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**CLINICAL SIGNIFICANCE OF ANATOMICAL VARIATIONS OF THE RENAL
ARTERIES IN DIAGNOSTIC IMAGING AND SURGICAL PRACTICE**

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Abstract

Renal arterial anatomy demonstrates considerable interindividual variability, and recognition of these anatomical patterns is essential in diagnostic imaging, kidney transplantation, partial nephrectomy, renovascular surgery, endovascular interventions, and other procedures involving the retroperitoneum. Although the classical anatomical pattern consists of a single renal artery arising from the abdominal aorta and entering the renal hilum, multiple renal arteries, polar arteries, early arterial branching, and unusual arterial origins are frequently encountered. The present study aimed to analyze the principal anatomical variations of the renal arteries and evaluate their clinical importance in modern diagnostic and surgical practice. A narrative literature review was conducted using published anatomical, radiological, and surgical studies focused on renal arterial variations, computed tomography angiography, donor nephrectomy, renal transplantation, and vascular reconstruction. The reviewed evidence demonstrates that accessory or multiple renal arteries are among the most common renal vascular variants and may occur in approximately one fifth to one third of individuals, although prevalence varies according to population and methodology. Computed tomography angiography provides highly accurate preoperative visualization of the renal vasculature and allows identification of the number, origin, course, branching pattern, and renal entry point of renal arteries. Multiple arteries and lower polar arteries are especially relevant during renal transplantation because they may require additional vascular reconstruction and may influence ureteral blood supply. Early arterial branching may also complicate vascular clamping and anastomosis. Therefore, detailed preoperative assessment of renal arterial anatomy is essential for reducing vascular and urological complications and optimizing surgical planning. Anatomical variations of the renal arteries should be regarded as clinically significant vascular patterns rather than rare incidental abnormalities.

Keywords: renal artery, anatomical variation, accessory renal artery, polar artery, computed tomography angiography, kidney transplantation, nephrectomy, vascular anatomy.



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INTRODUCTION

The kidneys receive approximately 20–25% of cardiac output and therefore possess a highly developed vascular network. In the classical anatomical pattern, each kidney is supplied by a single renal artery arising laterally from the abdominal aorta, usually at the level of the first or second lumbar vertebra. The right renal artery generally courses posterior to the inferior vena cava before reaching the renal hilum, whereas the left renal artery has a shorter and more direct course toward the left kidney. Before entering the renal sinus, the renal artery divides into anterior and posterior divisions and subsequently into segmental arteries.

However, this classical vascular pattern is not present in every individual. Variations in the number, origin, branching pattern, course, and renal entry point of renal arteries are common. Studies using multidetector computed tomography angiography and cadaveric dissection have demonstrated that multiple renal arteries may occur in a substantial proportion of the population. Published prevalence estimates commonly range from approximately 20% to more than 30%, depending on the population and classification system used [1–4]. In one computed tomography study, multiple renal arteries were identified in 31.3% of patients, whereas another study reported accessory renal arteries in 31.9% of examined individuals [3,4].

The development of renal arterial variations is closely related to embryological migration of the kidneys. During embryogenesis, the developing kidneys ascend from the pelvic region to their definitive lumbar position. During this process, they are successively supplied by transient arterial branches arising from the aorta. Normally, the lower vessels regress as new cranial arteries develop. Persistence of one or more embryonic arteries results in accessory, hilar, or polar renal arteries.¹

Traditionally, terms such as “accessory,” “supernumerary,” and “aberrant” renal arteries have been used to describe additional renal vessels. However, these arteries frequently provide an essential blood supply to a specific renal segment and should not be regarded as functionally insignificant. Polar arteries, particularly inferior polar arteries, may directly enter the renal parenchyma rather than passing through the renal hilum.

Recognition of these anatomical variations has become increasingly important because of the expansion of laparoscopic donor nephrectomy, kidney transplantation, partial nephrectomy, renal artery interventions, abdominal aortic surgery, and endovascular procedures. Failure to identify an accessory renal artery can lead to unexpected bleeding, renal segmental ischemia, infarction, or postoperative complications.

Modern multidetector computed tomography angiography (CTA) allows detailed three-dimensional assessment of renal vascular anatomy. It can demonstrate the number, origin, diameter, course, branching pattern, and point of entry of renal arteries and has become one of the principal imaging modalities used in preoperative donor assessment [1,5]. A large study of 2,144 living kidney donors demonstrated agreement between CTA and intraoperative findings regarding renal artery number in 97.9% of donors, indicating the high accuracy of the technique [5].

The purpose of this study was to review the principal anatomical variations of the renal arteries, their embryological basis, prevalence, radiological characteristics, and clinical significance, with particular attention to kidney transplantation, nephrectomy, and diagnostic imaging.

MATERIALS AND METHODS

A narrative review of the scientific literature was performed to evaluate anatomical variations of the renal arteries and their importance in diagnostic imaging and surgical practice. Scientific publications concerning renal arterial anatomy, accessory renal arteries, polar arteries, early arterial branching, renal computed tomography angiography, living kidney donation, donor nephrectomy, and kidney transplantation were reviewed.

¹ Mello Júnior C.F., Araujo Neto S.A., Carvalho Junior A.M., et al. Multidetector computed tomography angiography of the renal arteries: normal anatomy and its variations. *Radiologia Brasileira*. 2016;49(3):190–195.



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The literature included anatomical studies based on cadaveric dissection as well as radiological studies using computed tomography angiography and multidetector computed tomography. Studies assessing renal vascular anatomy in potential living kidney donors were given particular attention because donor assessment provides high-quality imaging of otherwise healthy renal vasculature.

The following characteristics were extracted from the reviewed literature: number of renal arteries, origin of additional arteries, hilar or polar entry, early branching pattern, prevalence of variations, laterality, diagnostic performance of CTA, and reported surgical implications.

The information was organized into four principal categories: normal renal arterial anatomy, multiple or accessory renal arteries, polar renal arteries, and early/pre-hilar branching. Clinical importance was evaluated in relation to transplantation, nephrectomy, partial nephrectomy, vascular surgery, and radiological assessment.

As this investigation was based exclusively on previously published literature and did not include intervention on human participants or collection of identifiable patient data, institutional ethical approval was not required.

RESULTS

The reviewed literature demonstrated substantial variability in the arterial supply of the kidneys. Although a single renal artery remains the most frequent arrangement, additional renal arteries are common and should be expected during radiological and surgical evaluation.

Studies based on multidetector computed tomography angiography have reported multiple renal arteries in approximately 19–32% of subjects. One large radiological study found multiple renal arteries in 31.3% of patients, including two renal arteries in 22.2%, three in 7.5%, four in 1.4%, and five in 0.2% [3].

In another cross-sectional study involving 188 patients, 31.9% demonstrated accessory renal arteries. Hilar accessory arteries were observed in 20.2%, polar arteries in 11.1%, and a capsular artery in 0.5% [4].

A study involving 2,144 living kidney donors found that 81.1% possessed a single renal artery, while 17.2% had two arteries, 1.6% had three arteries, and 0.1% had four arteries [5].

These differences indicate that prevalence depends on the population, sample size, imaging technique, and terminology used for classification.

Table 1. Major Anatomical Variations of the Renal Arteries and Their Clinical Importance

Anatomical variation	Main anatomical feature	Approximate reported frequency	Clinical importance
Single renal artery	One artery from the abdominal aorta to the renal hilum	Most common pattern	Simplifies donor nephrectomy and vascular anastomosis
Multiple renal arteries	Two or more arteries supplying one kidney	~19–31%	Additional dissection and vascular reconstruction may be required
Hilar accessory artery	Additional artery entering through the renal hilum	Variable	Important during transplantation and nephrectomy
Superior polar artery	Artery entering superior renal pole	Variable	Segmental ischemia may occur if damaged
Inferior polar artery	Artery entering inferior renal pole	Variable	May supply ureter; preservation can be important



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Anatomical variation	Main anatomical feature	Approximate reported frequency	Clinical importance
Early renal artery branching	Division close to the aortic origin	~6–13% in several studies	Reduces available arterial length for clamping or anastomosis
Unusual arterial origin	Renal artery arising outside the typical aortic level	Rare	Important in vascular and retroperitoneal surgery

Multiple renal arteries represent the most frequently encountered renal arterial variation. These vessels generally arise directly from the abdominal aorta but may occasionally originate from the iliac, mesenteric, or other nearby arteries. In a CT-based study of renal arterial anatomy, multiple renal arteries were found in 19.35% of kidneys [6]. The same investigation showed that the diameter of the principal renal artery was smaller when multiple arteries were present compared with kidneys supplied by a single artery. Multiple renal arteries should be considered functional end arteries. Because segmental renal arteries have limited collateral circulation, injury or ligation may cause ischemia or infarction of the supplied renal territory. Polar arteries enter the kidney directly through either the superior or inferior pole rather than through the renal hilum. Inferior polar arteries have particular surgical importance because of their close relationship with the renal pelvis and ureter. An inferior polar artery may contribute to the vascular supply of the proximal ureter. Consequently, accidental ligation during donor nephrectomy or transplantation may theoretically increase the risk of ureteral ischemia and subsequent urological complications. Polar vessels may also cross the ureteropelvic junction and can contribute to extrinsic compression in selected patients with ureteropelvic junction obstruction. Early or prehilum branching occurs when the renal artery divides relatively close to its origin from the abdominal aorta. Definitions vary among studies depending on the distance used to define early division. Early branching has been reported in approximately 6–13% of patients in several radiological series [2,3,7]. One study of living kidney donors reported early branching in 13.7% of right renal arteries and 10.5% of left renal arteries when branching within 25 mm of the aorta was used as the definition [7]. Early division is important in transplantation because it reduces the length of the main arterial trunk available for vascular clamping and anastomosis. Multidetector CTA was consistently described as an effective imaging method for evaluation of renal arterial anatomy. It allows multiplanar reconstruction, maximum-intensity projection, curved planar reconstruction, and three-dimensional volume-rendered images. CTA is particularly useful before living donor nephrectomy because accurate identification of accessory arteries, early branching, venous variants, and renal parenchymal abnormalities is required for operative planning. In the study of 2,144 living kidney donors, CTA and operative findings demonstrated identical renal artery counts in 97.9% of donors.² Three-dimensional volume-rendered images may be particularly valuable for understanding the spatial relationship between renal vessels, the aorta, inferior vena cava, kidney, and surrounding structures [1,2].

DISCUSSION

The present review demonstrates that renal arterial variations are common and have substantial clinical relevance. The concept of a single artery supplying each kidney represents an anatomical standard rather than a universal arrangement. From an embryological perspective, renal vascular diversity can be explained by the ascending development of the kidneys. During migration from the pelvis to the lumbar region, the kidneys receive arterial branches at different levels. Failure of regression of transient arteries leads to persistence of additional vessels. The most important clinical

² Arévalo Pérez J., Gragera Torres F., Marín Toribio A., et al. Angio CT assessment of anatomical variants in renal vasculature: its importance in the living donor. *Insights into Imaging*. 2013;4:199–211.



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implication is encountered in kidney transplantation. Living donor nephrectomy requires precise knowledge of arterial anatomy because the donor kidney must be removed with sufficient arterial length for implantation into the recipient. The presence of two or more renal arteries may require multiple anastomoses or arterial reconstruction. Current European Association of Urology guidance describes several reconstructive strategies for kidneys supplied by multiple arteries, including separate implantation, creation of a common arterial channel, or end-to-side reconstruction of a smaller artery to a main renal artery. Lower polar vessels may require specific preservation or revascularization.

Historically, kidneys with multiple renal arteries were sometimes considered less desirable for transplantation because of technical complexity. However, contemporary evidence indicates that such grafts can generally be used successfully. A 2023 patient-level meta-analysis involving thousands of living-donor transplant recipients found no significant difference in overall patient survival or graft survival between grafts with single and multiple renal arteries [8]. A newer systematic review and meta-analysis published in 2026 nevertheless found somewhat higher overall and vascular complication rates in multiple-artery grafts, demonstrating that the anatomy continues to create technical challenges even when long-term transplantation remains feasible [9].

These findings suggest that the presence of multiple renal arteries should not automatically exclude a kidney donor. Instead, detailed anatomical assessment and appropriate surgical planning are required. Renal artery variations are equally important in partial nephrectomy. Modern nephron-sparing surgery attempts to preserve as much functioning renal parenchyma as possible. Understanding segmental vascular anatomy allows selective arterial clamping and can reduce warm ischemia to uninvolved renal tissue. Accessory arteries also have implications for renal artery stenosis, renal denervation procedures, endovascular repair of aortic aneurysms, retroperitoneal lymph node surgery, and interventional radiology. During endovascular aortic repair, an accessory renal artery arising from the aorta may be located within the intended landing zone of a vascular graft. The potential consequences of covering such vessels depend on their diameter and the amount of renal parenchyma supplied. Renal arterial variations may also influence catheter-based renal denervation because accessory arteries and early branching can alter the distribution of periarterial sympathetic nerves and may limit catheter access. A CT-based study demonstrated that accessory arteries and early branching substantially influence the anatomical eligibility of patients for some renal denervation techniques [7].

The radiologist therefore plays a central role in preoperative planning. Radiological reports should not simply state that a variation is present. They should describe the number of arteries on each side, site of origin, diameter where clinically relevant, course, branching pattern, relationship to renal veins, and whether the vessel enters the hilum or renal pole.

Standardized terminology is also important. Terms such as “aberrant artery” may incorrectly suggest that a vessel is pathological or dispensable. In reality, many so-called accessory arteries provide the exclusive blood supply to a specific renal segment.

Table 2. Surgical Consequences of Major Renal Arterial Variations

Variation	Potential surgical problem	Recommended consideration
Multiple renal arteries	Multiple anastomoses, longer operating time	Preoperative CTA and vascular reconstruction planning
Inferior polar artery	Segmental ischemia or ureteral vascular compromise	Preserve or reconstruct clinically significant artery
Superior polar artery	Upper-pole ischemia after ligation	Assess supplied parenchymal territory
Early branching	Short arterial pedicle	Plan clamp position and anastomosis carefully



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Variation	Potential surgical problem	Recommended consideration
Small accessory artery	Difficult identification intraoperatively	Review thin-section CTA and 3D reconstructions
Unusual arterial origin	Unexpected bleeding or vessel injury	Detailed preoperative vascular mapping

Despite the advantages of CTA, limitations should be considered. Exposure to ionizing radiation and iodinated contrast material may restrict its use in selected patients. Magnetic resonance angiography may serve as an alternative in appropriate circumstances, although spatial resolution and availability may vary.

Another limitation of the existing literature is substantial variation in terminology and classification. Some studies classify all additional renal arteries as accessory arteries, whereas others distinguish hilar, superior polar, and inferior polar arteries. The threshold used to define early branching also varies. These inconsistencies make direct comparison between prevalence studies difficult.

Nevertheless, the overall evidence consistently demonstrates that renal vascular variants are sufficiently common to justify systematic evaluation before major renal procedures.

CONCLUSION

Anatomical variations of the renal arteries are common and clinically important. Multiple renal arteries, hilar accessory arteries, superior and inferior polar arteries, and early arterial branching represent the principal patterns encountered in clinical practice. Multidetector computed tomography angiography provides highly accurate visualization of renal vascular anatomy and plays a major role in preoperative evaluation, especially in living kidney donors. Identification of vascular variants before surgery can assist in selecting the appropriate kidney, planning vascular anastomoses, reducing intraoperative vascular injury, preserving renal perfusion, and minimizing postoperative complications. The presence of multiple renal arteries should not automatically be considered a contraindication to kidney donation or transplantation. Modern reconstructive surgical techniques allow successful transplantation of kidneys with complex arterial anatomy, although these variants may increase technical complexity.

Therefore, detailed knowledge of renal arterial anatomy and its variations is essential for anatomists, radiologists, urologists, transplant surgeons, vascular surgeons, and interventional specialists. Integration of anatomical knowledge with high-resolution vascular imaging remains fundamental to safe and effective renal surgery.

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