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Anatomical Observations on the Renal Veins and Inferior Vena Cava at Magnetic Resonance Angiography

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Abstract
Purpose: To describe the renal vein and inferior vena cava (IVC) anatomy found at abdominal magnetic resonance (MR) angiography.
Methods: Gadolinium-enhanced, three-dimensional, time-of-flight MR angiograms of 150 patients were evaluated for the number and configuration of the renal veins, and the number, configuration, and dimensions of the IVC. Data were analyzed with the Student's *t*-test.
Results: Retroaortic left renal veins were found in 7% of patients, circumaortic left renal veins in 5%, multiple right renal veins in 8%, and duplicated IVCs in 0.7%. The length of the infrarenal IVC averaged 94 mm in females and 110 mm in males ($p<0.00001$). The length of the infrarenal IVC in patients with circumaortic and retroaortic left renal veins averaged 76 mm and 46 mm, respectively. The mean maximal caval diameter was 23.5 ± 4 mm. No megacavae (diameter of the mid-IVC > 28 mm) were identified.
Conclusion: Variant renal vein and IVC anatomy can be identified at MR angiography.

Key words: Inferior venae cavae—Vena cava—Magnetic resonance angiography

A thorough familiarity with inferior vena cava (IVC) and renal vein anatomy is necessary for all radiologists who image the abdomen, and crucial for those engaged in venous diagnosis and intervention. In particular, the location and number of the renal veins, and the size and the anatomy of the infrarenal IVC are of paramount importance when designing and placing IVC filters [1]. Based upon conventional venographic and anatomic studies, developmental variants of the renal veins are reported to occur in more than 30% of normal individuals [2, 3]. Developmental anomalies of the infrarenal IVC are less common, with an incidence that approaches 2%–3% [4]. Approximately 2%–3% of patients are thought to have IVCs greater than 28 mm in diameter (megacavae) [5, 6].

Inferior vena cavography and renal venography are the most direct, but invasive, imaging techniques for evaluating the cava and the renal veins [2, 7, 8]. Many noninvasive modalities can identify renal vein and IVC anomalies, including ultrasonography (US), computed axial tomography (CT), and spin-echo magnetic resonance (MR) [9–11]. However, renal vein variants are detected at a lower frequency by these methods when compared with anatomic and conventional venographic studies [9, 12, 13]. There are no large contemporary studies based upon cross-sectional angiographic techniques, such as MR angiography, that examine IVC and renal vein anatomy.

Contrast-enhanced, 3-dimensional (3-D), time-of-flight (TOF) MR angiography provides excellent visualization of the IVC without loss of signal from saturation of inplane flow [14]. With basic image reformatting software, the renal veins and the entire infrarenal IVC can be inspected in any plane. We report the results of a study of the IVC in 150 patients using these techniques, with particular emphasis upon the identification of variations of IVC and renal vein anatomy.

Materials and Methods

The study population was derived from patients referred for abdominal MR angiography over a 12-month period. Studied were 150 patients (106 males, 44 females, mean age of 67 years, range 20–90 years). Only examinations in which gadolinium contrast agents were used and the IVC was imaged were included. The indications for the MR angiograms were suspected native renal artery stenosis in 85 patients, abdominal aortic aneurysm (mean diameter 5.4 cm) in 51 patients, and aortoiliac occlusive disease in 14 patients. Gadolinium

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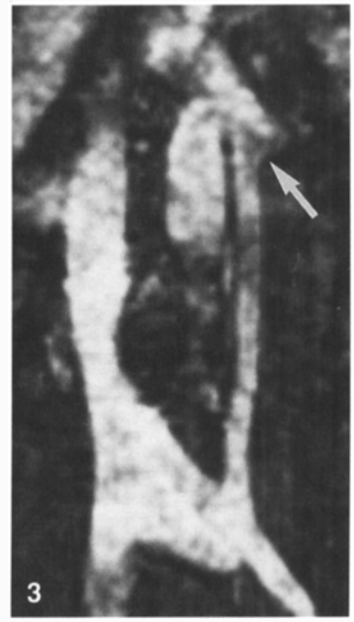

Fig. 1. A single oblique coronal reformatted slice from the MR angiogram of a patient studied for suspected renal artery stenosis. A retroaortic left renal vein can be seen inserting into the inferior vena cava above the confluence of the iliac veins. Because this is a single slice, only a portion of the left kidney is visualized, and the right renal vein and right kidney are out of plane. The posterior aspect of the aorta is seen above the left renal vein; the remainder of the vessel is also out of plane. The liver can be visualized in the right upper quadrant.

Fig. 2. Oblique coronal reformatted slice from the MR angiogram of a patient studied for abdominal aortic aneurysm demonstrating two right renal veins (straight arrows). A portion of the right renal artery can be seen medial to the IVC (curved arrow).

Fig. 3. Reformatted oblique coronal slice from the MR angiogram of a patient studied for suspected renal artery stenosis. A duplicated infrarenal cava is demonstrated, with a dominant right and a small left cava. The left cava arises from the left common iliac vein and inserts into the left renal vein (arrow) before it crosses the aorta. The apparent indentation upon the medial wall of the right cava is due to the psoas muscle in this oblique view.

enhanced MR angiography is used routinely in patients with suspected renal artery stenosis or abdominal aortic aneurysm (AAA). Patients with aortoiliac disease as the sole indication for the study received gadolinium only if the two-dimensional TOF MR angiogram of the infrarenal aorta and pelvis was inadequate. A log of the patients who had MR angiographic studies during the same period of time but were not included in this series was not maintained.

Gadolinum enhanced, 3-D TOF MR angiography was performed on a 1.5-T GE System using 4.7 and 4.8 software and the body coil according to a previously described technique [15]. Using a sagittal T1-weighted sequence as a localizer, an initial coronal or axial 3-D TOF MR angiogram was obtained during dynamic intravenous injection of a gadolinium contrast agent. Generally, only arterial structures were visualized in these images [14, 15]. Immediately following the dynamic acquisition, a second acquisition was obtained in order to image the venous structures. This second sequence is a standard part of our clinical protocol for abdominal MR angiography performed with dynamic contrast enhancement. Imaging was performed in the coronal plane with a spoiled gradient-recalled (SPGR) pulse sequence, flow compensation, 24/6.9 (TR/TE), flip angle of 40°, 36-cm FOV, 28 2–2.5 mm partitions, 256 × 256 matrix, one excitation, phase encoding in the right-to-left direction, and no presaturation. Image acquisition time was 3 min 18 sec. Contrast media used were gadopentetate dimeglumine (Magnevist, Berlex Laboratories, Cedar Knolls, NJ, USA) in 50% of patients, gadodiamide (Omniscan, Sanofi Winthrop, NY, USA) in 46% of patients, and gadoteridol (Prohance, Squibb Diagnostics, New Brunswick, NJ, USA) in 4% of patients. The doses ranged from 0.19 to 0.30 mmol/kg. The injected volume of contrast never exceeded 40 ml. All examinations were performed according to standard clinical scanning protocols.

The infrarenal IVC and renal veins were evaluated from the coronal 3-D TOF MR angiograms utilizing standard image reformatting software and an independent console (General Electric, Milwaukee, WI, USA). All measurements were performed on the console, and recorded on a standardized data collection form. The reformatting software allows the operator to "scroll" continuously through the data set in any plane. The length of the infrarenal IVC was measured from the caudal border of the orifice of the lowest renal vein to the confluence of the iliac veins. Caval diameters were measured in an axial plane at four equidistant points between and including the inferior border of the orifice of the lowest renal vein and the confluence of the iliac veins. When the course of the IVC was not straight, an oblique axial slice, oriented perpendicular to the tangent of the curve of the long axis of the IVC at the measurement point, was used to obtain the true diameter of the cava. At each level, two maximal caval diameters were measured at right angles. The number and location of the renal veins, the number of cavae, and the position of the cava relative to the aorta (right or left) were recorded. Data were analyzed with the Student's *t*-test (equal variances, two tailed) where applicable.

Results

Anatomic variants of the renal veins were identified in 30 patients (20%): retroaortic left renal veins in 11 (7%) patients (Fig. 1), circumaortic left renal veins in 7 (5%), duplicated right renal veins in 11 (7%) (Fig. 2), and triplicated right renal veins in 1 (0.7%) patient. A duplicated infrarenal IVC was found in 1 (.7%) patient (Fig. 3). No left-sided IVCs were observed.

Left renal vein variants were found in 6 (12%) patients with AAA. These consisted of retroaortic left renal veins in four patients and circumaortic left renal

Table 1. Inferior vena cava diameters (mm)

IVC level	Ax	Ay	Bx	By	Cx	Cy	Dx	Dy
Male	23 ± 3	11 ± 4	21 ± 3	13 ± 4	21 ± 4	14 ± 4	31 ± 6	12 ± 4
Female	23 ± 3	11 ± 5	20 ± 3	11 ± 4	20 ± 5	11 ± 4	30 ± 6	10 ± 2
p value	0.4	0.7	0.4	0.003	0.9	0.00005	0.3	0.0006
All patients	23 ± 4	11 ± 4	20 ± 3	12 ± 4	20 ± 4	13 ± 4	31 ± 6	11 ± 4

IVC = inferior vena cava; x = long axis of the cross-section of the IVC; y = short axis of the cross-section of the IVC; A = IVC at the level of the lowest renal vein; B = IVC at $^1/_3$ of distance between lowest renal vein and the confluence of the iliac veins; C = IVC at $^2/_3$ of the distance between lowest renal vein and the confluence of the iliac veins; D = IVC at the confluence of the common iliac veins; p value for comparison of male vs female patients. All measurements in millimeters

Table 2. Inferior vena cava diameters in the presence of an abdominal aortic aneurysm (mm)

IVC level	Ax	Ay	Bx	By	Cx	Cy	Dx	Dy
AAA	23 ± 5	11 ± 4	20 ± 3	13 ± 4	20 ± 5	13 ± 5	30 ± 6	13 ± 4
Others	23 ± 3	10 ± 4	20 ± 3	12 ± 4	21 ± 3	12 ± 4	31 ± 4	10 ± 3
p value	0.4	0.6	0.9	0.3	0.5	0.7	0.5	0.0003

Abbreviations same as Table 1

veins in two patients. The incidence of left renal vein variants in patients without AAA was also 12%.

The average length of the infrarenal IVC in patients without left renal vein anomalies was 94 mm (±14 mm) in females and 110 mm (±16 mm) in males. The difference between these two lengths was statistically significant ($p<0.00001$). In patients with a retroaortic left renal vein, the average length of the IVC below the left renal vein was 46 mm, range 17–82 mm. In patients with circumaortic left renal veins, the average length of the IVC below the lower retroaortic component was 76 mm, range 52–104 mm. In patients with circumaortic left renal veins, the average length of the cava between the orifices of the two left renal veins was 33 mm, range 19–45 mm. In patients with retroaortic left renal veins, the average distance between the right and left renal veins was 52 mm, range 21–100 mm.

The caval diameters at each level are presented in Table 1. No cavae with diameters greater than 28 mm in the middle two levels were found. The widest point of the cava was just above the confluence of the iliac veins, with an average maximal diameter of 31 ± 6 mm.

Round caval profiles (diameter x = diameter y) were found in nine patients, but never at more than one level in the same patient, and never at the confluence of the iliac veins. The cava assumed an ovoid configuration at all levels in 141 patients, with a mean maximal (x) diameter of 23.5 ± 4 mm, and a mean short-axis (y) diameter of 11.8 ± 4 mm. This difference in diameters was statistically significant ($p<0.00001$). There was no statistically significant difference between the maximal caval diameters of male and female patients (Table 1). The maximal diameter of the IVC was oriented in a transverse plane with the exception of the middle levels in patients with AAA. In these patients, the mid-cava was deformed by the AAA, so that the relationship of the maximal and minimal diameters was reversed when compared with patients without AAA. With the exception of the cava at the level of the confluence of the iliac veins, the dimensions of the IVC in patients with AAA did not differ significantly from those without aneurysms (Table 2). The single patient with a double cava had an average diameter left cava. The right cava was smaller, with a maximal diameter of 8 mm. Conventional contrast cavography was not obtained in any patients.

Discussion

Inferior vena cava and renal vein anatomy is clinically important. Meier et al. [16] described a patient with left-lower extremity deep vein thrombosis in whom a duplicated cava was not recognized until 72 h after a filter had been placed in the right cava. A second filter was then placed in the left IVC in order to provide adequate protection from pulmonary embolism [16]. Malden et al. [8] noted that in 110 patients undergoing cavography prior to IVC filter placement, renal vein variants diagnosed by selective renal venography resulted in a change in the final location of the filter in 16%. During surgery, unsuspected variant left renal veins can be traumatized easily during retroperitoneal dissections [17].

IVC and left renal vein variants are not noted as often during routine cross-sectional imaging of the abdomen as during conventional cavography or renal venography [2–4, 8, 12, 13, 18–20]. Selective renal venography is far superior to cavography in the detection of renal vein variants; in one study, cavography missed 70% of the renal vein variants detected by subsequent selective venography [8]. However, selective renal venography is not uniformly performed when evaluating the IVC prior to filter placement. For these reasons, the incidence of renal vein variants in some clinical practices may appear falsely low. An awareness of the incidence of these variants at MR angiography of the abdomen may improve recognition with other imaging techniques.

The overall 20% incidence of renal vein anomalies in our study is lower than the 30%–33% incidence detected at renal venography and in some anatomic studies [2, 3, 8]. This disparity is attributable to differing incidences of multiple right renal veins: 8% in our study versus 11%–28% in other studies [2, 8]. Small supernumerary right renal veins that could be detected by selective renal venography may not have been visible on the MR angiograms due to the 256 × 256 pixel matrix. In comparison, multiple right renal veins are rarely described in studies based upon CT and US [10, 13, 19].

The incidence of circumaortic left renal veins varies from 1%–11% in the imaging literature [2, 8, 12, 13, 19]. Autopsy studies report a 2%–17% incidence of circumaortic left renal veins. [2]. The 5% incidence reported in our series is in keeping with these studies. In contrast, the surgical literature suggests that circumaortic left renal veins are less common. Hoeltl et al. [19] detected circumaortic left renal veins in only 1% of 186 consecutive patients undergoing surgical procedures on the left kidney. In a series of 385 consecutive left donor nephrectomies, Yang et al. [21] did not report any circumaortic left renal veins. Perhaps varying methodologies and selection biases between the autopsy and surgical series can account for the differing incidences of circumaortic left renal veins. It would seem unlikely that intraoperative dissections in living individuals are equivalent to autopsy dissections.

The 7% incidence of retroaortic left renal veins in our study is greater than the 1%–3% incidence reported in the anatomic, conventional venographic, cross-sectional imaging, and surgical literature [3, 9, 12, 13, 19, 21]. Perhaps retroaortic left renal veins are more common than previously thought. However, the disparity may be attributable to our imaging technique. For example, very small preaortic veins in some of the patients in whom we diagnosed retroaortic left renal veins may have been obscured due to volume averaging or limited resolution.

The length of the infrarenal cava in patients with left renal vein variants has not been well described [2–4, 8, 12, 13, 18–20]. In our study, the infrarenal IVC was shorter in the presence of left renal vein variants than in patients with standard left renal vein anatomy. In patients with circumaortic left renal veins the length of the cava below the lowest left renal vein averaged 76 mm, whereas the mean length of the IVC below the insertion of retroaortic left renal veins was only 46 mm. One retroaortic vein inserted into the IVC just 17 mm above the confluence of the iliac veins. The length of the IVC below circumaortic or retroaortic left renal veins is an important consideration when placing an IVC filter. For example, the Bird's Nest filter, which is usually 60–70 mm long after deployment, may be too long for infrarenal placement in some patients with these renal vein variants [22]. The tip of a short filter, such as the Simon Nitinol, could prolapse into the renal vein orifice if placed below the circumaortic left renal vein [22, 23]. Alternative locations for filter placement in these patients include both common iliac veins or the suprarenal IVC [22].

The low incidence of duplicated cavae (0.7%) in our study is consistent with the experience of other investigators who note an incidence of 1%–3% [4, 9, 12, 13, 18, 19]. Similarly, the absence of any patients with a single left-sided IVC is also consistent, as this has been reported to occur in fewer than 1% of individuals [4, 9, 12, 13, 18, 19].

The incidence of megacava in patients with thromboembolic disease has been estimated to be 2%–3%, based upon the measurement of *in vivo* stainless steel Greenfield filters from abdominal plain films, and of the IVC at cavography [5, 6]. In our study, there were no IVCs that exceeded 28 mm in diameter in the mid portions of the infrarenal cava in 150 patients. This absence of megacavae may be attributable to the fact that none of our patients were studied for thromboembolic disease, in which acute right heart failure may distend the cava. Furthermore, imaging was performed over 3 min 18 sec so that variations in caval size due to respiration may have been averaged [24]. Limitations of prior studies include magnification errors at cavography [8] and possible overestimation of the incidence of megacavae if filter legs have penetrated the wall of the IVC [6]. The results of the present study imply that megacavae may be unusual in patients without thromboembolic disease.

The cross-sectional profile of the cava in this study was rarely circular, but was rather consistently ovoid in shape (Table 1). This may have practical implications, for many filter designs are intended to result in a circular caval profile after deployment [25]. A filter that exerts a low radial force at small diameters may not expand properly if deployed into the lateral recess of an oval-shaped cava. This mechanism may explain why the legs of the titanium Greenfield filter cluster to one side of the IVC in some patients [26]. However, the cross-sectional shape of the cava in patients with thromboembolic disease may be different.

There are several important limitations of this report. First, patients were only included if a gadolinium contrast agent was used during MR aortography; none of these patients were studied primarily to evaluate the IVC or renal veins. Second, only one MR angiographic sequence was performed, without correlation with a 'gold standard' modality such as cavography. The sensitivity and specificity of contrast-enhanced MR angiography for the identification of the various IVC and renal vein anomalies in this study cannot be calculated.

An awareness of the types and incidences of IVC and renal vein variants is important for all individuals involved in abdominal imaging and vascular intervention. We do not advocate MR angiography as a routine staging modality prior to IVC filter placement. Further studies are needed to determine the cost effectiveness and the sensitivity and specificity of this technique in the evaluation of the IVC.

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