Simplified approach to estimating renal function based on computerized tomography

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Introduction: *To determine whether a simplified approach to estimate renal function based on preoperative computerized tomography (CT) imaging correlates with nuclear renography (NR) following surgical treatment of ureteropelvic junction obstruction (UPJO).*
Materials and methods: *We reviewed the charts of 47 patients who underwent robotic assisted laparoscopic pyeloplasty (RALP) for UPJO who had performed preoperative and postoperative NR and preoperative CT imaging. Twenty patients satisfied our inclusion criteria. We calculated differential renal function by measuring parenchymal thickness at the upper pole, midpole and lower pole regions of the kidney on the preoperative CT. Distances were measured from the edge of the collecting system to the capsule at the midpoint of the kidney in the coronal plane. After parenchymal thickness measurements were calculated bilaterally, a differential parenchymal thickness was obtained, and the ratio of parenchymal area was compared to the observed function on NR. Measurements were taken by three blinded observers and compared to preop and postop differential renal function as measured by NR to assess if preoperative CT renal parenchymal thickness correlates well with differential function of the affected and contralateral kidneys.*
Results: *Estimated renal function was predicted with excellent accuracy and minimal interobserver variability. Pearson correlation coefficients for Observers 1, 2 and 3 were 0.89, 0.88 and 0.91, respectively when compared to the postoperative differential function on NR. The interclass correlation coefficient between the three observers was 0.957, which indicates an almost perfect correlation and reproducibility of the formula.*
Conclusions: *Estimating differential renal function based on renal parenchymal thickness on preoperative CT imaging correlates very well with observed postoperative differential renal function on NR following RALP.*

Key Words: kidney parenchyma, computerized tomography, formula, renal function, nuclear renogram

Introduction

When managing an obstructed renal unit, diuretic nuclear renography (NR) is the study of choice to assess degree of obstruction and estimate differential renal function. On some occasions, the kidney may have sustained significant functional loss and the determination of whether that kidney should be salvaged/repaired, observed or removed will be influenced by the functional capacity of the affected unit.[1] Under these circumstances, the best management may be a simple nephrectomy rather than any lengthy corrective procedure. In order to help make the appropriate management plan, urologists need to know the estimated function and recovery potential of the affected unit after relief of obstruction.

Because of its unique sensitivity to functional changes, NR has become the modality of choice in the evaluation of conditions that induce focal alterations in kidney function or drainage, assessment of kidney

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function and the detection of post-renal obstruction.[2,3] Iodinated contrast is not used, therefore NR can be used in the setting of contrast allergy and safely employed in situations of renal insufficiency, although its results can be suboptimal in setting of significant renal insufficiency and/or significant obstruction. The radionuclide is also safer than MR imaging in the setting of renal dysfunction since intravenous gadolinium can cause nephrogenic systemic fibrosis or nephrogenic fibrosing dermopathy.[3] Technetium99m-mercaptoacetyl triglycine (99mTc-MAG3), or MAG-3, which is 90% cleared by tubular secretion, has become the ideal agent for assessing obstruction, particularly in the setting of renal insufficiency. In addition to providing information about kidney obstruction through the half-time of excretion following diuretic administration, NR enables the calculation of differential function of the individual kidney units.[2-4]

Computerized tomography (CT) has the ability to assess renal anatomy and pathology thereby detecting renal masses, hydronephrosis, urolithiasis, and vascular anatomy. By using intravenous contrast, CT may also be able to evaluate for the degree of obstruction during the nephrographic and urographic phases.[1,2,5-7] Feder and colleagues showed that CT differential renal parenchymal area strongly correlates with the differential function reported by NR.[2] They presented a method by which a calculated prediction of the differential function of each kidney on CT even in the presence of unrelieved obstruction can be made. However, the method is complex and the issue of interobserver variability is unknown as there was only one observer reporting measurements in their study. Additionally, Morrisroe et al found that by using a combination of a computer algorithm and manual editing to measure cortical volume, differential function could be predicted with reasonable accuracy.[4] Nonetheless, this method can be time consuming and requires knowledge and manipulation of computer software that is not easily reproducible by non-radiologists.

Our objective was to determine whether a more simplified approach to estimate differential renal function based on preoperative CT imaging correlates with postoperative NR following successful surgical treatment of ureteropelvic junction obstruction (UPJO).

Materials and methods

We retrospectively reviewed an Institutional Review Board approved database of 47 patients who underwent a robotic assisted laparoscopic pyeloplasty (RALP) for UPJO between 2007 and 2011. We only included patients who underwent postoperative NR (median 58 days, range 35 to 188 days) and preoperative CT available for review at our institute. The median age of the patients was 35 (range 17 to 65). Patients who had indwelling stents (n = 6) and had any evidence of questionable radiographic obstruction postoperatively (n = 3) on postoperative NR were excluded. A total of 20 patients were included in this study. All patients had obstruction as confirmed by preoperative NR. All included patients had estimated glomerular filtration rate (eGFR) greater than 60 mL/min/1.73m^2 (median 86.5 mL/min/1.73m^2) as calculated by the modification of diet in renal disease (MDRD) equation. All patients underwent diuretic MAG-3 renal scans. Renal parenchymal thickness was measured on CT independent of intravenous contrast administration–contrast enhanced images were used when both contrast and non-contrast imaging were available. All CT measurements were performed with electronic calipers provided by the radiographic software. All measurements were made on coronal images.

We calculated differential renal function using the formula as shown in Figure 1. Estimated renal parenchymal thickness (ERPT) was calculated for each kidney. We used coronal CT images to locate the midpoint of the renal unit and used the slices with the best images with maximal parenchyma of each renal unit to determine their thickness – taking into account that a malrotated or anatomically abnormal unit may require different images to capture maximal parenchymal thickness. This midpoint was used as

Figure 1. Estimating renal parenchymal thickness and calculating differential function.
ERPT = estimated renal parenchymal thickness; R = right; L = left; RUP = right upper pole; RMP = right mid pole; RLP = right lower pole; LUP = left upper pole; LMP = left mid pole;L LP = left lower pole
*right ERPT = RUP + RMP + RLP
*left ERPT = LUP + LMP + LLP

the slice on which the following measurements were made. The right upper pole (RUP), right midpole (RMP) and right lower pole (RLP) ERPT was calculated – the locations of these measurements were based on the distance between the edge of the renal capsule and the edge of the collecting system, Figure 1, at the predetermined midpoint coronal slice. The same was done on the left side (LUP, LMP, LLP). The ERPT for each renal unit was calculated by adding the thickness for each pole as noted in Figure 1. This allowed us to calculate the estimated differential function (EDRF) of each renal unit by dividing the total thickness for that kidney by the total thickness of both kidneys summed. Accuracy was measured by comparing the predicted differential function between the renal units, as measured on CT, to the observed differential function, as reported on NR.

Three blinded observers (Observers 1, 2 and 3) made the measurements independently and results were assessed for accuracy, precision and reproducibility. Estimated postoperative differential renal function was calculated for the right kidney and compared to the postoperative NR predicted differential function for the right kidney (since this is differential renal function, all calculations can be similarly performed on the left side). Pearson's correlation coefficient and coefficient of determination (r and r^2, respectively) were calculated comparing the predicted function to the observed. An analysis of variance (ANOVA) was computed to compare differences between the observers' measurements and finally, an interclass correlation coefficient (ICC) was calculated to measure true interobserver variability and consistency to assess the reproducibility of our formula. ICC was used because all of the measurements used are assumed to be parametric (continuous and have a normal distribution). ICC can be interpreted as follows: 0-0.20 indicates poor agreement: 0.30-0.40 indicates fair agreement; 0.50-0.60 indicates moderate agreement; 0.70-0.80 indicates strong agreement; and > 0.80 indicates almost perfect agreement.[4] All statistics

TABLE 1. **Predicted renal function for right kidney**

Patient	GFR*	Right preop renal scan (%)	Right postop renal scan (%)	Observer 1 predicted function (%)	Observer 2 predicted function (%)	Observer 3 predicted function (%)
1	95	20	24	39.2	44	39.2
2	80	54	55	49.3	54.1	49.5
3	77	56	57	61.6	57.2	55
4	105	34	36	32.4	35.9	31.8
5	84	80	85	67.4	64.3	69.6
6	66	22	10	33.2	39.3	33.3
7	75	30	45	45.8	51.4	46.5
8	97	38	50	46.5	54.1	52.1
9	102	82	77	77.7	72.9	75.6
10	80	63	66	64.8	57.6	51.6
11	96	49	46	40.7	45.1	43.7
12	74	62	68	67.8	57	58.2
13	66	30	40	43.2	45.5	44.5
14	99	60	58	54.8	48.5	51.8
15	110	35	30	39.6	39.9	40.4
16	100	75	50	55.9	50.7	50
17	90	47	52	53.4	49.2	53.8
18	89	35	40	34.1	46.1	37.3
19	70	40	35	42.4	38	37.4
20	65	44	45	36.9	53	43.6

*GFR = estimated glomerular filtration rate derived from modification of diet in renal disease formula

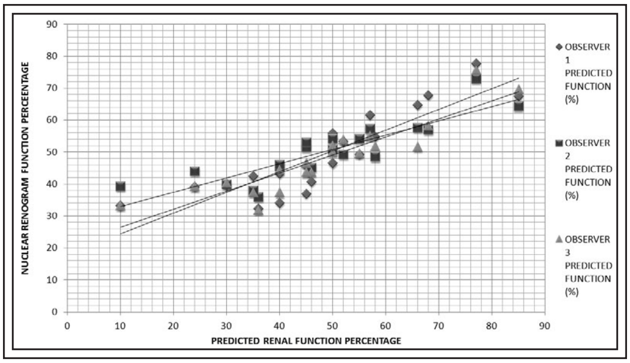

Figure 2. Linear regression comparing CT predicted differential function to post operative NR observed differential function.

analysis was prepared calculated using IBM SPSS version 20.

Results

Our study included 20 patients who underwent preoperative NR, preoperative CT and postoperative NR scan available for review. The postoperative NR scans were obtained at a median of 58 days after RALP for UPJO (range 35 to 188 days). Table 1 summarizes the data. Postoperative estimated differential renal function (EDRF) was very well predicted by measurements of preoperative CT scan parenchymal measurements compared to postoperative NR predicted function, Figure 2. Pearson correlation coefficients (r) for Observers 1, 2 and 3 as compared to the postoperative NR were 0.89, 0.88 and 0.91, respectively. More importantly, coefficient of determination was 0.79, 0.77 and 0.82 for the three observers, respectively, indicating a very strong correlation between estimated and observed postoperative differential renal function. There was almost perfect agreement between the three observers in measuring differential function with an ICC of 0.957 (95% confidence interval of 0.909-0.982). Linear regression confirmed that the difference between the three observers was not statistically significant ($p = 0.86$). Our analysis revealed that the measurements were much more predictive of postoperative differential renal function as measured by NR than preoperative function. Pearson's correlation coefficient comparing measured to observed preop NR for the three Observers yielded 0.862, 0.771 and 0.833 respectively, with much inferior coefficients of determination of 0.743, 0.594 and 0.694, respectively, Table 2.

Discussion

Urinary tract obstruction is a very common problem that, if untreated, may lead to progressive renal damage and eventual failure.[1] The decision to either treat or observe an obstructed renal unit or simply remove the obstructed moiety is partially based on the contribution of renal function of the affected renal unit to overall renal function in addition to symptoms. It has been suggested that adult kidneys that contribute less than 15%-20% overall function may not be worth salvaging and are more likely to have issues postoperatively following reconstructive surgery–and therefore simple nephrectomy is a reasonable option versus observation if asymptomatic. Diuretic NR is noninvasive and can provide functional information, however function estimates can be compromised in the setting of obstruction, poor renal function (which may also prevent proper diuretic response), and chronic kidney disease.[1-3]

In recent years, CT has become widely accepted as the preferred imaging technique for delineation of kidney anatomy and has been used in the diagnosis

TABLE 2. **Differential renal measurement correlation and interobserver variability**

Postop	**O1 v postop**	**O2 v postop**	**O3 v postop**	**Obs v postop variance**
Pearson's (r)	0.887	0.878	0.91	0.919
Preop	**O1 v preop**	**O2 v preop**	**O3 v preop**	**Obs v preop variance**
Pearson's (r)	0.862	0.771	0.833	0.865
O1 v O2 v O3 Interclass correlation coefficient	**95% confidence interval**			
0.957	0.9094 - 0.9816			

O1 = Observer 1; O2 = Observer 2; O3 = Observer 3
Obs = All three Observers combined

of both benign and malignant lesions of kidney. The improvements in CT technique and increased use of cross-sectional imaging and contrast enhancement can reveal intricate features of the kidneys through parenchymal enhancement, evidence of obstructing lesions with excretion of contrast medium, degree of obstruction, evidence of kidney stones, and details of the anatomy and vasculature for surgical planning.[5-7] CT may not only be used to determine differential function, it can also be used to provide detailed anatomical schematics and degree of obstruction with the use of contrast enhancement and delayed imaging protocol.[1,2,5-7] In patients with normal renal function, CT with delayed images can also provide information regarding degree of obstruction.

Both Feder et al and Mounier-Vehier et al have previously described calculating renal parenchymal area.[2,8] Feder et al used six measurements to determine the average thickness, three each from upper and lower poles. These measurements were anterior superior (AS), lateral superior (LS), posterior superior (PS), anterior inferior (AI), lateral inferior (LI) and posterior inferior (PI).[2] Mounier-Vehier et al calculated mean cortical thickness and area as a marker of atherosclerotic disease.[8] Feder et al reported a strong correlation between the differential parenchymal area on CT and differential renal function reported on nuclear renal scan (Pearson's correlation coefficient 0.959). Impressively the overall average difference in calculating differential function by CT versus that of nuclear scan was 4.73%. This accuracy between predicted and observed differential function was not significantly altered by variables such as infection, the presence of drains, or contrast enhancement.[2] It is important to note that in this study, only a single observer performed all measurements, therefore it is unclear whether the results are easily reproducible. The authors also propose a measurement tool composed of at least six components from each kidney, which can be time consuming and can further add unpredictability and interobserver variability to the equation.

Morrisroe et al calculated percent total volume of a renal unit by using semi-automated boundary delineation with a manual editing method. A trained technician traced out the renal contour, carefully excluding non-parenchymal areas, such as renal collecting system and vasculature. This revised contour was propagated to include the entire renal cortical parenchyma. The authors reported strong correlations between percent renal function and percent total renal volume as measured by in all kidneys (r = 0.90). They also found moderate correlations when differential renal function was less than 40% and 30%, with corresponding correlations of 0.76 and 0.64, respectively. This method uses semi-automated boundary delineation to generate renal contours but relied on the clinician to morphologically distinguish and manually exclude non-parenchymal structures from each image slice. This can be time consuming and requires an experienced eye. It is therefore important to note that due to the manual editing of the renal contour tracing, it may require trained personnel with software expertise that may not extrapolate to non-radiology personnel.[4] Nevertheless, we do acknowledge even our simplified technique requires some basic interpretation and familiarity with CT images and radiology software; obviously a bit more involved than the straightforward interpretation offered by a NR to determine differential function.

The purpose of our study was to identify a simple, yet effective, measurement technique of renal parenchyma on preoperative CT scans that was predictive of EDRF and functional recovery after surgical correction of the obstruction. Using only three measurements from each kidney in a coronal plane, we found that the EDRF was very well predicted by measurements of preoperative CT scan parenchymal measurements with good interobserver variability; the Pearson correlation coefficients (r) for Observers 1, 2 and 3 as compared to the post-operative NR were 0.89, 0.88 and 0.91, respectively. The high coefficients of determination, which were consistently around 0.80 for all three observers, indicate a strong correlation between estimated and observed postoperative differential renal function. We believe that the strong correlation (r ~0.90) coupled with the almost perfect agreement by multiple observers (ICC = 0.957) can translate to useful information in predicting postoperative renal function based on CT alone, even in the setting of ureteral/UPJ obstruction.

All patients had preoperative NR that confirmed obstruction and our results indicate that the differential function predicted by CT parenchyma does not correlate as well with preoperative NR (where obstruction was present). The Pearson correlation coefficients (r) for three observers were 0.86, 0.77 and 0.83, respectively, with noted variability between observers (the coefficient of determination for Observer 2 was below 0.60). One likely explanation is that predicting renal function using NR in the setting of obstruction is not ideal and this confirms the idea that CT ERPT correlates better with postoperative NR. In other words, the amount of parenchyma measured is likely directly proportional to the recovery potential of a renal unit once the obstruction is treated. This finding is different than Feder et al who found no difference in predicted differential renal function in patients with obstruction and in those in whom the obstruction was relieved with a percutaneous nephrostomy tube (PNT) or a ureteral stent prior to the NR.[2]

There exists a paucity of literature that specifically reports differential renal parenchymal area as it correlates to renal function. An interesting study by Muto et al utilized eGFR using the MDRD formula compared with renal volume calculated by a computer workstation using software that automatically contours the renal cortex and the renal parenchyma. In their retrospective study, the authors found a moderate relationship (r = 0.57) between the renal cortical volume and eGFR.[9] A similar result was found by a study by van den Dool et al, who found that renal cortical volume measured on magnetic resonance imaging was an indirect indicator of renal function using creatinine clearance as a parameter.[10]

Other studies have attempted to correlate renal volumes with renal function by measuring individual kidney creatinine clearance. Ng et al reported that after decompressing an obstructed kidney, the creatinine clearance determinations in the individual renal units were moderately correlated with the ratio of parenchymal volume measured on CT with a Pearson correlation coefficient of 0.756.[11] Studies looking at ultrasound as a prospective tool reported sub-optimal correlations, with Pearson correlation coefficients ranging from 0.50 to 0.65.[11,12] It is also important to note the reported comparisons of form and function using other imaging modalities and a variety of other functional measurements are much weaker than our results using a simple schematic to predict post de-obstructive procedural outcome.

Similar to Feder et al, we found that in patients with poor function measured by NR (≤ 25%), there seems to be a much larger variance in parenchymal measurements.[2] In our sample there were two patients (patients 1 and 6, see Table 1) that had < 25% differential function after surgery, but two of the observers measured the predicted EDRF to be approximately 40%. Feder et al offered a 2 mm subtraction to correct for the poorly functioning kidney to enhance the predictive ability of calculating renal function using CT in patients with a large variation in renal function.[2] We ascertain that a corrective measure is unnecessary because in poorly functioning kidneys, there does not seem to be an adequate alternative for NR to accurately measure function and dictate management at this time. It is important to remember that NR may give you a falsely lower reading due compromised baseline renal function and poor diuretic response.[1-3] In poorly functioning kidneys, there may not be an alternative to nuclear renal scan. In our results, these are the cases where CT overestimated recovery potential and was not accurate; therefore in very poor kidneys an ideal imaging tool is yet to be identified.

Our study has potential limitations. It was conducted retrospectively in a group of patients with UPJO who were considered successfully unobstructed radiographically as demonstrated by a T½ after diuretic administration of less than 20 minutes on postoperative NR. Therefore, to use this formula to estimate renal function in other clinical scenarios, further study of this simplified method will require validation, including in the setting chronic kidney disease, specifically when renal parenchyma is preserved and renal function is compromised from a non-obstructive etiology. Nevertheless, our results correlated very well between observers and were reproducible as demonstrated by the almost perfect consensus between individual observers with an ICC of 0.957.

No patients in our small cohort had greater than stage II chronic kidney disease - all patients had GFR greater than 60 mL/min/1.73m^2. This data is in itself limited in the setting of a likely normal contralateral kidney; therefore our method estimates split function as a surrogate for GFR of affected renal unit and the recovery potential of the obstructed kidney after surgery. We recognize that some would have concern for kidneys that do not fit into the coronal plane well and how variable measurements in these kidneys would be. This potential for variability is important to accept given that our goal was to create a formula that is easily reproducible with minimal (~3%) interobserver variability. All of the observers theoretically chose the same coronal plane to measure from as there was almost a 97% agreement between the three blinded observers. This is the only study to our knowledge that presents a simplified way to calculate differential renal function with CT scan imaging with excellent reproducibility.

Our method can be beneficial in counseling patients, and evaluating and following patients who have UPJO. This technique requires further investigation to see if it can be extrapolated to other disease processes to help determine differential renal function, such as in cases with renal tumors when attempting to determine radical versus partial nephrectomy or in cases that may require treatment of kidney stones in poorly functioning moieties that may or may not be simultaneously obstructed.

Conclusions

Estimating differential renal function based on renal parenchymal thickness on preoperative CT imaging correlates very well with observed post-operative differential renal function on NR. CT with delayed images can provide information about degree of obstruction and also adds renal and vascular anatomy detail that is not provided with NR. Given that this approach is accurate and reproducible, this estimate may obviate the need for additional imaging with NR in some cases where the estimated differential function is clearly greater than 25% for each renal unit. However, when the estimate is predicted to be < 25% differential function or if obstruction is unclear, NR is still the known modality of choice to help decide on the optimal treatment option. The ideal postoperative imaging study remains unclear with the inaccuracies of diuretic NR in poorly functioning kidneys. Our approach needs to be further investigated in the setting of other urologic disorders in order to determine if NR can be avoided in those situations thereby limiting costs and potential additional radiation exposure. ☐

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