Renal Sympathetic Denervation: MDCT Evaluation of the Renal Arteries

**Objective.** Percutaneous transluminal renal sympathetic denervation is a new treatment of refractory systemic hypertension. The purpose of this study was to assess the clinical utility of MDCT to evaluate the anatomic configuration of the renal arteries in the context of renal sympathetic denervation.

**Materials and Methods.** Two readers retrospectively evaluated the MDCT renal artery scans of 90 patients (mean age, 70 ± 13 years; range, 32–98 years). Analysis included the number of renal arteries on each side, ostial shape and size, angle off the aorta, branching pattern, degree of tortuosity, and distance to adjacent vascular structures.

**Results.** Sixty-five patients had one, 23 had two, and two had three renal arteries on one side. One hundred forty-six arteries were funnel-shaped (72 left and 74 right; mean ostial diameter, 0.9 ± 0.2 cm tapering to 0.6 ± 0.1 cm). The mean tortuosity index was 1.1 (range, 1 [no tortuosity] to 3.1). Compared with the left renal artery, the right renal artery was longer (4.0 ± 0.9 cm vs 5.0 ± 1.2 cm, p ≤ 0.001), originated at a more acute angle on axial (67° vs 98°, p ≤ 0.05) and coronal images (57° ± 16° vs 65° ± 14°, p ≤ 0.05), was significantly closer to the superior mesenteric artery (1.0 ± 0.7 cm vs 1.6 ± 1.2 cm, p ≤ 0.001), and came in closer contact with venous structures (0.0 ± 0.1 vs 0.2 ± 0.9, p < 0.05).

**Conclusion.** Our findings suggest MDCT of the renal arteries is an informative investigation in patients undergoing renal sympathetic denervation, providing data on the number and size of renal branches, ostial shape, and proximity to adjacent venous structures.

Keywords: antihypertensive agents, catheter ablation, kidney innervation, renal artery surgery, renal sympathetic denervation, sympathectomy methods, therapeutic use

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Systemic hypertension remains one of the most common conditions in the general population, with a prevalence ranging from 29% to 31% [1]. The disease remains difficult to control, with approximately one third of patients having adequately controlled blood pressure [2]. Resistant hypertension is defined in the 2008 American Heart Association guidelines as blood pressure that remains above goal in spite of concurrent use of three antihypertensive agents of different classes, one of which should be a diuretic [3]. Successful treatment has remained unsatisfactory despite multiple drug regimens, combination pharmaceutical agents, and resources to assist patient adherence and lifestyle changes [4].

The pathogenesis of systemic hypertension is poorly understood but is likely multifactorial, with increased sympathetic neural activity, abnormal angiotensin II metabolism, and genetic factors all playing a role [5]. Renal sympathetic nerve activity plays an important role in the development and persistence of hypertension [6]. Percutaneous transluminal renal sympathetic denervation is a relatively new technique being used for the treatment of refractory hypertension. It has recently been validated in a randomized controlled multicenter trial [7] in which endovascular catheter technology enabled selective radiofrequency energy delivery in the renal artery lumen, ablating the renal nerves located in the renal adventitia [8]. At 6 months, 41 of 49 (84%) patients who underwent renal denervation had a reduction in systolic blood pressure of 10 mm Hg or more, compared with 18 (35%) of 51 control subjects (p < 0·0001). Several additional proof-of-concept, safety, and therapeutic efficacy studies have shown similarly good results with an acceptable safety side effect profile extending to 24 months [7, 9–13].
MDCT of the Renal Arteries

was used to ascertain the optimum time to commence acquisition (20 mL of contrast medium injected at 4 mL/s with a region of interest placed over the ascending aorta) followed by 70 mL of iodinated contrast medium (iopamidol, Isovue 370, Bracco Diagnostics), which was injected at a rate of 4 mL/s followed by a 20-mL saline bolus chaser injected at 4 mL/s. Images were reconstructed with a 512 × 512 matrix and a smooth kernel with a 1-mm slice thickness and 0.5-mm slice overlap. Images were transferred to a workstation (Leonardo, Siemens Healthcare) for further analysis.

Renal Artery Analysis
Analysis of the renal arteries included the number of renal arteries on each side. For patients with more than one renal artery on one or both sides, the main renal artery was designated as the one with the largest ostium, and additional arteries were designated as accessory renal arteries. Length of the main renal artery was determined by measuring the curvilinear distance from the ostium of the renal artery to the first renal arcade on either side using curved multiplanar reformation images (MPRs). Secondary branches originating from the first 3 cm of the main renal artery were counted, and the distance from the ostium at which this branching occurred was recorded. The angle that the main renal arteries formed at the renal artery ostium was deemed the accessory artery. No. of main renal arteries was determined as the angle of the main renal artery to the inferior margin of the origin of the SMA using coronal MPRs. The distance from the ostium of the right main renal artery to the right renal vein or inferior vena cava (IVC) (whichever was closest) and from the ostium of the left renal artery to the left renal vein was recorded. Also, the minimum distance from the right renal artery to the right renal vein–IVC and left renal artery to the left renal vein within the first 2.5 cm of their courses was measured as well as the distance along the artery at which this minimum distance occurred.

Accessory Renal Arteries

The accessory renal arteries were assessed for ostial diameter (the long axis of the ostium using sagittal MPRs), whether they originated below, above, or at the level of the main renal artery and for the distance to the main renal artery (the vertical distance along the border of the abdominal aorta from the accessory ostium to the main renal artery ostium). Two patients had three renal arteries on one side, and the artery with the second largest ostial area was deemed the accessory artery.

Statistical Analysis
Patient demographics are provided as the mean ± SD with the range. Comparisons between groups for numeric values were performed using the paired Student t test and for ordinal categories using the chi-square test. A p value ≤ 0.05 was considered significant. All statistics were performed using SPSS 16.0.

Results
Renal Artery Analysis
A total of 213 renal arteries were identified branching from the abdominal aorta, 105

### TABLE 1: CT Analysis of Renal Arteries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of renal arteries (n = 213)</td>
<td>105</td>
<td>108</td>
</tr>
<tr>
<td>No. of main renal arteries</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Unilateral/bilateral duplication</td>
<td>8/5</td>
<td>11/5</td>
</tr>
<tr>
<td>Unilateral triplication</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Renal artery length (cm)</td>
<td>5.0 ± 1.2</td>
<td>4.0 ± 0.9</td>
</tr>
<tr>
<td>No. of side branches from renal artery</td>
<td>19</td>
<td>33</td>
</tr>
<tr>
<td>Distance to first side branch (cm)</td>
<td>1.6 ± 0.6</td>
<td>1.5 ± 0.7</td>
</tr>
<tr>
<td>Axial angle (°)</td>
<td>67 ± 20</td>
<td>98 ± 17</td>
</tr>
<tr>
<td>Coronal angle (°)</td>
<td>57 ± 16</td>
<td>65 ± 14</td>
</tr>
<tr>
<td>Renal artery ostia vertical axis (cm)</td>
<td>0.8 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Renal artery ostia horizontal axis (cm)</td>
<td>0.8 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Renal artery ostia area (cm²)</td>
<td>0.6 ± 0.3</td>
<td>0.7 ± 0.3</td>
</tr>
<tr>
<td>Arterial diameter at 25 mm (cm)</td>
<td>0.6 ± 0.1</td>
<td>0.6 ± 0.1</td>
</tr>
<tr>
<td>Funnel/tubular shaped</td>
<td>74/16</td>
<td>72/18</td>
</tr>
<tr>
<td>Renal artery tortuosity (axial)</td>
<td>1.1 ± 0.1</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>Renal artery tortuosity (coronal)</td>
<td>1.1 ± 0.1</td>
<td>1.2 ± 0.2</td>
</tr>
<tr>
<td>Accessory artery ostial diameter (cm)</td>
<td>0.5 ± 0.2</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>Accessory artery distance to main (cm)</td>
<td>1.8 ± 3.1</td>
<td>1.6 ± 1.3</td>
</tr>
</tbody>
</table>

Note—Measurements may vary with respiration.

*p < 0.05.

*p < 0.01.
from the right and 108 from the left (Table 1). Sixty-five (72%) patients were found to have a single renal artery on both sides, 23 (26%) had two renal arteries on one or both sides, and two (2%) had three arteries on one side. There was no significant difference in the incidence of accessory arteries between the left and right sides. Forty-five of 90 subjects (50%) had a side branch originating from one or both main renal arteries ≤4 cm from the ostium. Seventy-six side branches were identified, 32 on the right and 44 on the left. Fifty-two of 76 (68%) side branches originated in the proximal 2 cm and the remaining 24 (32%) originated between 2 and 4 cm from the ostium. The mean length of the right renal artery was longer than the left (5.0 ± 1.2 cm vs 4.0 ± 0.9 cm, p < 0.05). Of the 180 main renal arteries analyzed, 52 (29%) were found to have a secondary branch originating <3 cm from the ostium (mean distance, 1.5 cm). The right main renal artery originated at a more acute angle than the left on axial (67° vs 98°, p ≤ 0.05) and coronal images (57° ± 16° vs 65° ± 14°, p ≤ 0.05) (Figs. 1 and 2).

Regarding the renal artery ostia, mean ostial dimension for the right and left main renal arteries was 0.8 ± 0.2 cm and 0.8 ± 0.2 cm (p, not significant) and mean areas were 0.6 ± 0.3 cm² and 0.7 ± 0.3 cm², respectively (p, not significant). The main renal arteries tapered at a similar rate bilaterally, with both having mean diameters of 0.6 ± 0.1 cm at 25 mm from the ostium (p, not significant). One hundred forty-six (81%) main renal arteries were funnel-shaped, with the remaining 34 (19%) tubular. On the right side, 74 of 90 (82%) were funnel-shaped and on the left, 72 of 90 (80%) were funnel-shaped (p, not significant). The mean arterial tortuosity in axial sections was 1.1 ± 0.1 on the right and 1.1 ± 0.2 on the left (p, not significant), consistent with minimal convolution in almost all cases. There were cases of highly tortuous arteries with one artery having an index of 3.0, but these were uncommon as evidenced by the low SD. Tortuosity was similarly modest in the coronal image plane, with means of 1.1 ± 0.1 on the right and 1.2 ± 0.2 on the left (p, not significant).

Analysis of Adjacent Structures
The right renal artery was significantly closer to the SMA than the left renal artery (1.0 ± 0.7 cm vs 1.6 ± 1.2 cm, p ≤ 0.001). Two cases on the left and five on the right originated at the same level as the SMA. In one patient, the left main renal artery originated adjacent to the aortic bifurcation and the inferior mesenteric artery, 10.9 cm from the SMA (Fig. 3). The ostium of the right renal artery was slightly closer to nearby venous structures (renal vein and IVC) than the left (0.5 ± 0.4 cm vs 0.7 ± 0.9 cm (p, not significant)), respectively (Fig. 4 and Table 2). The right renal artery consistently came in contact with either the right renal vein or the IVC within the first 2.5 cm compared with the left renal artery distance to the left renal vein (0.0 ± 0.1 vs 0.2 ± 0.9, p < 0.05). The mean distance along the artery at which this occurred was 1.1 cm ± 0.6 cm. Finally, one patient had a left retroaortic renal vein (Fig. 5).

Accessory Renal Arteries
Thirty-one accessory arteries were analyzed, 14 on the right and 17 on the left. Eleven (35%) arteries were superior to the main renal artery, 16 (52%) were inferior, and four (13%) were at the same level. The mean distance between ostia was 1.8 ± 3.1 cm on the right and 1.6 ± 1.3 cm on the left. The mean ostial diameter was 0.5 ± 0.2 cm on both sides.

Discussion
The current study has emphasized important renal artery anatomic considerations using MDCT in the context of renal sympathetic denervation. In keeping with previous studies, we found many patients had two or more renal arteries on either side, with 26% of patients having two renal arteries on one or both sides and 2% having three arteries on one side. Because additional renal arteries may carry a proportion of the renal sympathetic innervation, the question of whether all renal arteries require ablation necessitates further study. Importantly, in the SympliCity HTN-1 and HTN-2 trials, patients with more than one renal artery on each side were excluded [10]. Thus, currently the efficacy of renal sympathetic denervation in this patient subgroup is entirely unknown. A recent report by Václavík et al. [15] described poor results from unilateral renal sympathetic denervation in a patient with resistant hypertension. In our center, we perform ablation on all major renal arteries bilaterally to maximize the treatment potential. Several main renal arteries had branch points <4 cm from the ostia. Currently, renal ablation is typically car-

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**Fig. 1**—63-year-old man with refractory hypertension. Invasive renal angiogram with renal artery denervation introducer sheath system within ostium of right renal artery shows angulation and radius of curvature of sheath (straight arrow) are poorly matched and aligned with longitudinal axis of proximal section of artery (curved arrow).

**Fig. 2**—74-year-old man with lower right limb claudication. A and B, MDCT images show coronal oblique (A) and axial oblique (B) mean angles of right and left renal arteries from aorta.
teryl ostia measured > 1 cm and others measured as circular. However, because some renal arteries were straighter than others, the optimal alignment should be caudal and posterior for the right renal artery and anterior for the left renal artery during breath-hold inspiration and may vary with respiration.

We found considerable interpatient variability in the renal artery angle from the aorta in both axial and coronal image planes, as has been previously described [16]. The right renal artery branched off the aorta at a more acute angle than the left, particularly in the axial plane (68° vs 98°, \( p < 0.01 \)). Thus, the direction of the catheter tip during renal ablation for optimal alignment should be caudal and posterior for the right renal artery and anterior for the left renal artery. It should be emphasized that renal artery angle measurements were made during breath-hold inspiration and may vary with respiration.

Most right and left renal arteries were funnel-shaped. However, because some renal artery ostia measured > 1 cm and others measured < 0.4 cm, our findings suggest a wide range of renal ablation catheter sizes may be required to address all patients with this therapy. A related point is the wide variability in the distance at which renal arteries tapered to a size that would preclude advancement of the renal sympathetic denervation catheter any further was between 2 and 3 cm. In the Symplicity HTN-2 trial, ostia < 0.4 mm were considered technically unsuitable and excluded [7]. Twelve arteries in our cohort had ostia measuring < 0.4 mm, which were technically unsuitable and excluded [7]. Twelve arteries in our cohort had ostia measuring < 0.4 mm. In a recent study, a delivery sheath induced a renal artery dissection during delivery of radiofrequency energy which caused the size and angle of the renal arteries to vary. A related point is the wide variability in the delivery of radiofrequency energy during renal sympathetic denervation procedure [12]. Such findings suggest the need for further study to address any changes in the renal arteries and the adjacent IVC or renal veins.

In our own renal sympathetic denervation practice, a preprocedure MDCT is performed for several reasons. First, the correct choice of catheter can be made before the procedure because the size and angle of the renal arteries affect the type and size of renal catheter systems. There are currently more than eight renal sympathetic denervation catheter systems in development, including high-intensity focused ultrasound, circumferential radiofrequency micromeshes, and various cryotherapy systems, all with a range of sizes of delivery sheaths and all with varying angles and radius of curvature. The MDCT findings have implications for ablative catheter selection as well as choice of angulation and radius of curvature of the delivery sheath. Second, a preprocedure MDCT avoids the need for aortography to depict the renal vessels at the time of the procedure.
It reduces the amount of IV contrast material required during renal sympathetic denervation and shortens the procedure time. Finally, we have found MDCT useful in assessing the tortuosity of the iliac vessels before renal sympathetic denervation, which influences the side to choose for catheter delivery.

Our study has several limitations. Not all of our patients had systemic hypertension, and patients with chronic systemic hypertension may have had even more variability in renal artery anatomy, particularly the tortuosity index. We did not measure interobserver agreement in this study, and it would be interesting to assess this aspect of CT in the context of renal sympathetic denervation in future work. Finally, we did not assess the effect of inspiration-expiration on our renal artery analysis, which is known to affect renal artery angles and tortuosity.

In conclusion, MDCT angiography of the renal arteries provides measurements that may be of importance for renal sympathetic denervation. Our findings suggest further study is required regarding the application of renal sympathetic denervation to patients with multiple renal branches in addition to more optimal catheter design and an assessment of the effect on adjacent venous structures.

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