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Systematic Review

Anatomical Variations of Renal Arteries and Their Clinical Implications in Urological and Transplant Surgeries: A Systematic Review

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ABSTRACT

Anatomical variations of the renal arteries are frequent and can complicate urological and transplant procedures. However, contemporary evidence on their prevalence and clinical implications remains fragmented. **Objectives:** To systematically review studies published between 2019 and 2025 that report renal artery variants and evaluate their surgical impact in urology and transplantation. **Methods:** This review was conducted following PRISMA 2020 guidelines. A systematic search of PubMed, Scopus, and Cochrane identified original human studies reporting quantitative data on accessory arteries, early branching, or unusual origins. Fifteen eligible studies were included in the final synthesis. Risk of bias was assessed using the Joanna Briggs Institute checklist for imaging studies and the Newcastle-Ottawa Scale for surgical cohorts. Risk of bias across imaging and surgical studies was rated low to moderate based on JBI and NOS appraisal. **Results:** The prevalence of accessory renal arteries and early branching varied widely, ranging from 10% to over 30% across populations. A recent donor CTA study reported accessory arteries in 25.6% and early branching in 17%, while a contemporary Omani series found more than 30% of kidneys with multiple arteries. In transplant cohorts, grafts with multiple renal arteries achieved outcomes comparable to those with single arteries when appropriate reconstruction was performed. Microsurgical and vascular techniques have enabled the successful management of complex arterial anatomy without compromising graft function. **Conclusions:** Renal artery variations are common and clinically important. Preoperative CT angiography remains the gold standard for differentiating true multiple arteries from early branches, ensuring safe surgical planning.

INTRODUCTION

The anatomy of the renal arteries exhibits substantial variability beyond the classical single-artery paradigm, a fact that carries real implications for surgical and interventional management [1]. In many kidneys, accessory arteries or early branching patterns arise, altering surgical strategies in donor nephrectomy, kidney transplantation, partial nephrectomy, and endovascular interventions. Despite advances in imaging technology, reporting of prevalence and morphometry remains inconsistent across populations, hindering the establishment of universal guidelines [2]. Recent studies reinforce the importance of high-resolution vascular mapping. For example, Çetinok *et al.* documented accessory renal arteries in 25.6% and early branching in

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17% [3]. In Ethiopia, a computed tomography evaluation found that more than 30% of kidneys had supplementary arterial supply [4]. In the transplant setting, White *et al.* (2021) reported that grafts requiring arterial reconstruction in multiple-artery kidneys had comparable long-term outcomes to single-artery grafts [5]. Likewise, Rathi *et al.* (2023) observed no significant functional disadvantage in recipients of multi-artery grafts through one year [6]. Microsurgical techniques to manage accessory arteries have shown durable success in living-donor settings [7]. Given this evolving landscape, a focused synthesis of post-2019 evidence offers an opportunity to clarify prevalence, compare surgical implications, and highlight best practices.

The research question guiding this review was: Among human populations undergoing imaging or surgical evaluation (Population), what are the frequencies and patterns of renal artery variations (Intervention/Exposure), and how do these variations influence surgical and transplant outcomes (Outcome)? This systematic review, therefore, aims to collate and interpret the latest data on renal artery variations, examine their clinical consequences, and propose standardized approaches for imaging and surgery in urology and transplantation.

METHODS

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. A comprehensive literature search was performed across PubMed, Scopus, and the Cochrane Library to identify studies reporting anatomical variations of the renal arteries and their implications in urological and transplant surgery. The search covered publications from January 2019 to August 20, 2025. The Boolean and Medical Subject Headings (MeSH) search strategy was explicitly detailed as follows: (“Renal Artery”[MeSH] OR “Kidney Artery” OR “Renal Arteries” OR “Accessory Renal Artery”) AND (“Variation” OR “Anatomy” OR “Anatomical Variation” OR “Anomalies” OR “Early Branching”) AND (“Computed Tomography Angiography” OR “CTA” OR “Magnetic Resonance Angiography” OR “MRA”) AND (“Transplantation” OR “Urological Surgery” OR “Living Donor” OR “Renal Surgery”). Search filters were limited to human studies, English language, and publications between 2019 and 2025. Reference lists of relevant articles were manually screened to capture additional eligible studies. Abbreviations were defined at first use as follows: CTA (Computed Tomography Angiography), MRA (Magnetic Resonance Angiography), DRA (Double Renal Artery), TRA (Triple Renal Artery), and EB (Early Branching). Studies were included if they reported quantitative data on renal artery variants such as accessory arteries, early branching, or unusual origins; were conducted in human subjects using CTA, MRA, or direct surgical visualization; and described clinical or surgical implications relevant to donor nephrectomy or transplantation. Exclusion criteria comprised reviews, meta-analyses, case reports, pilot studies without quantitative data, and non-human research. Two reviewers independently screened titles and abstracts, followed by full-text evaluation using a standardized eligibility checklist. Disagreements between reviewers were resolved through discussion and consensus, and when disagreement persisted, a third senior reviewer adjudicated. Agreement between reviewers during study selection was quantified using Cohen's kappa statistic (κ = 0.82), indicating strong concordance. Data extraction was performed independently by two reviewers using a predesigned proforma capturing author, year, country, study design, imaging modality, prevalence, and clinical implications. Methodological quality was assessed using the Joanna Briggs Institute (JBI) checklist for cross-sectional imaging studies and the Newcastle-Ottawa Scale (NOS) for surgical or transplant cohorts. The overall risk of bias was graded as low, low to moderate, or moderate, based on sample representativeness, imaging clarity, and completeness of reporting (Figure 1).

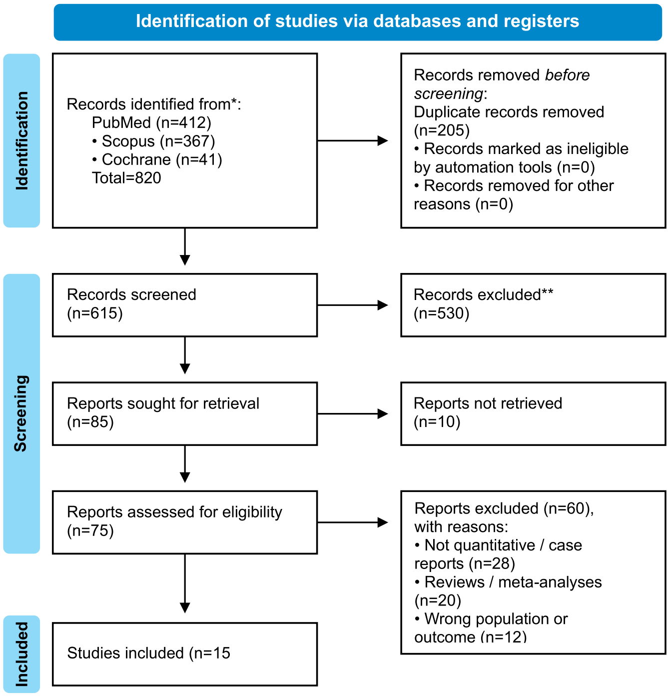

Figure 1: PRISMA 2020 Flow Diagram: PRISMA 2020 Flow Diagram of Study Selection for the Systematic Review of Anatomical Variations of Renal Arteries

RESULTS

The 15 included studies represented a diverse geographic distribution spanning Africa, Asia, Europe, and the Middle East. Most were cross-sectional radiological studies using Computed Tomography Angiography (CTA) or Multidetector CT (MDCT), while a subset involved surgical transplant cohorts. Sample sizes ranged widely, from 60 to 900 kidneys, reflecting heterogeneity in study design and population characteristics. Living-donor cohorts predominated, ensuring clinical relevance for transplantation. Other studies focused on general hospital populations or specific patient groups, such as resistant-hypertension cohorts and renal-denervation candidates. The consistent use of high-resolution imaging across studies supports the reliability of anatomical mapping, though variability in cohort type and sample size may influence external validity. This distribution provides a strong foundation for understanding anatomical variation across different populations and clinical contexts (Table 1).

Table 1: Characteristics of Included Studies

Sr. No.	References	Country/Region	Study Design	Sample Size (Kidneys/Arteries)	Population Characteristics	Imaging / Method
1	[8]	Nigeria	Radiological (CTA)	100 donors (200 kidneys)	Living kidney donors	CT angiography
2	[9]	India	Radiological (CTA)	90 pts (180 kidneys)	Adult hospital cohort	CT angiography
3	[10]	Iran	Radiological (CTA)	129 donors (258 kidneys)	Living kidney donors	CT angiography
4	[11]	Türkiye	Radiological (MDCT)	450 pts (900 kidneys)	Adults undergoing abdominal CT	MDCT angiography
5	[12]	Sudan	Radiological (CTA)	400 pts	Adults (202 M / 198 F)	CT angiography
6	[13]	Sudan	Radiological (CTA)	160 donors (320 kidneys)	Potential kidney donors	CT angiography
7	[14]	Romania	Radiological (CTA)	185 scans	Archived angio-CT files	CT angiography
8	[15]	Oman	Radiological (CTA)	128 pts (256 kidneys)	Adults 2023–24	CT angiography
9	[16]	Bulgaria	Radiological (CTA)	240 pts	Resistant hypertension cohort	CT angiography
10	[17]	Germany	Surgical transplant cohort	212 grafts	LDKT recipients	Intra-op + preop imaging
11	[18]	India	Surgical transplant cohort	200 grafts	LDKT recipients	Intra-operative series
12	[19]	India	Radiological (CTA)	60 pts (120 kidneys)	Prospective adult cohort	CT angiography
13	[20]	Pakistan	Radiological (CTA)	61 donors (122 kidneys)	Living donor evaluation	CT angiography
14	[21]	Korea	Radiological (MDCT)	200 pts (NR kidneys)	Renal denervation candidates	MDCT angiography
15	[22]	Greece	Surgical transplant cohort	251 recipients	LDKT recipients (accessory polar artery sacrifice)	Surgical + imaging correlation

The prevalence of accessory renal arteries (ARAs) varied significantly, ranging from as low as 6 % to over 30 %, with an average rate of 20–25 % across studies. Laterality patterns often showed slightly higher prevalence on the left kidney, though some studies highlighted side-specific differences. The aorta was consistently identified as the dominant origin of ARAs, with rare variants arising from the iliac arteries. Anatomical subtypes included hilar arteries, which enter at the hilum, and polar arteries, which supply the upper or lower poles. Several studies reported early branching as an important variant, particularly relevant in donor surgery. Studies emphasized the critical distinction between "true" multiple renal arteries and false multiplicity caused by early short branching, underscoring the importance of precise radiological interpretation. Overall, these findings highlight wide anatomical variability across populations that must be considered during surgical and radiological planning (Table 2).

Table 2: Prevalence and Patterns of Renal Artery Variations

Sr. No.	References	Kidneys Examined	Single RA (%)	Multiple/ Accessory RA (%)	Laterality (R vs L)	Origin of Accessory Arteries	Type (Hilar / Polar)	Other Notable Variations
1	[8]	200	68	32	Slight ↑ left	Aorta	Hilar and polar reported	Early branching 18%
2	[9]	180	82	18	NR	Aorta	DRA 88.9%; TRA 11.1%	Pattern taxonomy detailed
3	[10]	258	83	R 15.5; L 17.1	L > R	Aorta	NR	NR
4	[11]	900	76	24	R 16.8; L 14	Aorta (rare iliac)	Hilar and polar	Early branching 7%
5	[12]	800	94	6	NR	NR	NR	Sex-stratified rates
6	[13]	320	57.5	25.6	Bilateral ARA 3.8%	Aorta	Hilar and polar	Early branching 17%; M > F
7	[14]	370	NR	"False MRA" from early short branching	NR	Aorta	Mimics hilar	Emphasizes distinction of true vs false MRA
8	[15]	256	76	24.22	NR	Aorta	Hilar and polar (incl. double unilateral)	NR

9	[16]	480	NR	Variants ↑ in resistant HTN	NR	Aorta	NR	Clinical correlation with HTN
10	[17]	212 grafts	71	29 (MRA grafts)	NR	Aorta	NR	Focus on VR outcomes
11	[18]	200 grafts	71	29	NR	Aorta	NR	Transplant outcomes by MRA vs SRA
12	[19]	120	NR	Correlates with the main RA diameter	NR	NR	NR	Diameter ↔ ARA presence
13	[20]	122	NR	Side-specific prevalence reported	R > L (example)	NR	NR	Also notes venous variants /incidental pathologies
14	[21]	200	NR	Anatomical variants quantified	NR	Aorta	NR	Variation impacts catheter positioning (RDN)
15	[22]	251 grafts	NR	Focus on accessory polar artery	NR	Aorta	Polar (sacrificed subset)	No adverse impact on long-term function when sacrificed judiciously

*RA – renal artery, ARA – accessory renal artery, DRA – double renal artery, TRA – triple renal artery, MRA – multiple renal artery, EB – early branching, HTN – hypertension, NR – not reported.

Across the included studies, anatomical variations of the renal arteries were consistently associated with increased surgical complexity rather than uniformly poor outcomes. In donor nephrectomy, the presence of multiple or early-branching arteries increased the need for additional anastomoses, potentially prolonging ischemic time. However, transplant outcome studies demonstrated that grafts with multiple renal arteries generally achieved comparable functional results to those with single arteries, provided that careful vascular reconstruction was performed. In urological and interventional contexts, the variants influenced operative strategy (Table 3).

Table 3: Clinical Implications (Urological and Transplant Relevance)

Sr. No.	References	Clinical Context	Reported Surgical Challenges	Reported Postoperative Complications	Authors' Recommendations
1	[8]	Donor nephrectomy	More anastomoses; potential ↑ ischemic time with MRA/early branching	NR	Pre-op CTA mandatory; map early branching/ARAs.
2	[9]	Urology & transplant planning	Complexities with DRA/TRA types during anastomosis	NR	Use clear taxonomy (DRA vs TRA; hilar vs polar) for planning.
3	[10]	Donor selection	Side choice influenced by ARA prevalence (L > R)	NR	Routine CTA mapping in donors.
4	[11]	Surgical/interventional	Early branching shortens the pedicle; bleeding risk	NR	Systematic MDCT survey (aorto-iliac to poles).
5	[12]	General urology	Lower ARA prevalence in females (cohort finding)	NR	Consider sex-based planning; CTA before major renal surgery.
6	[13]	Donor nephrectomy	ARA 25.6% and EB 17% affect graft selection/reconstruction	NR	Anticipate bilateral ARA (3.8%); plan reconstruction strategies.
7	[14]	Pre-op imaging QA	Early branching can be misread as "multiple RAs"	NR	Distinguish false MRA (short RA) vs true MRA on CTA.
8	[15]	General urology	24% ARA; double unilateral ARA examples	NR	Routine CTA characterization of variants.
9	[16]	Hypertension workup	Variants associated with resistant HTN (OR≈4.7)	NR	Consider renal vascular variants in refractory HTN evaluation.
10	[17]	Transplant surgery	Multiple anastomoses in MRA grafts	Outcomes comparable to single-artery grafts	MRA kidneys not a contraindication; tailored vascular reconstruction.
11	[18]	Transplant surgery	Possible longer operative/ ischemia time	Similar DGF/stenosis/ survival (per article)	Safe to use MRA kidneys with appropriate technique.
12	[19]	Surgical planning	Main RA diameter predicts likelihood of ARA	NR	Use RA diameter to anticipate complexity.
13	[20]	Donor evaluation	Variant mapping avoids intra -op surprises	NR	Standard CTA map in donors; note coexisting venous variants.
14	[21]	Interventional (RDN)	Arterial variants affect the catheter approach	NR	MDCT mapping before renal denervation.
15	[22]	Transplant surgery	Selective sacrifice of the accessory polar artery when needed	No adverse long-term impact on graft function	Judicious sacrifice is acceptable when reimplantation is not feasible.

*CTA – computed tomography angiography; MRA – multiple renal artery; EB – early branching; DRA – double renal artery; TRA – triple renal artery; DGF – delayed graft function; NR – not reported.

Most cross-sectional CTA studies were rated as low risk of bias due to robust imaging methodology and adequate sample

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sizes. Moderate concerns arose in smaller or more selective cohorts, primarily related to limited generalizability or retrospective design. Studies focusing on special populations also carry a moderate risk, as their findings may not translate directly to general populations or donor cohorts. The transplant cohort studies (Roth, Modi, Panis) were generally rated as low to moderately low risk: although retrospective and single-center in nature, they demonstrated strong clinical follow-up and outcome reporting, which enhances reliability. Overall, the body of evidence can be considered of moderate to high quality, with its greatest strengths in consistent imaging methodology and real-world transplant outcomes, but with some limitations in representativeness and reporting detail (Table 4).

Table 4: Risk of Bias Assessment of Included Studies

Sr. No.	References	Study Design	Appraisal Tool	Risk of Bias	Main Concerns / Notes
1	[8]	CTA, cross-sectional	JBI Prevalence	Low	Clear donor cohort, good imaging, adequate sample.
2	[9]	CTA, cross-sectional	JBI Prevalence	Low-Moderate	Modest sample, single center, taxonomy strong.
3	[10]	CTA, cross-sectional	JBI Prevalence	Low	Good sample size, donor population, reproducible CTA.
4	[11]	CTA, cross-sectional	JBI Prevalence	Low	Large sample, robust MDCT, minimal bias.
5	[12]	CTA, cross-sectional	JBI Prevalence	Low-Moderate	Sex distribution analyzed, but recruitment not detailed.
6	[13]	CTA, donor cohort	JBI Prevalence	Low	Well-defined donor group, clear CTA methodology.
7	[14]	CTA, cross-sectional	JBI Prevalence	Low-Moderate	Novel "false vs true MRA" distinction, but retrospective imaging.
8	[15]	CTA, cross-sectional	JBI Prevalence	Low	Adequate sample, contemporary Omani population, clear imaging.
9	[16]	CTA, cross-sectional (HTN cohort)	JBI Prevalence	Moderate	Resistant hypertension focus may limit generalizability.
10	[17]	Transplant cohort (surgical)	NOS Cohort	Low	Long-term follow-up, robust outcomes, strong validity.
11	[18]	Transplant cohort (surgical)	NOS Cohort	Low-Moderate	Single-center retrospective, but outcomes well reported.
12	[19]	CTA, prospective cross-sectional	JBI Prevalence	Low	Prospective design, correlation analysis, small sample size.
13	[20]	CTA, donor evaluation	JBI Prevalence	Low-Moderate	Small cohort, but donor selection well defined.
14	[21]	CTA, interventional planning	JBI Prevalence	Moderate	Specific to renal denervation cohort; not general population.
15	[22]	Transplant cohort (surgical)	NOS Cohort	Low-Moderate	Retrospective single center, but large recipient sample.

DISCUSSION

The synthesis of fifteen primary studies confirms that renal artery variations are common and clinically significant. Several large imaging cohorts outside the included set support this high prevalence while highlighting population-specific and methodological effects. Karayağız *et al.* from Türkiye reported vascular variants in 59.4 % of 1,073 donors, with multiple renal arteries (MRA) in 35.4 % and early division in 21.4 % values at the higher end of the current review range and above those seen in non-donor hospital cohorts [23]. In contrast, Regmi *et al.* observed moderate, mixed-pattern frequencies, aligning with mid-range estimates [24]. Beyond donor cohorts, whole-abdomen CTA studies demonstrate a left-sided predominance and frequent polar arteries, echoing the laterality trend summarized in table 2. A Palestinian CT series reported arterial variants in 31 % of patients, again with a left-side bias, consistent with several included studies [24]. Kumaresan *et al.* in Indian donor data characterized peri-hilar branching in detail, noting accessory arteries in 39.4 % and early division in 21.2 %, reinforcing that early branching must be distinguished from true multiplicity, the same interpretive caution raised by Jianu *et al.* [25, 14]. Kaushik *et al.* further supported broad morphological diversity and confirmed that such findings are not modality-specific but anatomically genuine [26]. Clinical implications are consistent across studies. In transplantation, MRA grafts have shown comparable outcomes to single-artery grafts when reconstruction is performed carefully. Garcia et al reported similar patient and graft survival despite longer operative times [27]. Tabbara *et al.* detailed techniques to create a single inflow orifice in MRA grafts, emphasizing that meticulous vascular reconstruction underpins success [28]. Kurz *et al.* demonstrated that donors with remnant kidneys containing MRAs maintain normal long-term renal function and blood pressure, paralleling recipient outcomes [29]. Likewise, Colucci *et al.* found preserved renal and cardiovascular health in donors, supporting expansion of anatomical acceptance criteria in modern donor programs [30]. Outside transplantation, arterial variants have procedural relevance across multiple specialties. In endovascular and ablative settings, Bartoli *et al.* proposed a semi-automatic CTA method for mapping perfusion territories to guide complex aortic procedures [31]. For oncologic surgery, Lv *et al.* linked accessory arteries to larger tumor size and higher Fuhrman grade, suggesting possible correlations between vascular anatomy and tumor biology [32]. Hypertension-related evidence also supports clinical importance. Wu *et al.* and Jing Li *et al.* found higher blood pressure and vascular remodeling among patients with ARAs, consistent with the resistant-hypertension signal in Naydenov *et al.* [16, 33]. Imaging advances continue to evolve: Liu *et al.* validated multimodal ultrasound for identifying accessory arteries in patients for whom contrast CTA is contraindicated [34]. Finally, Shi *et al.* reported individualized management strategies in robotic renal surgeries, reflecting the need for tailored arterial handling [35]. Across datasets, heterogeneity in prevalence reflects cohort composition and imaging rigor. Donor-only series (India, Türkiye) tend to report higher accessory and early branching rates due to detailed arterial-phase CTA protocols that detect smaller branches [25]. Large-field abdominal CT audits, such as Jalamneh *et al.* reveal mid-range prevalence with a persistent left-sided skew, compatible with the pooled findings here [36]. Technical studies further demonstrate how standardized reconstruction methods (e.g., pantaloon, Carrel patch, or side-to-side trunk creation) yield outcomes equivalent to single-artery grafts, underscoring that anatomical variation alone is not a contraindication for transplantation [28]. Overall, the evidence demonstrates that accessory renal arteries and early branching are frequent anatomical patterns with significant surgical implications. CTA provides the most reliable pre-operative assessment tool for differentiating true multiple arteries from early divisions, thereby improving surgical planning and reducing intra-operative risks. When such variations are accurately mapped and surgical techniques are appropriately adapted, patient outcomes are comparable to those with single-artery anatomy.

Most studies were single-center, cross-sectional, or retrospective, with variability in imaging protocols and sample characteristics. This restricts generalizability and prevents robust meta-analysis. Few datasets provided direct inter-regional comparisons or long-term non-transplant outcomes, representing an area for future improvement. Larger multicenter prospective studies using standardized imaging criteria are needed to refine prevalence estimates and improve risk stratification. Further research should explore the effect of vascular variants on minimally invasive and endovascular procedures, integrating tools such as 3D reconstruction, AI-assisted segmentation, and automated morphometry to enhance accuracy and safety.

CONCLUSIONS

Renal artery variation is the norm rather than the exception. Evidence from recent donor, imaging, oncologic, and hypertensive cohorts demonstrates that accessory arteries and early branching patterns are frequent and clinically significant. Transplant and major urological surgeries can be performed safely when pre-operative vascular mapping and meticulous reconstruction are undertaken. Donors retaining kidneys with multiple arteries show stable long-term renal function, and recipients achieve comparable graft outcomes. For interventional and hypertensive cases, recognition and management of accessory vessels may influence procedural success and blood-pressure control. Future work should prioritize multicenter, prospective designs using standardized morphometric parameters such as diameter, ostial height, and branch angle to refine risk prediction and procedural algorithms.

Authors' Contribution

Conceptualization: SK
Methodology: MAJ, ASB
Formal analysis: SK, AHK
Writing and Drafting: SK, TM, MAJ, SMTS, AHK
Review and Editing: SK, TM, MAJ, SMTS, AHK, ASB

All authors approved the final manuscript and take responsibility for the integrity of the work

Conflicts of Interest

All the authors declare no conflict of interest.

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