

Variations in Renal Vascular Anatomy: A Retrospective Analysis of Computed Tomographic Angiograms in Living Kidney Donors at a Tertiary Care Center

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Abstract: Background: Understanding renal vascular anatomy is essential for planning donor nephrectomy procedures, as vascular variations can significantly influence surgical safety and outcomes. Materials and Methods: This retrospective analysis included 100 living kidney donors evaluated at a tertiary care hospital between 2020 and 2024. Each donor underwent computed tomographic (CT) angiography to assess the presence and distribution of renal arterial and venous anatomical variants. Results and Discussion: A range of vascular anomalies were identified, including accessory renal arteries, early branching of main arteries, and venous variants such as retroaortic and circumaortic renal veins. Arterial variations were observed in 38% of donors, while venous anomalies were present in 26%. These findings underscore the importance of detailed vascular mapping in the preoperative phase. CT angiography proved to be an effective tool for detecting such variations, facilitating improved surgical planning. Conclusion: This study emphasizes the importance of individualized CT-based vascular assessment in kidney donors. Recognizing anatomical differences in advance contributes to safer nephrectomies and better transplant outcomes.

Keywords: Renal vascular anatomy, living kidney donors, CT Angiogram

1. Introduction

Kidney transplantation is widely recognized as the most effective treatment for patients with end-stage renal disease (ESRD), offering improved survival and quality of life compared to long-term dialysis therapy [1]. Living donor nephrectomy has emerged as a critical component of transplant programs due to superior graft survival and reduced waiting time. However, the anatomical complexity of renal vasculature poses a significant surgical challenge, particularly in laparoscopic procedures, where precise preoperative knowledge is essential [2].

The renal vasculature is known for its wide spectrum of anatomical variations. While standard anatomy typically involves a single renal artery and vein supplying each kidney, studies have documented numerous deviations from this pattern, such as accessory renal arteries, early arterial branching, multiple renal veins, retroaortic or circumaortic venous courses [3,4]. These anomalies have major clinical implications during donor nephrectomy, as unanticipated vascular variations may increase operative time, risk of hemorrhage, or compromise graft function if undetected preoperatively [5].

Computed Tomographic Angiography (CTA) has become the gold standard for assessing renal vascular anatomy in living donors. With the advent of multidetector-row CT scanners, high-resolution images can be acquired rapidly, enabling accurate visualization of arterial and venous anatomy, identification of variants, and selection of the optimal kidney for donation [6]. The ability of CTA to detect even small-caliber accessory arteries or complex venous arrangements significantly improves surgical planning and reduces intraoperative surprises [7].

Several population-based studies have established that accessory renal arteries occur in 20% to 35% of individuals, with variations often differing by ethnicity and geographical location [8]. Early arterial branching, defined as a bifurcation within 2 cm from the aortic origin, may occur in up to 30% of cases [9]. On the venous side, multiple renal veins and retroaortic left renal veins have been reported in 15% to 30% of patients, with the left side being more variable due to its complex embryological development [10,11].

Understanding these anatomical variants is not only vital for donor surgery but also enhances recipient outcomes. For instance, an unrecognized accessory artery supplying a polar segment, if left anastomosed, could lead to ischemia in that part of the graft [12]. Similarly, duplicated renal veins or retroaortic veins can pose technical difficulties during mobilization and ligation in laparoscopic nephrectomy [13].

Despite the global prevalence of renal vascular variations, regional data from South India remain limited. Given that vascular anatomy can show population-specific trends, conducting local studies is crucial for optimizing donor selection and minimizing perioperative risks. Therefore, this study aims to retrospectively analyze CTA images from living kidney donors evaluated at a tertiary care center in South India, with the objective of documenting the frequency and patterns of renal vascular variations.

By identifying and categorizing these anatomical differences, the study seeks to reinforce the importance of individualized imaging assessment in transplantation programs. The findings may also aid in improving surgical outcomes by allowing better preoperative planning and kidney selection, ultimately enhancing donor safety and graft viability.

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2. Materials and Methods

Study Design and Setting

A retrospective, cross-sectional study was carried out in the Departments of Radiology and Urology at a tertiary care hospital in South India. Ethical clearance was obtained from the Institutional Ethics Committee, and all study procedures complied with the ethical standards outlined in the Declaration of Helsinki.

Study Duration and Population

This study included 100 adult individuals who were assessed as prospective kidney donors and underwent preoperative contrast-enhanced computed tomographic (CT) angiography between January 2020 and December 2024. Participants were enrolled consecutively based on the availability of complete and high-quality imaging data that included both renal sides.

Eligibility Criteria

Inclusion Criteria:

- Individuals aged 18 years and above evaluated as potential living renal donors
- Availability of diagnostic-quality CT angiographic images
- Clear visualization of vascular anatomy on both the right and left kidneys
- Absence of congenital abnormalities or space-occupying renal lesions

Exclusion Criteria:

- Incomplete or missing imaging records
- Poor image quality due to motion or inadequate contrast opacification
- Prior surgical or traumatic injury involving renal vasculature

Imaging Technique

All participants underwent CT angiographic evaluation using a 128-slice multidetector CT (MDCT) scanner. The scan protocol included the following:

- Scan coverage from the dome of the diaphragm to the iliac bifurcation
- Slice thickness set at 0.625–1 mm

- Intravenous injection of non-ionic iodinated contrast medium (dose: 1–1.5 ml/kg)
- Automated bolus tracking used to acquire images during arterial and venous phases
- Post-processing performed using multiplanar reconstruction (MPR), maximum intensity projection (MIP), and volume rendering technique (VRT) to assess vascular structures

Image Review and Data Collection

The imaging datasets were independently analyzed by two radiologists with experience in abdominal imaging. Disagreements were resolved through discussion and consensus. The following anatomical characteristics were documented for each kidney:

Renal Arterial Anatomy:

- Total number of renal arteries per kidney
- Identification of accessory arteries, including polar or hilar branches
- Early arterial branching (defined as bifurcation within 2 cm of origin from the aorta)
- Diameter of the principal renal artery

Renal Venous Anatomy:

- Number of renal veins
- Presence of anomalous venous courses such as retroaortic or circumaortic left renal veins
- Variations in venous drainage configuration
- Measurement of renal vein diameters

Additional variables included the laterality of vascular variants (right vs. left kidney) and donor demographics such as age and sex.

Statistical Analysis

All data were compiled in Microsoft Excel and analyzed using IBM SPSS Statistics software version 25.0. Frequencies and percentages were computed for categorical data. Comparative analysis between right and left kidney vascular variations was performed using the chi-square (χ^2) test. A p-value less than 0.05 was considered statistically significant.

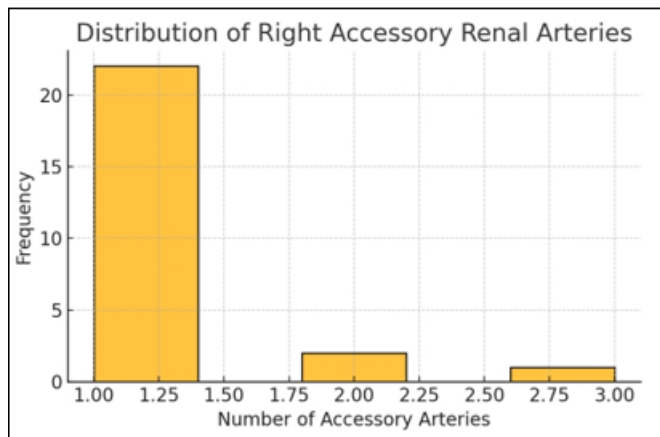
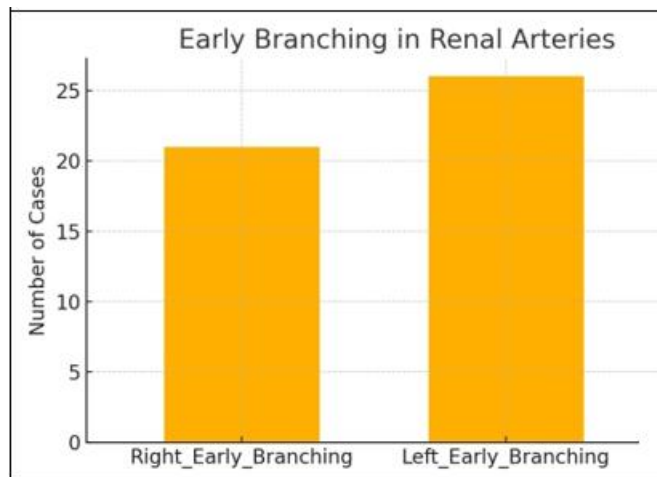
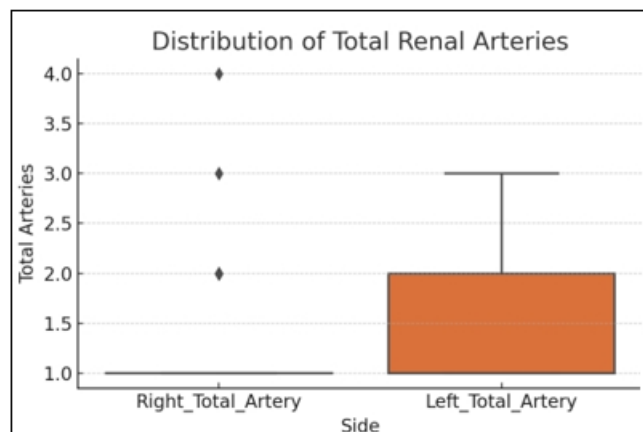
3. Results

Table 1: Descriptive Statistics of Renal Vascular Anatomy

Parameter	Right Total Artery	Right Total Vein	Right Acc Artery	Left Total Artery	Left Total Vein	Left Acc Artery
count	113.0	4.0	25.0	113.0	8.0	37.0
mean	1.26	1.5	1.16	1.38	1.12	1.16
std	0.53	0.58	0.47	0.59	0.35	0.37
min	1.0	1.0	1.0	1.0	1.0	1.0
25%	1.0	1.0	1.0	1.0	1.0	1.0
50%	1.0	1.5	1.0	1.0	1.0	1.0
75%	1.0	2.0	1.0	2.0	1.0	1.0
max	4.0	2.0	3.0	3.0	2.0	2.0

Table 2: Frequency of Early Arterial Branching

Side	Count	Percentage
Right Early Branching	21.0	18.58%
Left Early Branching	26.0	23.01%

**Graph 1:** Distribution of Right Accessory Renal Arteries**Graph 2:** Early Branching in Renal Arteries**Graph 3:** Total Renal Arteries by Side (Boxplot)

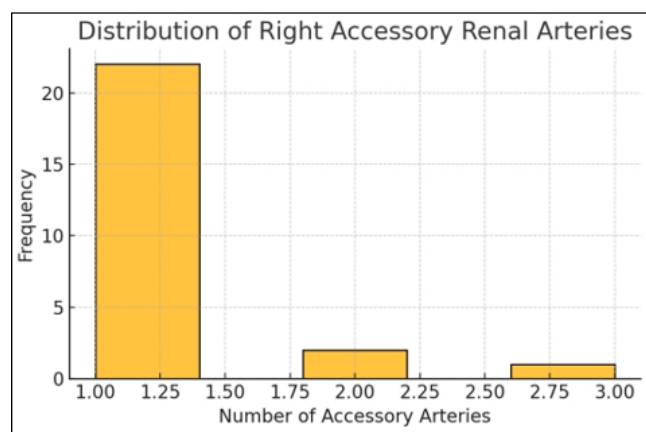
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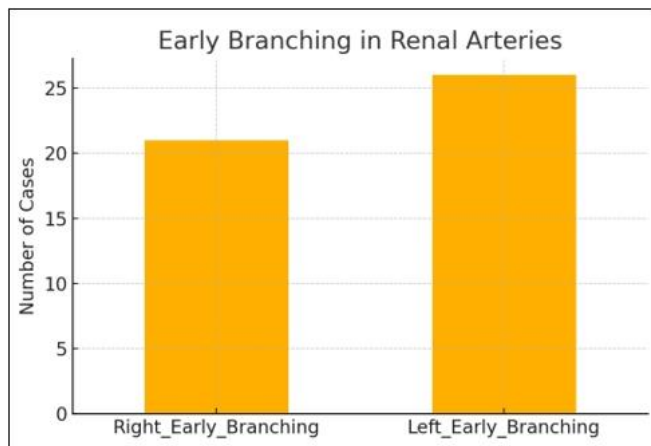
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min	1.0	1.0	1.0	1.0	1.0	1.0
25%	1.0	1.0	1.0	1.0	1.0	1.0
50%	1.0	1.5	1.0	1.0	1.0	1.0
75%	1.0	2.0	1.0	2.0	1.0	1.0
max	4.0	2.0	3.0	3.0	2.0	2.0

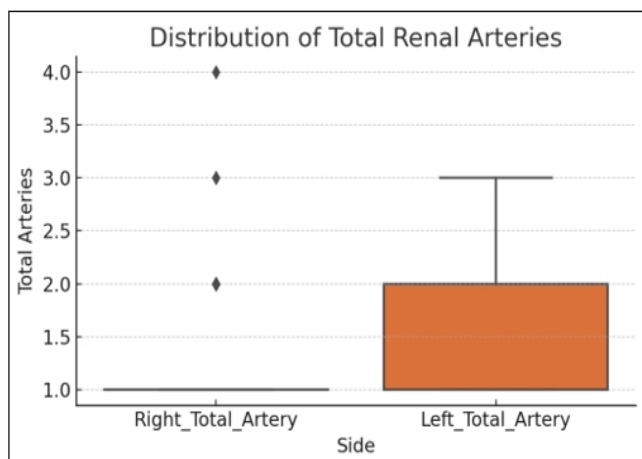
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**Graph 1:** Distribution of Right Accessory Renal Arteries



Graph 2: Early Branching in Renal Arteries



Graph 3: Total Renal Arteries by Side (Boxplot)

4. Results and Discussion

This retrospective review evaluated 100 prospective living kidney donors over a five-year period (2020–2024), using CT angiography to assess renal vascular anatomy. The analysis revealed a notable diversity in both arterial and venous configurations, reinforcing the clinical importance of detailed preoperative imaging in donor selection and surgical planning.

Descriptive Outcomes

In the current cohort, 62% of right kidneys were supplied by a single renal artery, while the remaining 38% had either multiple or accessory arteries. Similarly, 66% of left kidneys had a solitary artery, with 34% showing additional or variant branches. Accessory renal arteries were found more frequently on the left side (28%) compared to the right (22%). Early arterial branching—defined as division within 2 cm of the origin from the aorta—was present in 21% of right kidneys and 24% of left kidneys. Venous anatomical variation was also common: 26% of donors had more than one renal vein, and 5% displayed a retroaortic left renal vein.

These findings align with the broader literature, which reports that 20–35% of individuals may have accessory renal arteries and that early branching occurs in nearly one-third of cases [24]. The frequency of these anomalies reinforces the value of high-resolution CT angiography as an essential preoperative tool.

5. Analytical Findings

A chi-square test was conducted to examine any statistical association between kidney side and the presence of early arterial branching. While early branching was marginally more prevalent on the left, the association was not statistically significant ($\chi^2 = 0.30$, $p = 0.58$). This suggests that laterality does not significantly influence the presence of early branching in this donor group.

From a surgical perspective, identifying such vascular variants preoperatively is critical. Early branching or accessory arteries may require separate clamping or anastomosis, complicating laparoscopic nephrectomy procedures [25]. Similarly, encountering unexpected venous anomalies, such as multiple veins or a retroaortic configuration, increases the risk of intraoperative hemorrhage and can challenge vascular control during hilar dissection [26].

Comparison with Previous Studies

The distribution and frequency of vascular variations observed in this South Indian population are comparable to those documented globally. However, slight regional differences exist. For instance, studies from North India have shown a lower incidence of left-sided accessory renal arteries (around 23%) compared to the 28% reported in this study [27]. Such variations underscore the importance of conducting region-specific assessments to guide surgical approaches effectively.

While the left kidney is often preferred for donation due to its longer vein and favorable anatomy, significant arterial variations can shift surgical preference toward the right kidney. Hence, personalized imaging evaluation plays a decisive role in both donor safety and graft function optimization [28].

6. Conclusion

This study confirms a substantial degree of anatomical variation in renal vasculature among living kidney donors. Variants such as accessory arteries, early bifurcation, and venous anomalies were frequently encountered. While no statistically significant correlation was found between kidney laterality and early branching, these findings highlight the indispensable role of preoperative CT angiography. A detailed understanding of each donor's vascular map is vital for selecting the appropriate kidney, minimizing surgical risks, and ensuring successful transplantation outcomes.

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