Evaluation of CT as a predictor for kidney and renal artery mobility

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PURPOSE
Renal artery stent failure may result from excessive kidney mobility in some patients. We used computed tomography (CT) to determine the prevalence and magnitude of renal displacement due to postural changes.

MATERIALS AND METHODS
A retrospective review of 100 consecutive CT colonography examinations was performed to measure renal artery location and displacement in both axial and coronal views using paired supine and prone non-contrast scans. Kidney displacement from the prone to supine position was correlated with a change in renal artery angular deviation. Statistical significance was determined using t-tests and Pearson correlations. Results were based on measurements made by a single observer.

RESULTS
Mobility and angular displacement between the prone and supine positions were significant bilaterally and in both planes ($P < 0.01$) except for the coronal plane kidney mobility on the left ($P = 0.32$). The axial plane correlation between kidney and artery mobility was significant bilaterally (left/right $r=0.44/0.22$, $P < 0.01/0.03$); the coronal plane correlation was only significant on the left (left/right $r=0.26/0.18$, $P = 0.01/0.08$). The mean axial plane mobility and angle change were greater on the left (left/right mobility 13 mm/7 mm; left/right angle change 18°/8°). In contrast, the mean coronal plane mobility and angle change were greater on the right (left/right plane mobility 4 mm/22 mm; left/right angle change 4°/8°). Fourteen patients had a mobility in excess of 32°.

CONCLUSION
During postural changes, the kidneys and renal arteries demonstrate significant correlated mobility. Renal artery movements can be identified using a low-radiation dose CT exam.

Key words: CT colonography • renal artery obstruction • atherosclerosis

The movement of a stent within a mobile artery exacerbates the risk of stent restenosis and thrombosis in addition to the risk of stent fracture (17). Restenosis is most commonly the result of stent-induced endothelial trauma leading to an exaggerated repair process, inflammation and intimal hyperplasia (18–23). Similarly, thrombosis results from the exposure of thrombogenic arterial wall components after endothelial injury (24). In addition to intimal hyperplasia, chronic stent recoil has been shown to account for some lumen loss in stented renal arteries (25). The additional shear stress caused by a mobile artery may potentially accelerate stent recoil and restenosis and increase the risk of thrombus formation (17, 26).

Kidney and renal artery mobility are likely factors in stent failure and restenosis, and establishing mobility preoperatively may be clinically useful in predicting future failure. Knowledge about the magnitude of renal artery and stent movements may also be useful in designing and testing new stents. Kidney position and the renal artery angle have been shown to change with inspiration and expiration (27–29). Body position changes have also been shown to alter cardiovascular and renal physiology (30–33). However, no data exist on the range of kidney or renal artery mobility with changes in body position. Additionally, the magnitude of renal artery movement required to cause stent malfunction is unknown.

To evaluate the ability of computed tomography (CT) to identify kidney and renal artery mobility, we retrospectively compared supine and prone images from a cohort of CT colonography patients and measured the changes in kidney location and renal artery angle. We also correlated the degree of kidney mobility to the change in renal artery angle.

Materials and methods

Patients
All patients undergoing CT colonography consented to participation in this research study. The scans of 100 consecutive patients were analyzed; the patient population included 51 males and 49 females, with
Kidney mobility measurement

The anteroposterior and cephalocaudal displacement of the kidneys was measured based on the change in location of the center of the kidney between prone and supine views. The center of the kidney was visually approximated in all three planes and marked. The change in the kidney position was then determined by measuring the distance between the kidney center and a vertebral landmark reference point in both the supine and prone positions. Multi-planar reconstructions were viewed in 10 mm thick reconstructions. The method of measuring anteroposterior mobility of the kidney as seen in the axial plane is described in Fig. 1. The method of measuring the cephalocaudal mobility of the kidney as seen in the sagittal plane is described in Fig. 2.

Renal artery angle measurement

The anteroposterior and cephalocaudal displacement of the kidneys was measured based on the change in location of the center of the kidney between prone and supine views. The center of the kidney was visually approximated in all three planes and marked. The change in the kidney position was then determined by measuring the distance between the kidney center and a vertebral landmark reference point in both the supine and prone positions. Multi-planar reconstructions were viewed in 10 mm thick reconstructions. The method of measuring anteroposterior mobility of the kidney as seen in the axial plane is described in Fig. 1. The method of measuring the cephalocaudal mobility of the kidney as seen in the sagittal plane is described in Fig. 2.
the renal artery angle change as seen in the axial plane is shown in Fig. 3b. The method of measuring the renal artery angle change as seen in the coronal plane is described in Fig. 4. The measurements were performed independently for the main right and left renal arteries. Accessory vessels were not included.

Data analysis

Results were based on a single medical student’s measurements (observer #1). In addition, observer #1 and another medical student (observer #2) each performed two sets of measurements on a random sample of ten consecutive patients to determine intra- and inter-observer variability. Observers underwent a detailed tutorial from an experienced supervising radiologist on how to take kidney mobility measurements; however, they did not have prior experience interpreting abdominal images. Data were analyzed separately for the right and left kidneys, for the axial and coronal planes, and for the supine and prone positions. We calculated the difference in the renal artery angles and the kidney movement between the two body positions and evaluated each for statistically significant changes using a paired t-test. Statistical significance only indicates that there was a measurable difference in the renal position and renal artery angle with a postural change and does not imply clinical significance. A t-test was also used to determine any differences in the angle change and kidney mobility between males and females. For each patient, changes in the angle were plotted against the corresponding kidney mobility to generate a scatter plot. A trend line was interpolated from the scatter plot, and the data were subjected to a Pearson correlation test to determine the statistical significance of the relationship. Pearson correlation was also used to determine the relationship of renal artery movement between the right and left sides and between the axial and coronal planes on the same side.

To approximate an angle change that could potentially have a clinically significant risk, the mean and standard deviation of the absolute magnitude of all angle changes (i.e., in both axial and coronal planes and on both sides) were calculated. The absolute value of the angle changes were chosen for...
this calculation because the magnitude of movement, and not the direction, would be of greater clinical significance and because the absolute value data could be more easily utilized in future studies of mobility. Angle change values of one standard deviation and two standard deviations above the mean were arbitrarily chosen as thresholds that could potentially pose a clinically significant risk for stent malfunction, and the number of patients with movement above each of these angle thresholds was determined. Extreme angle change was defined as greater than two standard deviations above the average.

The concordance correlation coefficient (CCC) and Pearson correlation coefficient \( r \) were used to assess intra- and inter-observer agreement in measuring the renal artery angle change and kidney mobility (34, 35). The average value of each observer’s two measurements was used for inter-observer analysis. The study was conducted with approval of the institutional review board.

Results

Kidney mobility

The prone to supine kidney position changes were averaged for both kidneys and for both anteroposterior and cephalocaudal directions of movement (Table 1). Movement of the kidney with body position change from prone to supine was statistically significant in both directions on the right and only in the anteroposterior direction on the left \( (P < 0.01; \text{Fig. 5a and 5b}) \). The cephalocaudal left kidney movement was not statistically significant on average \( (P = 0.29) \); there was a significant difference in females \( (P = 0.01) \) but not in males \( (P = 0.73) \). Anteroposterior mobility was greater on the left; however, cephalocaudal plane mobility was greater on the right (Table 1).

Renal artery angle change

The left and right renal artery ostium angle changes were averaged for both the axial and coronal views (Table 2). With the change in body position, the renal artery angle changed significantly on both sides and in both planes \( (P < 0.01; \text{Fig. 5c and 5d}) \). The greatest angle change was seen on the left side in the

![Figure 5](image-url)

Figure 5. a–d. Changes in the renal artery angle (a, b) and the kidney position (c, d) with prone to supine patient movement. Data points on the longer line represent mean values. A/P, anteroposterior.
axial plane (Table 2). The mean absolute angle change on either side and in either plane was 12.7°±9.6°. Mobility greater than one standard deviation above the mean (>22°) was present in 47 out of the 100 cases. Mobility greater than two standard deviations above the mean (>32°) was defined as extreme and was present in 14 out of the 100 cases.

**Kidney-renal artery mobility correlation**

In each patient, the axial plane renal artery angle change was plotted against the anteroposterior kidney movement for both the left and right side. The equations for the trend lines were \( y=0.4802x-12.05 \) for the left side and \( y=0.2506x-9.34 \) for the right side (Fig. 6). The same method was used to plot the coronal plane artery angle change against the cephalocaudal kidney mobility for both sides. The coronal plane trend line equations were \( y=0.2044x-3.45 \) for the left side and \( y=0.1245x-3.95 \) for the right side.

The Pearson correlation (\( r \)) was performed to evaluate the significance of the correlation between kidney mobility and the renal artery angle change and to evaluate the correlation between the movement of the right and left renal arteries within the same plane. In the axial plane, the correlation between the renal artery angle change and kidney movement was significant for both the left and right (\( r=0.44, P<0.01 \) and \( r=0.22, P=0.03 \), respectively). There was a correlation between the coronal plane artery angle change and cephalocaudal kidney mobility for both sides, although this correlation was significant only on the left side (left: \( r=0.26, P=0.01 \); right: \( r=0.18, P=0.08 \)). The correlation in angle change between the right and left renal arteries was significant in the axial plane but not in the coronal plane (axial \( r=0.2, P=0.04 \); coronal \( r=0.11, P=0.28 \)). There was no correlation in renal artery movement between the axial and coronal planes on the same side (left: \( r=0.13, P=0.33 \); right: \( r=0.07, P=0.46 \)). Therefore, the amount of arterial mobility in one plane did not predict the amount of movement in the other plane.

**Male-female variability**

There were significant male-female differences in left artery angle change and left kidney mobility, both in the axial plane (Table 1). The mean absolute angle change in prone position was 13 (range, -1 to 49) \( P<0.01 \) and in supine position was 7 (range, -4 to 32) \( P<0.01 \).

**Table 1. Renal mobility (n=100 patients)**

<table>
<thead>
<tr>
<th>Position in prone (mm)</th>
<th>Position in supine (mm)</th>
<th>Change in position (Prone-supine) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial plane(^a)</td>
<td>Left kidney</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Right kidney</td>
<td>15</td>
</tr>
<tr>
<td>Coronal plane(^b)</td>
<td>Left kidney</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Right kidney</td>
<td>131</td>
</tr>
</tbody>
</table>

\(^a\)Antero-posterior kidney mobility.  
\(^b\)Cephalo-caudal kidney mobility.  
Kidney center determined in coronal plane; distance from landmark measured in sagittal plane.
coronal plane ($P = 0.007$ and $P = 0.03$, respectively). All other measurements were similar between the sexes.

**Measurement variability**

The intra- and inter-observer CCC and $r$ were both greater than 0.80 for kidney mobility on both sides and in both planes and for the left-sided axial renal artery angle change. The CCC and $r$ values $>0.80$ indicated that these particular results were reliable. Lower measurement reproducibility was observed for the measured angle changes in the coronal plane on both sides and in the right renal artery angle change in the axial plane (Observer 1 left/right coronal and right axial: CCC=0.43/0.54 and 0.66, $r=0.49/0.56$ and 0.81, respectively; Observer 2 left/right coronal and right axial: CCC=0.63/0.67 and 0.46, $r=0.64/0.71$ and 0.46, respectively; inter-observer agreement left/right coronal: CCC=0.56/0.65, $r=0.59/0.69$, and right axial CCC=0.24, $r=0.33$).

**Discussion**

Renal movement had a direct small but statistically significant correlation with renal artery angle change on both sides in the axial plane. Axial plane direction changes in kidney position and renal artery angle were smaller in magnitude on the right side compared to the left side. This difference in mobility may be related to the right kidney’s position caudal to the liver, which hinders the kidney from moving forward, and the right renal artery position posterior to the inferior vena cava (IVC), which prevents movement of the artery. Conversely, Suh et al. suggested that greater movement of the left renal artery could be due to its greater entanglement, creating fulcrum points along the vessel (Suh et al., presented at the 2007 ASME Summer Bioengineering Conference in Keystone, Colorado, USA). Consistent with these findings, stent fractures were found to be more frequent on the left by Robertson et al. (8) (left, 67%; right, 33%).

The relationship between kidney mobility and renal artery angle change was significant for the left side but was not significant on the right in the coronal plane. We postulate that the lack of correlation on the right is based on two anatomic factors. First, the IVC may have hindered right renal artery movement in the coronal direction when the kidney changed positions. Second, the renal arteries have a naturally occurring bend that is more acute on the right due to the renal artery’s course behind the IVC (27). Our angle measurements were based only on the proximal segment of the artery and likely insufficiently captured the mobility or angle change of the distal portion of the artery. Therefore, a kidney movement in the cephalic direction will move the distal artery alone, without significantly affecting the proximal artery position or angle. In agreement with the results of a previous study, we found that the maximal coronal plane kidney displacement occurred on the right (27).

Our study had several limitations. One observer was used to make all of the CT measurements used for data analysis. This limitation was partially addressed by showing an intra- and inter-observer correlation greater than 0.80 for the majority of measurements. Our study did not evaluate movement that occurs during posture change from supine or prone to upright. However, CT scanning in the upright position was not feasible, and our aim was to establish a practical test that could identify patients with highly mobile arteries. Due to the measurement method, only proximal renal artery movement with respect to the aorta was evaluated, and distal bending was not assessed. However, because the majority of atherosclerotic disease, and therefore stenting, is localized to the proximal portion of the renal artery, this limitation may not necessarily hinder the usefulness of our results. All CT colonography exams in this study were performed without contrast and at a low radiation dose. While the use of contrast and a higher radiation dose may have resulted in superior image quality, the image resolution in this study was adequate to assess renal position and vasculature. Because the aim of our study was to evaluate both a practical and minimally invasive method to test for kidney mobility, the use of contrast or a higher radiation dose would have undermined the future applicability of our results. Finally, while the effect of respiration was not addressed in this study, previous studies have shown that respiratory motion has an effect on renal displacement (27–29). Although all patients were scanned using breath-hold after maximal inspiration in both the supine and prone positions, the prone position likely prevented the same amount of inspiration as in the supine position.

Our data support a direct relationship between kidney mobility and the change in the renal artery angle as viewed in multiple planes. Our results are consistent with those of a prior study and confirm the finding that kidney movement occurs with changes in body position (36). This movement is likely implicated in stent fracture (7–11). Additionally, inflammation and intimal hyperplasia caused by excessive stent movement may promote restenosis and thrombosis (17). In patients who develop stent failure or thrombosis, low-dose CT scans in varying positions may reveal if kidney mobility was an implicating factor. Knowledge of renal artery mobility and biomechanics may also be employed for stent design and in planning trans-renal aortic graft placement (37–39).

The current study provides a benchmark range of movement that can be used as a reference for comparison.

### Table 2. Renal artery angle change (n=100 patients)

<table>
<thead>
<tr>
<th></th>
<th>Angle in prone position</th>
<th>Angle in supine position</th>
<th>Change in angle (Prone–supine)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Axial plane</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left renal artery</td>
<td>106°</td>
<td>88°</td>
<td>18° (range, -1° to 42°) $P &lt; 0.01$</td>
</tr>
<tr>
<td>Right renal artery</td>
<td>92°</td>
<td>84°</td>
<td>8° (range, -4° to 32°) $P &lt; 0.01$</td>
</tr>
<tr>
<td><strong>Coronal plane</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left renal artery</td>
<td>73°</td>
<td>68°</td>
<td>4° (range, -19° to 25°) $P &lt; 0.01$</td>
</tr>
<tr>
<td>Right renal artery</td>
<td>68°</td>
<td>60°</td>
<td>8° (range, -10° to 27°) $P &lt; 0.01$</td>
</tr>
</tbody>
</table>
It is unknown what magnitude of renal artery angle change may be clinically significant. Our study had a wide range of measured renal artery angle changes; 47% of patients had an angle change greater than 22°, and 14% had a change of 32° or more. We suggest further study regarding kidney mobility in cases of stent intervention failure, which will lead to a more complete understanding of the factors involved in failure and improve future treatment options.

Conflict of interest disclosure
The authors declared no conflicts of interest.

References