobserver volume correlation was calculated for 40 kidneys where both investigators calculated the volume. Demographic, tumor, pathologic, surgical, and hospital related variables were also determined. GFR values were estimated using the MDRD formula.

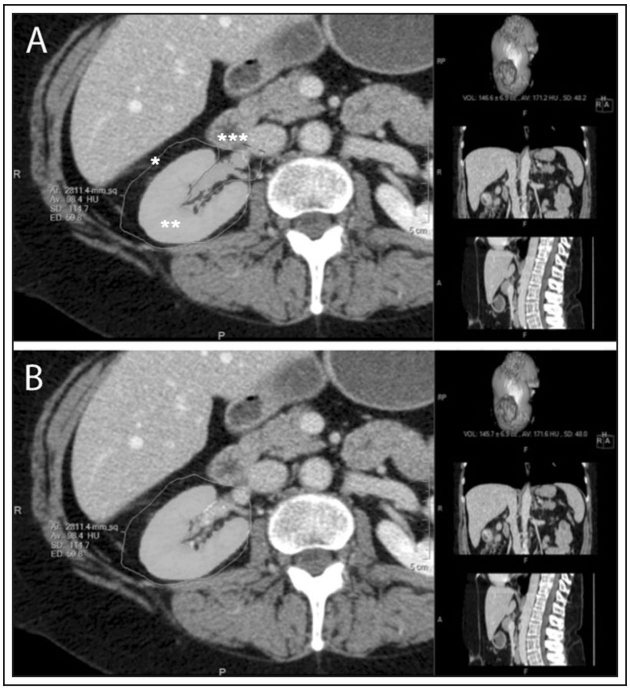

Figure 2. The line (*) is drawn to limit the segmentation. The highlighted area (**) represents the segmentation selection. **A)** The manual subtraction of hilar structures (***) is performed in a standardized fashion. **B)** The hilar structures have been unselected for modeling.

Statistical analysis

Descriptive analysis was performed for demographic and surgery data, and Student's T-test was used for continuous variables and Pearson chi-square test for categorical variables. Odds ratios were used to compare the risk of a 20% volume loss. Univariable predictors of mean %volume loss were determined by linear regression. Multivariable linear regression was used to determine predictors of %volume loss. For the multivariable regression analysis, ischemia time and preoperative GFR were included a priori as these variables were likely confounders. Age and gender were included as the means for these variables were different between groups ($p < 0.05$). Renorrhaphy and tumor diameter were included in the multivariable analysis based on achieving $p \leq 0.2$ on univariable analysis. A priori significance was set at $p < 0.05$ for all other analyses. Tumor diameter was felt to be more generalizable than tumor volume and thus chosen for multivariable analysis. Tumor diameter was broken into three categories based on scatterplot analysis with %volume loss as the dependent variable: < 2.0 cm, 2.0 cm-4.5 cm, and ≥ 4.5 cm.

Potential bias associated with selection for renorrhaphy technique was further adjusted for using propensity scoring analysis methods. Adjustments were made using multivariable logistic regression model to calculate the propensity of undergoing renorrhaphy versus non-renorrhaphy for each patient. Nephrometry was excluded due to missing values. Balance of covariates between procedures was verified after propensity adjustment. See Table 1 for variables included in the logistic model to generate propensity scores and adjusted p values. Propensity score stratification by quintiles was performed and used for the analysis. Cases outside the overlapping region of propensity score distribution were excluded.[16] All statistical analyses were performed using Stata 13.1 (Stata Corp. LP, College Station, TX, USA).

Results

Demographic and patient characteristics data with propensity adjustment are shown in Table 1. The renorrhaphy group (cortical renorrhaphy and base-layer sutures) had a higher percentage male (p = 0.001) and was older (p = 0.035). The overall median RENAL nephrometry score (p = 0.82), Charlson comorbidity

TABLE 1. **Demographics and patient characteristics**

	Base-layer only mean (SD)	Base-layer + renorrhaphy mean (SD)	Total	p value	Propensity adjusted p value
n	38	118	156		
Surgery performed in last half of study, no. (%)	20 (53)	71 (60)	91 (58)	0.41	
Age (years)	54.6 (13)	59.6 (13)	58.4 (13)	0.035	0.59
Male, no. (%)	15 (39)	81 (69)	96 (62)	0.001	0.80
Caucasian, no. (%)	35 (92)	112 (95)	147 (94)	0.52	0.83
Right side, no. (%)	26 (68)	61 (52)	87 (55)	0.07	0.97
BMI (kg/m^2)	32.3 (8)	30.6 (6)	31.0 (7)	0.20	0.88
DM, no. (%)	10 (26)	22 (19)	32 (21)	0.31	0.83
HTN, no. (%)	24 (63)	74 (63)	98 (63)	0.96	0.94
Charlson index	3.6 (1.6)	3.3 (1.7)	3.4 (1.7)	0.45	0.62
Tumor diameter (cm)	2.9 (1.1)	3.1 (1.3)	3.1 (1.3)	0.36	
Tumor diameter, no. (%)				0.62	0.84
< 2 cm	7 (18)	15 (13)	22 (14)		
2 cm-4.5 cm	26 (68)	83 (70)	109 (70)		
> 4.5 cm	5 (13)	20 (17)	25 (16)		
Tumor volume (cm^3)	12.0 (12)	15.7 (19)	14.7 (17)	0.47	
Nephrometry	6.6 (1.5)	6.7 (1.7)	6.6 (1.6)	0.82	
Low (4-6), no. (%)	14 (48)	49 (48)	63 (48)	0.98	
Intermediate (7-9), no. (%)	15 (52)	50 (49)	65 (50)	0.80	
High (10-12), no. (%)	0 (0)	3 (3)	3 (2)		
Malignant, no. (%)	31 (82)	104 (88)	135 (87)	0.30	
Tumor stage, no. (%)				0.50	
pT1a	25 (81)	84 (81)	109 (81)		
pT1b	6 (19)	14 (13)	20 (15)		
pT2a	0 (0)	1 (1)	1 (0.7)		
pT3a	0 (0)	5 (5)	5 (3.7)		
Fuhrman grade	2.1 (0.6)	2.3 (0.6)	2.2 (0.6)	0.25	

BMI = body mass index; DM = diabetes; HTN = hypertension index ($p = 0.45$), estimated blood loss ($p = 0.45$), length of stay ($p = 0.13$), and tumor size ($p = 0.36$) were similar between the study groups. The renorrhaphy group had a longer operating room time ($p < 0.001$). The renorrhaphy group had a longer warm ischemia time (WIT, $p < 0.001$) and overall ischemia time ($p < 0.001$). Notably, however, the mean ischemia time for both groups was less than 25 minutes duration.

Differences between the two surgical groups are shown in Table 2. The mean percent GFR loss was greater for the renorrhaphy group (mean 8.9% versus 2.4%, $p = 0.026$) while the median GFR follow up time was similar for both groups ($p = 0.62$). The interobserver volume correlation for 40 kidneys done by two investigators was 0.96. The three largest volume losses for both groups are shown in Figure 3.

TABLE 2. **Differences between base-layer and two-layer**

	Base-layer only mean (SD)	**Base-layer + cortical renorrhaphy mean (SD)**	**Total**	**p value**	**Propensity adjusted p value**
OR duration (min.)	122 (29)	214 (54)	191 (63)	< 0.001	
Ischemia					
Overall (min.)	11.1 (5)	22.7 (11)	19.9 (11)	< 0.001	0.81
WIT, no. (%)	34 (94)	79 (77)	113 (78)	0.02	
WIT (min.)	11.0 (5)	20.9 (8)	18.0 (8)	< 0.001	
WIT > 25 min., no. (%)	0 (0)	21 (27)	21 (19)	0.001	
CIT, no. (%)	2 (6)	24 (23)	26 (17)	0.22	
CIT (min.)	14.0 (1)	34.4 (8)	32.8 (9)	0.001	
Zero ischemia, no. (%)	0 (0)	9 (8)	9 (6)	0.08	
EBL (mL)	236 (166)	274 (294)	264 (268)	0.45	
Length of stay (days)	3.5 (1.1)	3.1 (1.5)	3.2 (1.1)	0.13	
Preop GFR (mL/minute/1.73 m^2)	77.3 (26)	78.4 (21)	78.7 (22)	0.86	0.78
Postop nadir GFR (mL/minute/1.73 m^2)	68.8 (24)	60.5 (18)	62.5 (20)	0.02	
Follow up GFR (mL/minute/1.73 m^2)	74.8 (26)	70.9 (20)	71.7 (22)	0.36	
%GFR loss, mean (SD)	2.4 (13)	8.9 (15)	7.7 (15)	0.026	
GFR follow up time (months)	10.3 (6)	9.7 (6)	9.9 (6)	0.62	
Preop volume, affected side (cm^3)	164.7 (48)	170.4 (44)	168.6 (45)	0.66	
Volume loss, affected side (cm^3)	6.5 (15)	23.4 (17)	17.0 (18)	< 0.001	
%volume loss, affected side, mean (SD)	3.8% (9.8)	15.6% (10.8)	11.8% (11.8)	< 0.001	
%volume gain, non-affected side	3.3% (6)	3.7% (8)	3.5% (7)	0.85	
CT follow up time (months)	8.7 (2.9)	7.4 (4.0)	7.8 (3.7)	0.22	
Risk of 20% volume loss, no. (%)	1 (6)	12 (32)	13 (23)	0.031	
Complications					
Urine leak, no. (%)	2 (5.3)	2 (1.7)	4 (2.6)	0.23	
Drain placed, no. (%)	1 (2.6)	0 (0)	1 (0.6)		
Postop bleeding, no. (%)	2 (5.3)	3 (2.5)	5 (3.3)	0.41	
Selective embolization, no. (%)	0 (0)	1 (0.8)	1 (0.6)		
Clavien 2, no. (%)	6 (15.8)	17 (14.4)	23 (14.7)	0.83	
Clavien 3, no. (%)	2 (5.3)	3 (2.5)	5 (3.3)	0.41	
Clavien 4, no. (%)	1 (2.6)	3 (2.5)	4 (3.4)	0.98	
Clavien 5, no. (%)	0 (0)	0 (0)	0 (0.0)		

OR = operating room; WIT = warm ischemia time; CIT = cold ischemia time; EBL = estimated blood loss; GFR = glomerular filtration rate; CT = computed tomography

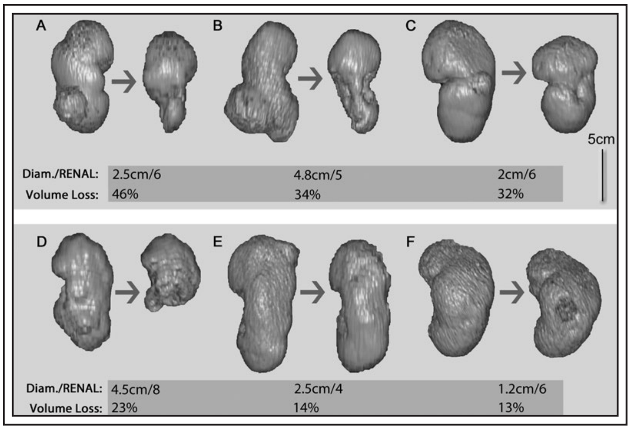

Figure 3. The three largest volume losses for both groups are shown with tumor diameter and RENAL nephrometry score. The renorrhaphy group **(A-C)** shows atrophic affects far from the tumor. The non-renorrhaphy group **(D-F)** shows volume losses predominantly related to resection.

The renorrhaphy group (A-C) appears to show atrophic affects remote from the tumor site and the non-renorrhaphy group (base-layer sutures only) (D-F) appears to shows volume losses predominantly near the resection site. The preoperative GFR ($p = 0.86$) was not statistically different between groups, but the nadir GFR was lower for the renorrhaphy group ($p = 0.02$). The median postoperative month of the CT follow up study was similar in both groups ($p = 0.62$). The %volume loss (mean 15.6% versus 3.8%, $p < 0.001$) and overall volume loss (23.4 cm^3 versus 6.5 cm^3, $p = 0.001$) were greater for the renorrhaphy group. In a sub analysis limiting ischemia time to < 25 minutes, the renorrhaphy group still had a larger mean %volume loss (13.6% versus 5.1%, $p = 0.003$). The non-renorrhaphy group had two (5.3%) urine leaks and two (5.3%) bleeding complications, and the renorrhaphy group had two (1.7%) urine leaks and three (2.5%) bleeding complications ($p = 0.23, 0.41$). The risk of a 20% volume loss was 12/38 (32%) in the renorrhaphy group compared to only 1/18 (6%) in the non-renorrhaphy group (odds ratio 7.8, $p = 0.02$).

Univariable, multivariable, and propensity adjusted predictors of %volume loss can be found in Table 3 and Table 4. Ischemia time, warm ischemia time, ischemia time > 25 minutes, preoperative GFR, tumor volume, tumor diameter, and renorrhaphy were all predictors on univariable analysis. The multivariable linear regression model, Table 3 was statistically significant ($p = 0.001$) with $R^2 = 0.49$. Cortical renorrhaphy ($\beta = -15.2\%$, $p < 0.001$)

TABLE 3. **Predictors of %volume loss**

	Univariable regression (β)	p value	Multivariable regression (β)	95% CI	p value
Tumor diameter (< 2 cm, 2 cm-4.5 cm, >/= 4.5 cm)	-6.7%	*0.01	-7.4%	-12.2, -2.5	0.004
Renorrhaphy (two-layer)	-11.9%	*< 0.001	-15.2%	-22.9, -7.5	< 0.001
Age (years)	-0.1%	*0.37	0.14%	-0.07, 0.4	0.20
Gender (male)	1.5%	*0.64	5.2%	-0.4, 10.7	0.07
Preoperative GFR (mL/minute/1.73 m^2)	-0.2%	*0.027	0.13%	-0.002, 0.3	0.10
Ischemia time (min.)	-0.5%	*0.001	0.0%	-0.4, 0.4	0.97
Body mass index	0.0%	0.99			
Hypertension	-0.2%	0.95			
Diabetes	-1.2%	0.79			
Charlson index	0.4%	0.67			
Nephrometry	0.3%	0.78			
Surgical side (right)	-0.05%	0.99			
Preoperative affected kidney size (cm^3)	0.02%	0.61			
Eestimated blood loss (mL)	0.0%	0.88			

*included in multivariable regression analysis if univariate analysis p value < 0.2, a priori, or if a significant difference between groups existed in Table 1. GFR = glomerular filtration rate. The model is statistically significant at $p < 0.001$ with $R^2 = 0.49$.

TABLE 4. **Propensity score analysis for renorrhaphy**

	Linear regression	95% CI	p value
Unadjusted	-11.9%	-17.9, -5.8	< 0.001
Multivariable	-15.2%	-22.9, -7.5	< 0.001
Propensity adjusted multivariable model (linear term)	-14.4%	-23.2, -5.6	0.002
Propensity adjusted multivariable model (quintiles)	-14.3%	-23.5, -5.0	0.004

*effect of cortical renorrhaphy on %volume loss after partial nephrectomy

and categorical tumor diameter (β= -7.4, p = 0.004) were predictors of %volume loss on multivariable analysis. Cortical renorrhaphy remained significant on propensity-adjusted analysis (β = -14.3, p = 0.004).

Discussion

In this study, renal reconstruction with both base-layer sutures and cortical reapproximation (renorrhaphy) was associated with more than four-times the mean renal volume loss when compared to leaving the parenchyma open (non-renorrhaphy) after applying base-layer sutures only during partial nephrectomy (15.6% versus 3.8%, p < 0.001). The mean %GFR loss was also greater in the renorrhaphy group (8.9% versus 2.4%, p = 0.03). This association persisted on multivariable analysis, Table 3 and propensity score adjusted analysis, Table 4 with the presence of renorrhaphy having the largest overall effect on volume loss (β = -14.3%, p < 0.004). Furthermore, 19 of the 20 largest volume losses occurred in the renorrhaphy group, Figure 4, and the risk of a 20% volume loss was 12/38 (32%) in the renorrhaphy group compared to only 1/18 (6%) in the non-renorrhaphy group (odds ratio 7.8, p = 0.02). The use of volume measurements has the potential advantage of less day-to-day variation than serum creatinine based GFR calculations. A recent study showed CT based volume measurements correlated better with creatinine clearance than serum creatinine based GFR calculations.[14] Also, CT scans are often obtained following partial nephrectomy for cancer follow up and therefore available for volume calculations.

The increased volume loss in the renorrhaphy group supports the hypothesis that functional loss after partial nephrectomy is not only due to resected healthy parenchyma, but also to segmental artery devascularization or reconstruction related calyceal ligation. Three-dimensional images showing the three highest volume losses for both groups are in Figure 3. The renorrhaphy group shows atrophic effects remote from the original tumor location, and the non-renorrhaphy group shows volume losses predominantly local to the tumor resection site. For example, the first kidney in the non-renorrhaphy series (D) represents the results of a hemi-nephrectomy while the last kidney in the renorrhaphy series (C) represents significant mid-pole atrophy from a relatively small tumor (2 cm diameter). CT scan-based three-dimensional imaging has the advantage of providing both quantitative data (volume loss) and easy to visualize data on structural changes.

A recent study compared renal volume and functional loss after robotic partial nephrectomy between renorrhaphy (two-layer) and non-renorrhaphy (base-layer only) and was matched by nephrometry score.[17] No urine leaks or bleeding complications were seen in the non-renorrhaphy group. Similar to the current study, omitting cortical renorrhaphy was

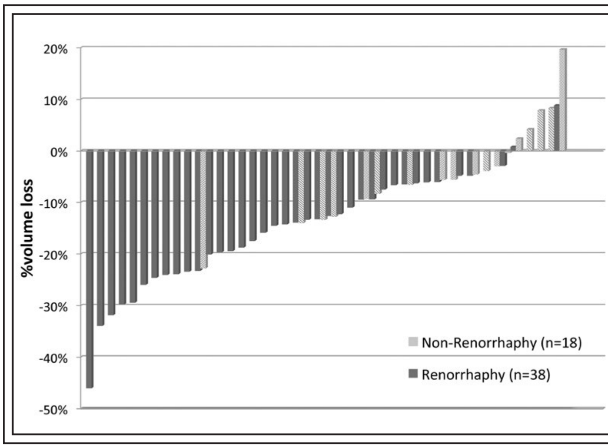

Figure 4. Waterfall plot demonstrating %volume loss for all cases in both groups. Nineteen of the 20 largest volume losses occur in the renorrhaphy group.

associated with improved volume loss (%volume loss: 9 cm^3 versus 17 cm^3, $p = 0.003$) and renal function loss (risk of 10% GFR loss: 13% versus 47%, $p = 0.03$). The amount of healthy margin resected was also found to be similar between the groups by an estimation technique using photographs of the gross specimen.

Another hypothesis for delayed volume loss is a partial Page kidney or compartment syndrome effect wherein the stitches used to close the cortex tighten the renal capsule causing the interstitial pressure to rise throughout the kidney. However, we are not aware of any data in support of this hypothesis. Also, a recent study with 184 subjects and a short mean WIT (21.4 minutes) showed that the parenchymal thickness distant from the site of resection is 99% preserved 1 year out from surgery.[18] Our data supports the authors' conclusion that below the accepted threshold for WIT, most volume loss is not related to ischemia time but to resection or reconstruction and in particular due to renorrhaphy.

Volume losses following partial nephrectomy with cortical renorrhaphy similar to the 15.6% found in the current study have been reported. In 2008, a report on 21 patients after partial nephrectomy with solitary kidneys found an average volume loss of 15% between preoperative and postoperative CT scans. The mean tumor volume was larger in their study (52.3 cm^3 versus 14.7 cm^3). Presumably, they routinely performed a parenchymal renorrhaphy.[11] In 2009, a report on 117 patients after partial nephrectomy with renorrhaphy found an average volume loss of 22% in the operated kidney. The average mass size was 2.9 cm compared to 3.1 cm in the current study. They concluded that volume loss was the most significant factor predicting renal function loss.[19]

A more recent study used precision of excision through CT-based volume preservation to look for modifiable factors of volume loss.[20] They predicted the expected percentage of ipsilateral renal volume preserved on follow up CT scan by assuming a 5 mm rim of healthy parenchyma is removed during resection. The only factor associated with precision of resection on adjusted analysis was the presence of a solitary kidney. Solitary kidneys made up 45/122 (37%) of their study group. Using the RENAL score 65% of their tumors were of intermediate or high complexity compared to 49% in the current study. The operated kidney lost a median of 22% volume and there were 9/122 (7%) urinary fistulas reported. They hypothesized that extra effort was exerted with solitary kidneys and that the improved precision in this group points to the existence of modifiable factors. Our data supports their hypothesis that modifiable factors exist.

In the present study there were significant differences between the study groups including ischemia time, age, and gender. It is important to note that the non-renorrhaphy group is not a historic control, but was performed during the same period as the renorrhaphy technique. In fact, 53% of the non-renorrhaphy patients underwent surgery during the last half of the study period (July 2010-December 2012) compared to 60% of the renorrhaphy patients ($p = 0.41$). The ischemia time was higher for the renorrhaphy group, but was only associated with %volume loss on univariable and not multivariable analysis. In a sub analysis limiting ischemia time to < 25 minutes, the renorrhaphy group still had a larger mean %volume loss (13.6% versus 5.1%, $p = 0.003$). As the tumor size and nephrometry scores were the same between groups, it is unlikely the increased ischemia time is due to increased complexity in the renorrhaphy group. This is more likely due to early unclamping and quicker surgical pace (operating time: 122 minutes versus 214 minutes, $p < 0.001$) in the non-renorrhaphy group. While renorrhaphy patients were older and higher percent male, this had little effect on the adjusted analysis, as both gender and age were not statistically significant predictors.

Tumor diameter was divided into three categories based on scatterplot analysis with %volume loss as the dependent variable (< 2.0 cm, 2.0 cm-4.5 cm, ≥ 4.5 cm) and was associated with %volume loss on multivariable analysis ($\beta = -7.2$, $p = 0.004$). Existing anatomic classification systems such as PADUA and RENAL use cancer staging size criteria (≤ 4 cm, 4 cm-7 cm, ≥ 7 cm), but were developed to predict complications or surgery type (radical versus partial nephrectomy) not renal function.[21,22] Taking into account the majority of partial nephrectomies are performed for tumors <4cm, further studies should work to validate size categories associated with volume and functional loss that are more relevant to partial nephrectomy.

Whether renorrhaphy is modifiable for practical purposes depends on the ability to perform a non-renorrhaphy partial nephrectomy without complications. Complications were similar between groups in the current study. In the non-renorrhaphy group, one urine leak required a postoperative drain, but both postoperative bleeds resolved with urinary catheter placement and did not require renal embolization. Overall, there were four Clavien grade 4 complications: cerebrovascular accident, myocardial infarction, atrial fibrillation with rapid ventricular response, and respiratory failure requiring intubation.

In this study the non-renorrhaphy group was performed by the open technique, but there is a recent shift towards robotic assisted partial nephrectomy. A report from 2009 described partial nephrectomy as the fastest growing robotic procedure among all surgical specialties in 2008.[23] At our institution, between 2002 and 2013 the utilization of minimally invasive partial nephrectomy increased from 5% to 79%. In 2013 the non-renorrhaphy technique was introduced during robot assisted partial nephrectomy without increasing bleeding our urine leak complications.[17]

The retrospective and small nature of our study makes it vulnerable to known and unknown confounders and bias. Retrievable CT scans were available in a minority of patients, which could result in selection bias. However, those excluded due to absence of a CT scan were analyzed and there were no differences between the renorrhaphy and non-renorrhaphy groups for tumor diameter ($p = 0.92$), Charlson score ($p = 0.2$), or nephrometry score ($p = 0.69$). The non-renorrhaphy group was performed exclusively by the open technique creating another possible source of selection bias. Fortunately, the two surgeons contributing all the non-renorrhaphy cases performed non-renorrhaphy in every case thereby minimizing selection bias based on tumor size or complexity. In the majority of renorrhaphy cases available for volume analysis (34/38, 90%) a 36 mm needle (CT-1, MH) was used for the cortical renorrhaphy. Thus we are unable to assess the effects of smaller or larger needles. This study was conducted at a tertiary care medical center and may not be generalizable. In order to minimize interobserver variation during volume calculation, a segmentation algorithm set to detect a Hounsfield unit of 50 was used and the resultant interobserver correlation was 0.96.

Conclusions

CT scans can be used to monitor not only cancer recurrence, but also renal function after partial nephrectomy. This paper suggests potential volumetric and GFR benefits of one layer closure when feasible, but larger prospective studies are needed to support this hypothesis. Future techniques for partial nephrectomy should minimize reconstructive injury while also minimizing complications. □

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