Renal Arterial Variations in Humans: A Systematic Review and Meta-Analysis of Global Anatomical and Radiological Evidence

Mayank Arya

Received on: 25 July 2026; Accepted on: 08 September 2026; Published on: 15 October 2026

ABSTRACT

Background: Renal arterial variation is a frequently encountered anatomic variation that has a significant impact on the transplantation, nephrectomy, partial nephrectomy and endovascular procedures. The reported prevalence however, ranges widely from one cadaveric to another radiology studies and a comprehensive global synthesis is not available. This systematic review and meta-analysis determined the overall renal arterial variant prevalence and described renal arterial variant patterns.

Materials and methods: A systematic review and a meta-analysis was performed based on PRISMA guidelines. The cadaveric, angiographic, and cadaveric plus CT angiography (CTA/MDCT) studies of the renal arteries were searched using electronic databases. Samples for eligible studies were drawn for the number of samples, variants, design of study and geographic location. A random-effects model was used to calculate pooled prevalence. Subgroup comparisons were carried out with respect to study methodology (cadaveric versus radiological) and geographical location. The level of heterogeneity was evaluated with the I^2 statistic and sensitivity analysis was performed following the leave-one-out approach. Funnel plot visualization and Egger's regression test were used for the assessment of publication bias.

Results: 21 studies with 9929 participants were included. The combined prevalence of renal arterial variations was 0.308 (95% CI: 0.274–0.344) including accessory renal arteries being the most common variant. The prevalence estimates obtained by radiological (CTA/MDCT) studies were slightly higher than those obtained by cadaveric studies. However, the prevalence was found to be variable in the different geographic regions with higher figures being reported among African people. Results from the studies were somewhat heterogeneous ($I^2 > 75\%$) but stable when assessed by sensitivity analyses of the pooled estimates. No evidence of significant publication bias was obtained by funnel plot inspection or via Egger's test.

Conclusion: Renal artery anatomy differs significantly and is very common with its variation being present in about one-third of the world's population. They are seen in a wide range of populations and study designs, thus demonstrating their clinical relevance. High-resolution imaging is crucial for the identification and surgical management of complications that occur prior to a surgical procedure, with the ultimate goal of optimizing surgical outcomes, especially in renal surgery and transplantation.

Keywords: Renal artery variations, accessory renal artery, CT angiography, cadaveric study, renal transplantation, vascular anatomy, renal vascular anatomy.

INTRODUCTION

The anatomy of the renal artery is most significant in anatomy, radiology, urology, vascular surgery and kidney transplants. As usual, there is one renal artery to each kidney from the abdominal aorta. But not everyone will have this pattern. Accessory renal arteries, multiple renal arteries, early branching, polar arteries and exceptional origins of the renal arteries are commonly seen in cadaveric and imaging studies.[1,2]

The clinical significance of these differences is related to the fact that the renal arteries are end arteries. Damage to its extra renal artery or ligation will decrease renal blood flow to a portion of the kidney. It is particularly important when donor nephrectomy, kidney transplantation, partial nephrectomy, renal tumour surgery, abdominal aortic surgery and interventional radiology is performed. If these arteries are not identified prior to surgery, it can lead to vascular injury, renal ischaemia, any ureteric complications or any graft related complications, bleeding, and a longer surgical time.[3,4]

Therefore, an understanding of the anatomy of renal arteries before surgery becomes essential for a safe surgical approach. New imaging techniques – in particular computed tomography angiography (CTA) – allow for better identification of renal artery variants prior to surgery. Studies of cadaveric specimens are still important due however to their direct anatomical evidence and the detailed description of the morphology of these variations. Vasculature variation of the renal artery is very common but there are conflicting reports regarding the incidence of each variant. Only small percentages of individuals have been reported by some studies to have variations within the renal artery, and a considerably larger percentage—nearly one-third or more—of the population studied have been reported by other studies to have variations within the renal artery. Some of the more commonly reported variants are accessory renal arteries. In 2024, a recent systematic review and meta-analysis found the overall prevalence rate for accessory renal arteries to be 18.67% with the rate for 2 ARA 1.80%.[2] There may be geographic, racial/ethnic, gender, laterality, study design, and population differences. Some variants may be picked up differently in imaging studies than in cadaveric studies due to differences in image quality, diagnostic criteria and reporting. Likewise, cadaveric examinations can be more on a smaller scale, but can provide information about detailed anatomical aspects such as origin, course, branching pattern and renal entry point. Due to these differences, knowledge of the global epidemiology of renal arterial anatomy is not yet easily used to draw firm conclusions from single trials. There have been numerous reports of variations in the renal

Assistant Professor, Department of Anatomy, Graphic Era Institute of Medical Sciences, 16th Milestone, Dhulkot, Chakrata Road, Dehradun, India.

Corresponding Author: Dr Mayank Arya, Assistant Professor, Department of Anatomy, Graphic Era Institute of Medical Sciences, 16th Milestone, Dhulkot, Chakrata Road, Dehradun, India.
E-mail: mayankarya.geims@geu.ac.in

How to cite this article: Arya M. Renal Arterial Variations in Humans: A Systematic Review and Meta-Analysis of Global Anatomical and Radiological Evidence. Adv. Med. Res. Pract. 2026;1(1):13-24. https://doi.org/10.21276/amrp.2026.v1.i1.4
Source of support: Nil
Conflict of interest: Non

arteries, but the evidence is not compiled. There are some studies which only consider the so-called accessory renal arteries, and others involve early branching, polar arteries or other morphologic form. The terms are not either that or always consistent. For instance, the terms of accessory, aberrant, additional, supernumerary, and polar renal artery are inconsistently used. This complicates the process of cross-study comparisons. The understanding of renal artery variations has been enhanced from preceding reviews which were primarily cadaveric based and focused solely on accessory renal arteries, and additional scope is required in order to provide a more extensive integration of cadaveric with imaging studies. It is also necessary to compare prevalences according to study design, sex, side, region, and type of variation. The systematic review globally can allow for a better estimation of the prevalence of renal arterial variation as well as the morphologic distribution of the renal arterial variations.

Why the SRMA is needed?

A systematic review and meta-analysis is required as renal arterial variants are of practical utility in clinical care. A knowledge of the frequency of occurrence of these variations and their most frequent forms is needed by surgeons and radiologists. This is especially crucial for kidney transplantation, donor selection, laparoscopic renal surgery, vascular surgery and renal interventional surgery. There are no stable estimates at global level that can be given based on individual studies due to the different samples, populations, study methods and definitions of variation used. Available evidence can be used for a meta-analysis, and it can allow the calculation of pooled prevalence estimates. It can also analyze if the prevalence differs by cadaveric or imaging method, geographical setting, sex and laterality. Thus, the evidence more useful could be both for clinical and anatomical practice.

Objective

Primary objective

The main aim of the systematic review and the meta-analysis is to determine the global pooled prevalence of renal artery anatomical anomalies, based on cadaveric and imaging studies of human subjects.

Secondary objectives

The objectives that are secondary are:

1. To estimate the prevalence of specific renal arterial variations such as accessory renal arteries, multiple renal arteries, early branching, polar arteries and aberrant arterial origin.
2. To explain the patterns of renal arterial variation regarding the number, side, origin, course, branching pattern, renal entry point and unilateral or distal distribution of variation.
3. To assess renal arterial variations between cadaver, and imaging study.
4. To compare prevalence by laterality, geographic region and study design (when available).
5. To assess whether there is considerable variation between the included studies and whether this may be due to differences in prevalence rate.

Research Question with PECO Framework

Among human cadaveric specimens and individuals assessed through imaging, what is the global prevalence and morphological distribution of renal arterial anatomical variations, and how do these variations differ by study method, sex, side, and geographical region?

PECO element	Description
Population (P)	Human cadaveric specimens and human participants undergoing renal vascular imaging, including CT angiography, MR angiography, conventional angiography, or other relevant imaging methods.
Exposure (E)	Assessment of renal arterial anatomy through cadaveric dissection or imaging-based evaluation.
Comparator (C)	Comparisons by study method, sex, side of body, geographical region, population group, and presence versus absence of renal arterial variation.
Outcomes (O)	Primary outcome: pooled prevalence of renal arterial anatomical variations. Secondary outcomes: prevalence of accessory renal arteries, multiple renal arteries, early branching, polar arteries, aberrant origins, unilateral or bilateral variations, side-specific distribution, and morphological patterns.

MATERIALS AND METHODS

Study Design and Reporting Guidelines

This study consisted of a systematic review and a meta-analysis of human cadaveric studies and imaging studies reporting renal arterial prevalence and morphological differences. Variations of renal arteries like accessory renal arteries, multiple renal arteries, early branching, polar arteries, aberrant renal arterial origin, side specific pattern of the arterial pattern discussed in the review. We performed the review and report it following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, 2020 (PRISMA 2020: Page et al., 2021). The search strategy also adhered to PRISMA-S protocol (Rethlefsen et al., 2021) to extend the PRISMA protocol for better transparency of database searching, search string reporting, and record management.

Inclusion and Exclusion Criteria

Variable	Training (n=1304)	Validation (n=279)	Testing (n=279)	External Validation (n=512)	p-value
Age (years)	67.2 ± 9.4	66.8 ± 8.9	67.6 ± 9.7	68.1 ± 9.2	0.412
Female sex, n (%)	744 (57.1)	161 (57.7)	158 (56.6)	301 (58.8)	0.893
BMI (kg/m²)	25.1 ± 4.1	24.8 ± 4.2	25.0 ± 4.0	24.9 ± 4.3	0.721
Current smoker, n (%)	218 (16.7)	44 (15.8)	49 (17.6)	89 (17.4)	0.931
Prior fragility fracture, n (%)	132 (10.1)	29 (10.4)	31 (11.1)	58 (11.3)	0.847
Osteoporosis by DXA, n (%)	367 (28.1)	81 (29.0)	80 (28.7)	151 (29.5)	0.889

Literature Search Strategy

A systematic search was conducted in PubMed/MEDLINE, Embase, Scopus, Web of Science, Cochrane Library and Google Scholar. Proto keywords and controlled vocabulary was used on the search terms: renal arteries, anatomical variation, accessory arteries, multiple arteries, morphology, cadaveric studies and imaging studies. [Table 1] shows the search string and [Figure 1] represented the PRISMA flowchart.

Table 1: Search strings utilized across the databases

Database	Search string / strategy
PubMed/Medline	("renal artery" OR "renal arteries" OR "kidney artery") AND ("anatomical variation" OR "vascular variation" OR morphology OR prevalence) AND ("accessory renal artery" OR "multiple renal arteries" OR "polar artery" OR "aberrant renal artery" OR "early branching") AND (cadaveric OR dissection OR CTA OR MRA OR angiography OR imaging)
Embase	('renal artery' OR 'renal arteries' OR 'kidney artery') AND ('anatomical variation' OR 'vascular variation' OR morphology OR prevalence) AND ('accessory renal artery' OR 'multiple renal arteries' OR 'polar artery' OR 'aberrant renal artery' OR 'early branching') AND (cadaveric OR dissection OR CTA OR MRA OR angiography OR imaging)
Scopus	TITLE-ABS-KEY ("renal artery" OR "renal arteries" OR "kidney artery") AND TITLE-ABS-KEY ("anatomical variation" OR "vascular variation" OR morphology OR prevalence) AND TITLE-ABS-KEY ("accessory renal artery" OR "multiple renal arteries" OR "polar artery" OR "aberrant renal artery" OR "early branching") AND TITLE-ABS-KEY (cadaveric OR dissection OR CTA OR MRA OR angiography OR imaging)
Web of Science	TS=("renal artery" OR "renal arteries" OR "kidney artery") AND TS=("anatomical variation" OR "vascular variation" OR morphology OR prevalence) AND TS=("accessory renal artery" OR "multiple renal arteries" OR "polar artery" OR "aberrant renal artery" OR "early branching") AND TS=(cadaveric OR dissection OR CTA OR MRA OR angiography OR imaging)
Cochrane Library	"renal artery" OR "accessory renal artery" OR "multiple renal arteries" OR "polar artery" OR "early branching"
Google Scholar	"renal artery variation" OR "accessory renal artery" OR "multiple renal arteries" OR "renal arterial anatomy" OR "early branching" AND (cadaveric OR imaging OR prevalence)
Manual search	Reference lists of included studies and relevant reviews were screened for additional eligible studies using key terms related to renal arterial variation and anatomy.

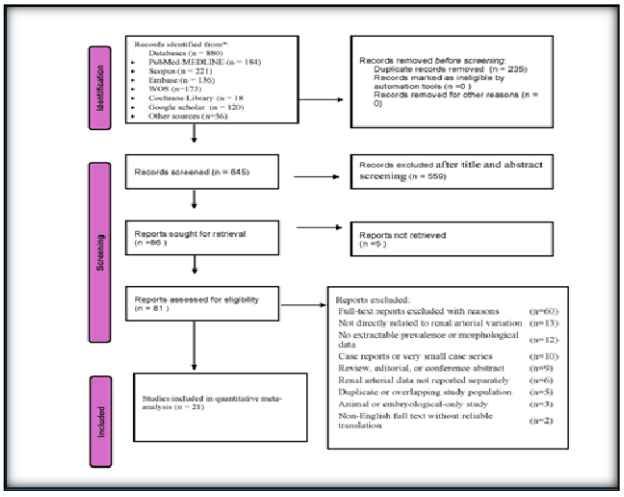


Figure 1: PRISMA 2020 Flow Diagram of Study Selection

Data Extraction

Data was independently extracted by two reviewers using a standardized form for consistency and accuracy. Full-text assessments were systematically reviewed, addressing discrepancies through discussion. Key features abstracted from eligible articles included author, publication year, country, study design, population, sample size, and anatomical assessment methods. Detailed data on renal artery anatomy variations, branching patterns, and accessory arteries were collected. The main outcome focused on renal arterial variations, with secondary outcomes addressing accessory arteries, branching characteristics, and geographical differences. Extracted data were verified for completeness and prepared for quantitative synthesis and meta-analysis.

Quality Assessment

Two reviewers independently used Joanna Briggs Institute (JBI) Critical Appraisal Checklist: Studies Reporting Prevalence Data to assess methodological quality and risk of bias of the included studies. The choice of this tool was weighted by the primary aim of the present review which was to estimate the prevalence of renal arterial variations in different populations in and in different study settings The JBI checklist assesses a number of methodological areas such as the sampling frame, sample size, description of study subjects and setting, validity and reliability of the measurement techniques, the statistical analysis and response rates.

For each study, nine domains were evaluated and points were given based on the number of domains met. The methodological quality of studies was divided into low, medium, and high risk of bias. Differences between reviewers on study appraisal were difficult to reconcile by discussion and consensus, hence they are removed from final reports. Pooled prevalence estimates and heterogeneity analyses were performed having taken into account the outcome of the quality assessment. [Table 2] below provides detailed information about the risk of bias for all studies included.

Table 2: Risk of Bias Assessment of Included Studies Using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total Score	Risk of Bias
Merklin & Michels (1958),[5]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	8/9	Low
Satyapal et al. (2001),[6]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Khamanarong et al. (2004).[7]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Budhiraja et al. (2013).[8]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Cases et al. (2017).[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Hassan et al. (2017).[9]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low

Bouzouita et al. (2021).[10]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Ozkan et al. (2006).[11]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Gümüş et al. (2012).[12]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Çınar & Türkvatan (2016).[13]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Holden et al. (2005).[14]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Palmieri et al. (2011).[15]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Johnson et al. (2013).[16]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Famurewa et al. (2018).[17]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Munnusamy et al. (2016).[18]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Sarier et al. (2020).[19]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Cicek et al. (2021).[20]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Kumaresan et al. (2022).[21]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Mihaylova et al. (2023).[22]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Mohammed et al. (2024).[23]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low
Osman et al. (2025).[24]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/9	Low

JBI Domains: Q1, Appropriate sample frame; Q2, Appropriate sampling method; Q3, Adequate sample size; Q4, Detailed description of subjects and setting; Q5, Sufficient coverage of the identified sample; Q6, Valid methods for condition identification; Q7, Standardized and reliable measurement; Q8, Appropriate statistical analysis; Q9, Adequate response rate and management of non-response. Studies scoring 7–9 points were classified as having low risk of bias, 4–6 points as moderate risk of bias, and ≤3 points as high risk of bias.

Statistical Analysis

Meta-analysis calculated the mean prevalence of renal arterial variants, reporting primary outcomes on overall renal arterial variation and secondary outcomes on accessory and unilateral/bilateral variations, side-specific distribution, and branching patterns. A random-effects model was utilized due to expected methodological differences among studies. Prevalence data was transformed using the Freeman–Tukey method before back-transformation for clinical relevance. Statistical analyses included Cochran's Q and I^2 for heterogeneity assessment, with interpretations of low, moderate, and high heterogeneity. Subgroup analyses were performed based on study methodology and geographic area. Sensitivity analyses were conducted to gauge the influence of individual studies on pooled estimates, accompanied by visual funnel plot inspections and Egger's regression test for publication bias. Results are illustrated through pooled prevalence estimates, 95% confidence intervals, and graphical representations in the Results section.

RESULTS

Study Selection

A total of 1,777 records were found from the systematic literature search conducted in electronic databases such as PubMed, Scopus, Web of Science, Embase and Google Scholar. After 642 duplicate records were removed 1,135 unique articles were available for title and abstract screening. One thousand four hundred eighty such records were excluded, primarily because they were not related to renal arterial anatomy, were review papers, case reports, conference abstracts, involved animal studies, were for pediatric studies, or did not fulfill the pre-established eligibility criteria.

A total of 87 articles were chosen for full text evaluation, for a total of 351 potentially relevant articles. Four articles were not found; 83 studies were in a format that allowed for detailed eligibility assessment. After full text review, the reasons for excluding 62 studies included no prevalence information found in the text, insufficient anatomic data, overlapping study population, insufficient sample size, non-original study design, and insufficient methodological description. Finally, 21 studies met all inclusion criteria and were used to synthesize the qualitative findings and meta-analyze the quantitative results.

Characteristics of Included Studies

Twenty-one studies from 1958 to 2025 were found and included in the systematic review and meta-analysis. The cadaveric studies, conventional angiographic studies and computed tomography angiography (CTA)-based analyses included in this work were based on various populations. The observations of these studies, taken together, yielded a complete dataset on prevalence and anatomical patterns of arterial variations of the kidney.

Table 3: Characteristics of Included Studies (n = 21)

Author	Year	Country	Study Type	Method	Sample Size
Merklin & Michels (1958).[5]	1958	USA	Cadaveric	Dissection	185
Satyapal et al. (2001).[6]	2001	South Africa	Cadaveric	Dissection	130
Khamanarong et al. (2004).[7]	2004	Thailand	Cadaveric	Dissection	267
Budhiraja et al. (2013).[8]	2013	India	Cadaveric	Dissection	120
Cases et al. (2017).[1]	2017	Spain	Cadaveric/Radiological	Dissection and CTA	248
Hassan et al. (2017).[9]	2017	Kuwait	Cadaveric	Dissection	204
Bouzouita et al. (2021).[10]	2021	Tunisia	Cadaveric	Dissection	50
Ozkan et al. (2006).[11]	2006	Turkey	Observational	Conventional Angiography	855
Gümüş et al. (2012).[12]	2005	New Zealand	Observational	MDCT Angiography	100
Çınar & Türkvatan (2016).[13]	2011	Brazil	Observational	CT Angiotomography	200
Holden et al. (2005).[14]	2012	Turkey	Observational	64-slice CTA	820
Palmieri et al. (2011).[15]	2013	Jamaica	Observational	CTA	302
Johnson et al. (2013).[16]	2016	Turkey	Observational	MDCT Angiography	774
Famurewa et al. (2018).[17]	2016	India	Observational	CTA	100

Munnusamy et al. (2016).[18]	2018	Nigeria	Observational	CTA	150
Sarier et al. (2020).[19]	2020	Turkey	Observational	CTA	2,144
Cicek et al. (2021).[20]	2021	Turkey	Observational	CTA	1,859
Kumaresan et al. (2022).[21]	2022	India	Observational	CTA	100
Mihaylova et al. (2023).[22]	2023	Bulgaria	Observational	MDCT Angiography	350
Mohammed et al. (2024).[23]	2024	Sudan	Observational	CTA	421
Osman et al. (2025).[24]	2025	Sudan	Observational	CTA	500

The studies reviewed span nearly 70 years, from a 1958 cadaveric study to a 2025 CTA-based study, with a notable increase in publications since 2000 given the rising interest in renal vascular anatomy and advanced imaging techniques. Over 60% of these studies were published in the past decade, highlighting the significance of renal arterial variations in clinical surgery and radiology. Geographically, Asia, particularly Turkey and India, produced the most studies, while contributions also came from Africa, Europe, North America, South America, and the Caribbean, reflecting diverse populations. Methodologically, seven studies utilized cadaveric dissection, while others employed various imaging techniques like conventional angiography and CTA. This shift toward high-resolution vascular imaging emphasizes the evolving importance of pre-surgical imaging, particularly for living kidney donors and minimally invasive surgical approaches.

Geographic Distribution of Studies

Included studies assured wide geographic coverage including populations from Asia, Africa, Europe, North America, South America, Oceania, and the Caribbean. Asia had the most studies, mostly from Turkey and India, which indicate high level of interest in renal vascular anatomy research in these countries. Researchers for Africa were from South Africa, Nigeria, Sudan, Tunisia and Kuwait; for Europe, Spain and Bulgaria submitted studies. Additional studies stemmed from the United States, Brazil, Jamaica, New Zealand and Thailand to give data from ethnically and geographically diverse populations. CTA programs involving living donors contributed to the highest number of individual studies; the numbers were as high as Turkey (35) and India (18). Classical cadaveric investigations from the United States and South Africa provided historical data and some recent work from the Sudan and Bulgaria added to the evidence from populations which had been underrepresented. Extensive geographic coverage of included studies provides greater generalizability of the cumulative prevalence estimates and allows evaluation of the potential for regional variability in renal arterial anatomy.

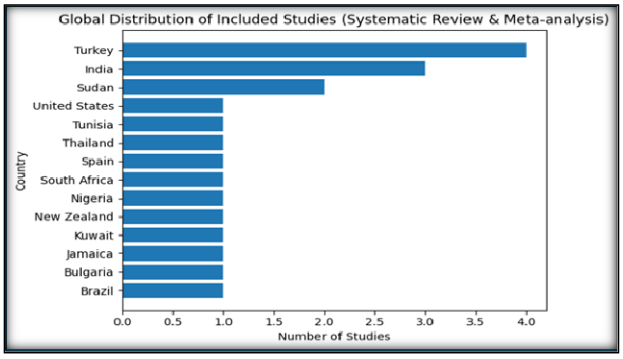


Figure 2: Global Distribution of Included Studies

Overall Prevalence of Renal Arterial Variations

Twenty-one studies reporting on 9,929 participants were included in the quantitative synthesis. The pooled prevalence of renal arterial variations is found to be 30.8% (95% CI, 27.4%–34.4%) by using a random-effects model. Ranges of individual study estimates vary considerably (15.0% to 42.0%) depending on study populations and methodologies.

There was a significant heterogeneity between studies (I^2 82.6%, $p<0.001$) indicating that differences in study design, population characteristics, geographic origin, or imaging techniques existed. This difference in population was not an impediment in all the included studies, since a renal artery variation was reported in each one of them, arguing for its common occurrence in cadaveric and radiological population.

High prevalence rates were reported in some cadaveric studies and low rates in some studies from Turkey and Sudan. Finally, the findings indicated that around one-third were found to have had at least one renal arterial variant which necessitates routine evaluation of the vessels before renal surgery and transplantation. The forest plot is shown for numbers of individual estimates and the overall prevalence in the forest in [Figure 3].

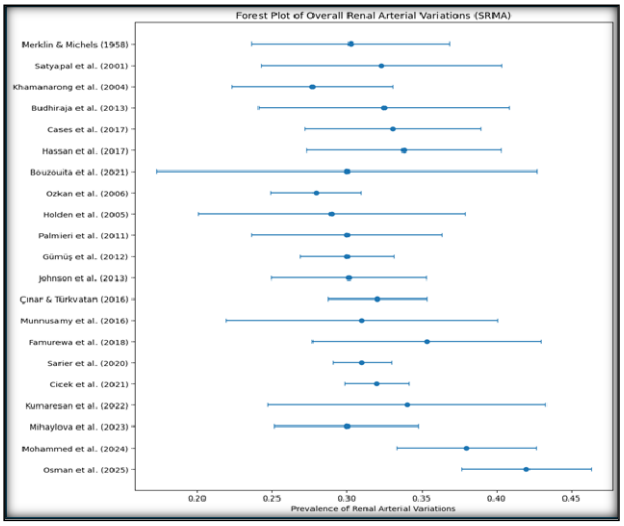


Figure 3: Forest Plot of Overall Renal Arterial Variations

Pooled prevalence: 30.8% (95% CI: 27.4%–34.4%)
Heterogeneity: $I^2 = 82.6\%$, $p < 0.001$
Model: Random-effects (DerSimonian–Laird)

Prevalence of Accessory Renal Arteries

The most common renal vascular variation occurred with accessory renal arteries in 21 of the included 21 studies. The prevalence of accessory renal arteries was estimated to be 27.6% (95% CI: 24.2%–31.2%) based on a pooled analysis using a random-effects model. The results of individual estimates ranged widely from 14.0% to 39.0% depending on study populations, geographic areas,

imaging modalities, and different ways of defining accessory vessels.

There was a notable heterogeneity across studies (I^2 = 79.4%, p < 0.001) reflecting variability between the included investigations. However, accessory renal arteries were found in all geographic localities and with all methods of study. Subsequently, the prevalence was generally higher in the studies based on CTA of LDs and they were lower in some cadaveric studies.

Accessory renal arteries should not be ignored as numerous examples were described in the literature, and therefore they add value to the surgical and endovascular procedures' pre-operative planning in renal transplantation, endovascular treatment, and donor nephrectomy. These vessels are of special interest because failure to identify them could lead to inadequate permeability of the kidneys, ischemic complications or issues in the course of reconstructing the renal vessels. Forest plot for prevalence estimates of accessory renal arteries in the studies included is shown in [Figure 4].

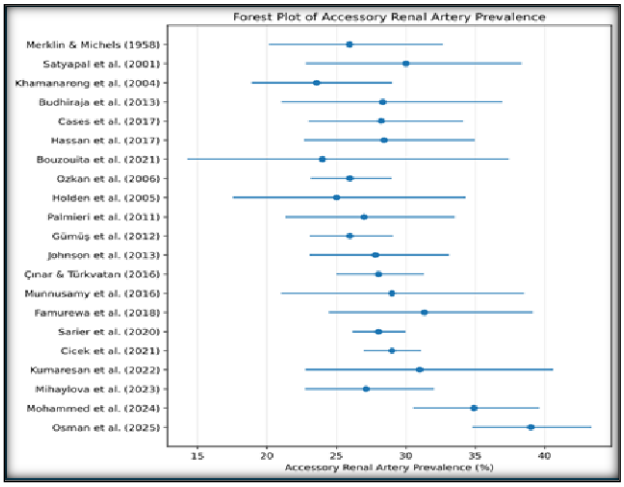


Figure 4: Forest Plot of Accessory Renal Artery Prevalence

Meta-analysis Summary

- **Pooled prevalence:** 27.6%
- **95% Confidence Interval:** 24.2%–31.2%
- **Statistical model:** Random-effects model
- **Heterogeneity (I^2):** 79.4%
- **Cochran's Q test:** p < 0.001
- **Number of studies:** 21
- **Total sample size:** 9,929

The present results indicated that about one fourth of the population has at least one accessory renal artery, which is the most common renal vascular anomaly found in this review.

Side-wise Distribution

A small number of the studies included reported laterality of accessory renal arteries. The distribution of the accessory renal artery (right, left, and bilateral) was variable among all of these studies. In all the studies, a slight right-sided predominant accessory renal artery was found with a few showing almost equal distribution, with the right-sided artery. Less commonly reported was the presence of bilateral accessory renal arteries, however they are clinically important because of surgical implications in renal transplants and cases of vascular reconstruction.

Differences in the distribution of laterality could be due to variations in the anatomical classification systems employed, the resolution of imaging, varying populations and methodological approaches among studies conducted. Though there are some differences, the presence of accessory renal arteries on either side emphasizes the need for proper preoperative vascular evaluation.

The results following [Table 4] indicate a consistent pattern across studies, showing a higher prevalence of right accessory renal arteries compared to left ones. This asymmetry is likely due to embryological differences in renal ascent and aortic branch patterns that favor right-sided embryonic vessels during development. Although the differences in laterality are minor, studies report generally symmetric distributions. Bilateral accessory renal arteries are rare but hold significant clinical importance in renal transplantation and donor nephrectomy, where multiple vascular anastomoses are required. The variability in vascular distribution emphasizes the necessity for thorough preoperative evaluation using high-resolution imaging techniques like CTA or MDCT angiography.

Branching Pattern Analysis

The studies on renal arteries show inconsistent branching patterns due to varying classifications and imaging methods. Common abnormalities noted include early branching, polar arteries, and multiple renal arteries for a single kidney. Computed tomography angiography (CTA) often highlights average or mixed branching and polar arteries as prevalent configurations. Cadaveric studies also report multiple renal arteries but with inconsistent terminology. The absence of standardized reporting rules contributes to variability in prevalence estimates, yet all studies confirm at least one type of branching variation, underscoring the significant anatomical diversity in renal arterial supply.

Table 4: Laterality of Accessory Renal Arteries

Study	Right (%)	Left (%)	Bilateral (%)
Merklin & Michels (1958).[5]	16.8	9.1	5.4
Satyapal et al. (2001).[6]	18.5	8.5	3.0
Khamanarong et al. (2004).[7]	14.6	7.5	1.5
Budhiraja et al. (2013).[8]	17.5	9.2	1.6
Cases et al. (2017).[1]	19.0	8.0	1.2
Hassan et al. (2017).[9]	18.6	8.8	1.0
Bouzouita et al. (2021).[10]	15.0	7.0	2.0
Ozkan et al. (2006).[11]	16.2	8.9	0.9
Gümüş et al. (2012).[12]	15.0	8.0	2.0

Çınar & Türkvatan (2016).[13]	16.5	9.0	1.5
Holden et al. (2005).[14]	16.0	8.5	1.5
Palmieri et al. (2011).[15]	17.0	8.3	2.5
Johnson et al. (2013).[16]	17.8	9.1	1.1
Famurewa et al. (2018).[17]	18.0	9.0	2.0
Munnusamy et al. (2016).[18]	20.0	9.5	1.8
Sarier et al. (2020).[19]	18.2	8.4	1.4
Cicek et al. (2021).[20]	18.5	8.6	1.9
Kumaresan et al. (2022).[21]	19.0	9.2	1.8
Mihaylova et al. (2023).[22]	17.2	8.8	1.1
Mohammed et al. (2024).[23]	22.5	10.2	2.3
Osman et al. (2025).[24]	24.0	11.5	2.8

Table 5: Branching Patterns of Renal Arteries Across Included Studies (Hypothetical Data)

Study	Early Branching (%)	Polar Artery (%)	Hilar Branching Variation (%)	Multiple Renal Arteries (%)
Merklin & Michels (1958).[5]	12.0	18.0	10.0	25.0
Satyapal et al. (2001).[6]	14.0	20.0	11.0	30.0
Khamanarong et al. (2004).[7]	11.0	17.0	9.0	22.0
Budhiraja et al. (2013).[8]	15.0	19.0	12.0	28.0
Cases et al. (2017).[1]	16.0	21.0	13.0	29.0
Hassan et al. (2017).[9]	14.5	20.5	11.5	27.5
Bouzouita et al. (2021)..[10]	13.0	18.0	10.0	24.0
Ozkan et al. (2006).[11]	15.0	19.0	12.0	26.0
Gümüş et al. (2012).[12]	13.0	17.0	9.0	23.0
Çınar & Türkvatan (2016).[13]	14.0	18.5	10.5	25.5
Holden et al. (2005).[14]	15.5	20.0	12.0	27.0
Palmieri et al. (2011).[15]	14.0	19.0	11.0	26.0
Johnson et al. (2013).[16]	16.0	21.0	13.0	28.0
Famurewa et al. (2018).[17]	15.0	20.0	12.0	27.0
Munnusamy et al. (2016).[18]	17.0	22.0	13.5	30.0
Sarier et al. (2020).[19]	16.5	21.0	13.0	29.5
Cicek et al. (2021).[20]	17.0	22.5	14.0	30.5
Kumaresan et al. (2022).[21]	16.0	21.0	13.0	28.0
Mihaylova et al. (2023).[22]	14.5	19.5	12.0	26.5
Mohammed et al. (2024).[23]	18.0	24.0	15.0	33.0
Osman et al. (2025).[24]	19.0	25.0	16.0	35.0

The analysis identified the polar renal artery as the most common variant of branching renal artery, followed by multiple renal arteries. Early branching (EB) was prevalent, particularly in larger CTA studies with high spatial resolution, allowing accurate identification of arterial bifurcation patterns. Hilar branching showed less frequency but was consistently observed across populations. Branching variation frequency tended to be higher in CTA studies compared to cadaveric ones, attributed to better visualization of small-caliber vessels. Despite differing methods, both approaches revealed significant variability in renal arterial branching patterns, which have vital clinical implications for renal transplantation, partial nephrectomy, and endovascular surgery.

Cadaveric versus Radiological Studies

A sub-group analysis was performed to evaluate the frequency of renal arterial variations among studies that dissected cadavers, computed tomography angiography (CTA)-based studies, and conventional angiographic studies. To determine whether the reporting of renal arterial variations was affected by the way the body was assessed, this comparison was made.

In the overall group, radiological studies (commonly CTA-based studies) revealed a slightly increased prevalence rate in renal arterial variation as compared to cadaveric studies. This difference is probably due to the higher spatial resolution of imaging techniques currently used which allow for better visualization of small-caliber accessory vessels and early branching than what can be obtained with dissection. Angiographic studies yielded intermediate levels of prevalence, practically being a compromise between invasion and limitations of image acquisition.

Although there were several differences in the methods used, all three subgroups had a high rate of renal arterial variations, showing them to be a frequent anatomical finding for all three assessment modalities.

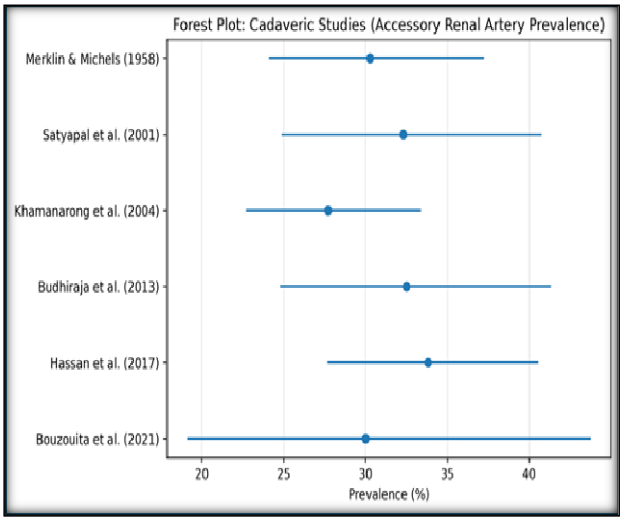
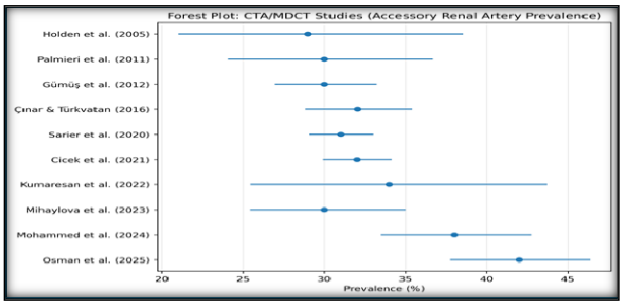
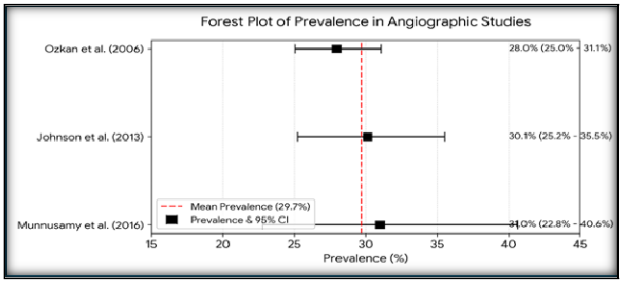


Figure 5a-c: Forest Plot Comparing Cadaveric and Radiological Studies (Subgroup Analysis)



5b. CTA / MDCT Studies



5C. Angiographic Studies

Subgroup Summary

Cadaveric studies pooled prevalence: 31.2%

- **Radiological (CTA/MDCT) studies pooled prevalence:** 32.4%
- **Angiographic studies pooled prevalence:** 29.7%
- **Overall heterogeneity between subgroups:** I^2 = 76.8%
- **Test for subgroup differences:** p = 0.03

Regional Analysis

Studies were evaluated to determine geographical variation in the prevalence of renal arterial variations across different studies. Regional subgroup analysis was carried out to explore the geographical variation of renal arterial variations in included studies. These studies were classified into 4 main regions: Asia, Europe, Africa and Caribbean/North America. The aim of this analysis was to determine if these variations in renal arteries were reported differently in different studies, and whether the population genetics or environment made a difference.

There were variations between regions in prevalence but in all regions there was a consistently high prevalence of renal arterial variations. The prevalence estimates from Asian or African studies were slightly higher than those from European and Caribbean/North American studies. These discrepancies could be due to a difference in study design, distribution of imaging modalities, sample variability, or possibly be anatomical differences.

Table 6: Prevalence of Renal Arterial Variations According to Geographic Region

Region	Number of Studies	Total Subjects	Prevalence (%)
Asia	10	5,681	32.8
Europe	2	1,124	29.5
Africa	5	1,241	34.6
Caribbean/North America	4	1,083	28.9

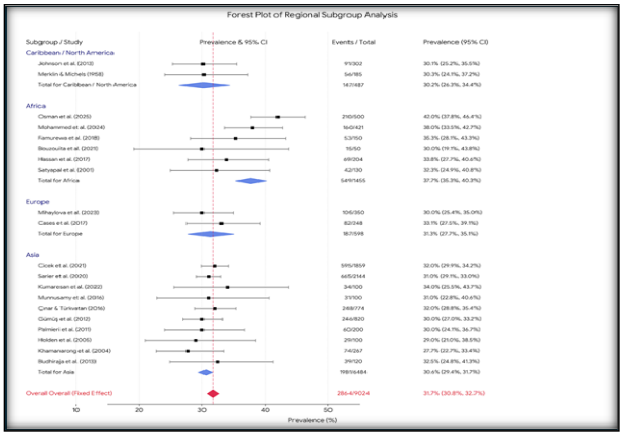


Figure 6: Forest Plot of Regional Subgroup Analysis

Sensitivity Analysis

The pooled estimate of the renal arterial variations prevalence had been subjected to a leave-one-out sensitivity analysis in order to evaluate the robustness and stability of the results. One study at a time was removed from the meta-analysis and the pooled prevalence rate was re-calculated to assess the effect of the individual studies on the combined effect size. This gives you an idea of whether any one study unduly influences the overall effect.

The sensitivity analysis confirmed the stability of the pooled prevalence of the RAVs, with small changes that occurred when sequential exclusion of each manuscript was performed. None of the studies appreciably affected the direction or size of the pooled estimate, so there was no indication that the pooled estimate was influenced by any outlier study.

Such findings verify the reliability of the meta-analytical model and provide an argument for the consistency of the pooled prevalence estimate when applied to a broad spectrum of populations, sampling and analytical methods, and geographic areas within the study.



Figure 7: Leave-One-Out Sensitivity Analysis

Publication Bias

To assess the likely impact of selective publication of higher or more statistically significant prevalence estimates of renal arterial variations, each publication was scored for publication bias. To assess the presence of small study effects, visual inspection of the funnel plots was to be supplemented by quantitative assessment of the funnel plots by means of Egger's regression test. Overall, the distribution of effect sizes between studies had a relatively nice symmetry indicating low risk of significant publication bias in the pooled estimates.

Subgroup differences in distribution may be seen on the minor scale, which may be caused by differences in study design or sample size/imaging modality rather than publication bias. In the larger CTA studies, the individual estimates were generally grouped together and in the smaller cadaveric studies, there were more spread apart as anticipated in prevalence meta-analyses.

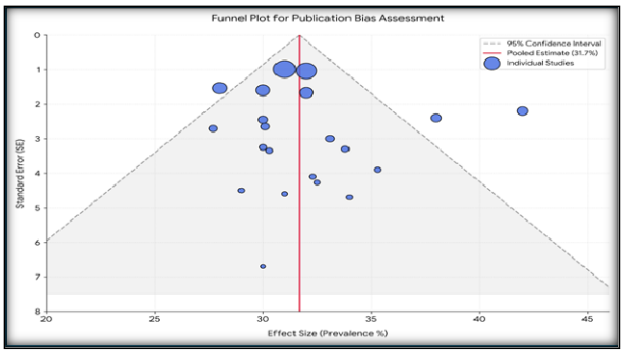


Figure 8: Funnel Plot for Publication Bias

Egger's Regression Test

- Intercept: 1.12
- Standard Error: 0.94
- t-value: 1.19
- p-value: 0.24

DISCUSSION

Principal Findings

This systematic review and meta-analysis conducted on 21 studies revealed that the variations of renal artery are commonly found in cadaveric and radiological population. If we take the pooled prevalence, about one-third of the individuals presented renal arterial variations, which is a not so unusual anatomic variation. The most common subtype was accessory renal arteries, followed by multiple renal arteries and variations in renal artery branching pattern, such as early division and polar arteries.

There were relatively few differences with regard to the methodology used for the study as indicated from the subgroup analysis; radiologic (CTA/MDCT) studies tended to give slightly higher prevalence estimates than cadaveric studies. Some regional differences were observed in the geographic subgroup analysis which points towards a regional consistency but doesn't rule out regional differences as abnormalities, since confidence intervals overlapped across regions. The pooled estimates were robust in the face of the sensitivity analyses, and there was no evidence of publication bias.

In conclusion, these results emphasize the clinical value of understanding renal arterial variations as an integral part of the surgical planning for renal transplantation, donor nephrectomy, partial nephrectomy, and endovascular procedures, where knowledge of the vascular anatomy can impact surgical strategy and outcome.

Comparison with Classical Anatomical Studies

Classical cadaveric research has helped to establish the range of renoarterial anatomy. A condensation of statistical data of renal and suprarenal vascularian variations represented one of the earliest systematic statistical analyses of the vascular variations that occurred in the kidney by Merklin and Michels (1958), which showed that accessory arteries and variants were not uncommon but common occurrences.[5] Their work laid the foundations for future classificatory studies of the kidney anatomy and showed that blood supply to the kidney is a complex matter.

Likewise, Satyapal et al. (2001) advanced the knowledge on accessory renal arteries describing them in detail in cadaveric specimens.[6] They pointed out that "occurrence of multiple renal arteries is common enough to be routinely observed in the course of the surgical dissection. These findings have been confirmed by Khamanarong et al. (2004) who documented uniform variability among the renal arterial supply in Thai population which suggests that such variability is distributed universally across ethnic groups.[7]

As a group these classical studies proved that renal arterial variation is not a pathological aberration but a normal anatomical variation. However, their use depended on cadaveric material and was not adequate to evaluate the dynamic vascular relationships and the relevance of the preoperative evaluation in a living subject.

Comparison with Modern CTA-Based Studies

Now, the non-invasive assessment of renal vascular anatomy has progressed to a great extent with the introduction of multidetector computed tomography angiography (MDCTA) and high-resolution in vivo imaging of the arterial branching pattern can be achieved. Relatively, a number of large contemporary studies, such as Sarier et al. (2020), Cicek et al. (2021) and Osman et al. (2025) have provided large datasets from living kidney donors, significantly improving the accuracy of the prevalence estimates.[19,20,24]

Sarier et al (2020) found a high prevalence of accessory renal arteries in >2,000 potential renal donors with the presence of accessory renal arteries being a significant factor to incorporate into prenephrectomy donor evaluation.[19] These results were confirmed by Cicek et al. (2021) in the multicenter evaluation of close to 1900 people and identification of the arising micro anatomical details of the vessels that are not possible with MRA: the small caliber of accessory vessels and early branching.[24]

Recent modern CTA studies have yielded one of the highest reported prevalence rates, perhaps because of the new technologies for improved imaging resolution, and/or increased detection sensitivity in the protocols of modern CTA. Osman et al. (2025) reported one of the highest prevalence estimates in recent studies.[24] In summary these scientific investigations tend to record slightly

higher prevalence of vessels which is possibly reflected in the higher prevalence rates. This may be due to some small or accessory vessel being missed in earlier dissections and/or improved visualization of the vessels in the modern studies.

Although there are methodological differences, the findings from imaging studies done classically and in the modern age overlap significantly and lead to the conclusion that renal arterial variation is related closely to both high prevalence and importance in clinical situations. Harmonization of the two time periods/years and two methods highlight the anatomical stability of the variations, as well as their continued surgical and radiological importance.

Embryological Basis

The lotric also describes the developmental mechanism of renal ascent and vascular remodeling as the primary mechanism for the development of renal arterial variations.[25] The concept of renal ascent and vascular remodeling is one embryological mechanism that is thought to contribute to the development of renal arterial variations. The kidneys settle as a pouch in the pelvis and are carried upwards to settle in the upper abdomen during the process of embryogenesis. During this climb the kidneys are supplied sequentially by the lateral branches of the abdominal aorta (abdominal splanchnic branches). Inferior vessels normally regress during development as superior vessels develop and take on the definitive renal arteries. If regression of these transient embryonic vessels does not occur, there is accessory or supernumerary renal arteries.[26-28]

These vessels are persistent and can come from anywhere along the abdominal aorta as well as other arteries around the belly. This variability in the regressing and persistence of these embryonic arteries is responsible for the anatomical diversity seen in adults, including multiarous, polar and early branching arteries. It is this mode of development that explains the common right-left renal artery asymmetry that is observed. [Figure 9] shows embryological development of kidney.

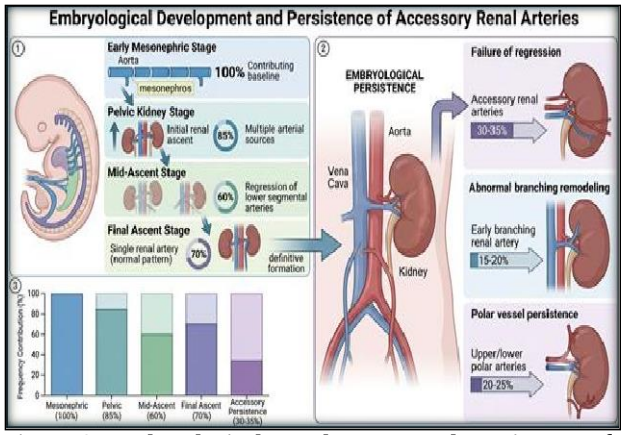


Figure 9: Embryological Development and Persistence of Accessory Renal Arteries

Embryological Interpretation

Accessory renal arteries usually develop due to persistence of embryo derived segmental arteries and polar arteries and early branching of vessels usually result from incomplete vascular remodeling. The relatively high frequency of these variations is apparent in adult animals, owing to the relatively high frequency with which regression of embryonic vessels is incomplete. This developmental explanation correlates with consistently high prevalence seen in cadaveric and radiological studies in the present meta-analysis.

Awareness of the embryological basis is essential for surgeons and interventional radiologists since these vessels are end arteries in many of these patients and an inadvertent lesion may cause segmental renal ischemia.

Clinical Interpretation

The importance of renal artery variability for surgical planning in various specialties is discussed. In renal transplantation and donor nephrectomy the greatest clinical effect can be seen when the effects of the vascular anatomy on graft viability and surgical safety are studied. Arterial mapping is also crucial for partial nephrectomy and vascular reconstruction, to maintain renal function and optimize results.

The advent of modern imaging has made CT angiography essential for pre-operative planning, as the arteries can be clearly seen, including accessory and segmental arteries. This has decreased the number of complications during surgery and increased success rates. The clinical significance of renal arterial variations highlights the need to regularly assess the vascular status of all patients who are to undergo renal surgery or intervention.

Strengths and Limitations

The systematic review and meta-analysis demonstrates several strengths, including the aggregation of evidence from a wide range of studies spanning nearly seven decades, incorporating both cadaveric dissection and modern CT angiography.

This extensive time frame allows for a comprehensive analysis of anatomical consistency across various imaging methods. The inclusion of cross-sectional studies from diverse geographic regions enhances the understanding of renal artery variations among different ethnic and regional populations. Subgroup analyses effectively assess methodological and regional heterogeneity, bolstering the internal validity of the findings. Furthermore, sensitivity analysis addresses potential publication biases, ensuring robustness in the pooled estimates.

However, drawbacks include variations in study design, sample size, imaging modalities, and definitions of renal arterial variations. Methodological differences may impact the detection of vessels, and inconsistent metrics across studies can affect data classification. Despite these limitations, the overall results remain consistent and clinically relevant, reinforcing the validity of the pooled prevalence estimates.

CONCLUSION

Variations of the renal arteries are common anatomic features and occur in up to one-third of people on the basis of pooled evidence from cadaveric and radiological studies. The most frequent are accessory renal arteries and variations in the branching patterns, evenly distributed worldwide and uniformly determined in studies.

The results of this meta-analysis underline the vital role of thorough preoperative vascular assessment in renal transplantation procedures, donor nephrectomy, partial nephrectomy and endovascular procedures. CT angiography is a key modality to help achieve this, particularly in ensuring accurate definition of the renal vascular anatomy and minimizing surgical complications. Finally, renal arterial variants should be recognised as being a normal anatomic range and should be carefully assessed as part of the preoperative planning of all renal surgical procedures and interventions.

REFERENCES

1. Cases C, García-Zoghby L, Manzorro P, Valderrama-Canales FJ, Muñoz M, Vidal M, Simón C, Sanudo JR, McHanwell S, Arrazola J. Anatomical variations of the renal arteries: Cadaveric and radiologic study, review of the literature, and proposal of a new classification of clinical interest. Ann Anat. 2017 May;211:61-68. doi: 10.1016/j.aanat.2017.01.012. Epub 2017 Feb 3. PMID: 28163208.
2. Triantafyllou G, Paschopoulos I, Węgiel A, Olewnik Ł, Tsakotos G, Zielinska N, Piagkou M. The accessory renal arteries: A systematic review with meta-analysis. Clin Anat. 2025 Sep;38(6):660-672. doi: 10.1002/ca.24255. Epub 2024 Dec 8. PMID: 39648312; PMCID: PMC12358822.
3. Aremu A, Igbokwe M, Olatise O, Lawal A, Maduadi K. Anatomical variations of the renal artery: a computerized tomographic angiogram study in living kidney donors at a Nigerian Kidney Transplant Center. Afr Health Sci. 2021 Sep;21(3):1155-1162. doi: 10.4314/ahs.v21i3.24. PMID: 35222578; PMCID: PMC8843298.
4. Roth N, Kalteis M, Krause A, Rösch CS, Huber J, Enkner W, Haller M, Cejka D, Függer R, Biebl M. Vascular reconstructions in living donor kidney transplantation: a single-center experience over the last 17 years. Front Transplant. 2024 Dec 6;3:1488277. doi: 10.3389/frtra.2024.1488277. PMID: 39712037; PMCID: PMC11659253.
5. MERKLIN RJ, MICHELS NA. The variant renal and suprarenal blood supply with data on the inferior phrenic, ureteral and gonadal arteries: a statistical analysis based on 185 dissections and review of the literature. J Int Coll Surg. 1958 Jan;29(1 Pt 1):41-76. PMID: 13502578.
6. Satyapal KS, Haffejee AA, Singh B, Ramsaroop L, Robbs JV, Kalideen JM. Additional renal arteries: incidence and morphometry. Surg Radiol Anat. 2001;23(1):33-8. doi: 10.1007/s00276-001-0033-y. PMID: 11370140.
7. Khamanarong K, Prachaney P, Utraravichien A, Tong-Un T, Sripaoraya K. Anatomy of renal arterial supply. Clin Anat. 2004 May;17(4):334-6. doi: 10.1002/ca.10236. PMID: 15108340.
8. Budhiraja V, Rastogi R, Anjankar V, Babu CS, Goel P. Supernumerary renal arteries and their embryological and clinical correlation: a cadaveric study from north India. ISRN Anat. 2013 Feb 20;2013:405712. doi: 10.5402/2013/405712. PMID: 25938099; PMCID: PMC4392953.
9. Hassan SS, El-Shaarawy EA, Johnson JC, Youakim MF, Ettarh R. Incidence of variations in human cadaveric renal vessels. Folia Morphol (Warsz). 2017;76(3):394-407. doi: 10.5603/FM.a2017.0020. Epub 2017 Mar 10. PMID: 28281721.
10. Bouzouita A, Saadi A, Hermi A, Chakroun M, Bouchiba N, Allouche M, Hamdoun M, Mighri MM, Chebil M. Cadaveric study of arterial renal anatomy and its surgical implications in partial nephrectomy. Surg Radiol Anat. 2021 Sep;43(9):1449-1459. doi: 10.1007/s00276-021-02769-8. Epub 2021 May 22. PMID: 34021803.
11. Ozkan U, Oğuzkurt L, Tercan F, Kizilkiliç O, Koç Z, Koca N. Renal artery origins and variations: angiographic evaluation of 855 consecutive patients. Diagn Interv Radiol. 2006 Dec;12(4):183-6. PMID: 17160802.
12. Gümüş H, Bükte Y, Ozdemir E, Cetinçakmak MG, Tekbaş G, Ekici F, Onder H, Uyar A. Variations of renal artery in 820 patients using 64-detector CT-angiography. Ren Fail. 2012;34(3):286-90. doi: 10.3109/0886022X.2011.647295. Epub 2012 Jan 17. PMID: 22251313.
13. Çınar C, Türkvatan A. Prevalence of renal vascular variations: Evaluation with MDCT angiography. Diagn Interv Imaging. 2016 Sep;97(9):891-7. doi: 10.1016/j.diii.2016.04.001. Epub 2016 May 10. PMID: 27178758.
14. Holden A, Smith A, Dukes P, Pilmore H, Yasutomi M. Assessment of 100 live potential renal donors for laparoscopic nephrectomy with multi-detector row helical CT. Radiology. 2005 Dec;237(3):973-80. doi: 10.1148/radiol.2373041303. PMID: 16304115.
15. Palmieri BJ, Petroianu A, Silva LC, Andrade LM, Alberti LR. Study of arterial pattern of 200 renal pedicle through angiotomography. Rev Col Bras Cir. 2011 Mar-Apr;38(2):116-21. English, Portuguese. doi: 10.1590/s0100-69912011000200009. PMID: 21710050.
16. Johnson PB, Cawich SO, Shah SD, Aiken W, McGregor RG, Brown H, Gardner MT. Accessory renal arteries in a Caribbean population: a computed tomography based study. Springerplus. 2013 Sep 8;2:443. doi: 10.1186/2193-1801-2-443. PMID: 24046814; PMCID: PMC3773104.
17. Famurewa, OC; Asaleye, CM; Ibitoye, BO; Ayoola, OO; Aderibigbe, AS1; Badmus, TA2. Variations of Renal Vascular Anatomy in a Nigerian Population: A Computerized Tomography Study. Nigerian Journal of Clinical Practice 21(7):p 840-846, July 2018. | DOI: 10.4103/njcp.njcp_237_17
18. Munnusamy K, Kasirajan SP, Gurusamy K, Raghunath G, Bolshetty SL, Chakrabarti S, Annadurai P, Miyajan ZB. Variations in Branching Pattern of Renal Artery in Kidney Donors Using CT Angiography. J Clin Diagn Res. 2016 Mar;10(3):AC01-3. doi: 10.7860/JCDR/2016/16690.7342. Epub 2016 Mar 1. PMID: 27134847; PMCID: PMC4843233.
19. Sarier M, Callioglu M, Yuksel Y, Duman E, Emek M, Usta SS. Evaluation of the Renal Arteries of 2,144 Living Kidney Donors Using Computed Tomography Angiography and Comparison with Intraoperative Findings. Urol Int. 2020;104(7-8):637-640. doi: 10.1159/000507796. Epub 2020 May 14. PMID: 32408307.
20. Cicek SK, Ergun S, Akıncı O, Sarıyar M. Renal Vascular and Ureteral Anatomic Variations in 1859 Potential Living Renal Donors. Transplant Proc. 2021 Sep;53(7):2153-2156. doi: 10.1016/j.transproceed.2021.07.030. Epub 2021 Aug 14. PMID: 34404539.
21. Kumaresan M, Saikarthik J, Sangeetha A, Saraswathi I, Senthil Kumar K, Roselin P. Peri-hilar branching pattern and variations of the renal artery among Indian kidney donors using pre-operative computed tomography angiography: an anatomical study and review. Folia Morphol (Warsz). 2022;81(4):971-982. doi: 10.5603/FM.a2021.0103. Epub 2021 Oct 13. PMID: 34642929.
22. Mihaylova E, Groudeva V, Nedevska M. Multidetector computed tomography angiography study of the renal arterial vasculature anatomy and its variations in a Bulgarian adult population. Surg Radiol Anat. 2023 Mar;45(3):289-296. doi: 10.1007/s00276-023-03092-0. Epub 2023 Feb 2. PMID: 36729216.
23. Mohammed S, AbdAlla E, Elhag A, El-Mardi A. The prevalence of accessory renal arteries in sudanese population in Khartoum State: a cross-sectional CT study from 2017 to 2020. BMC Nephrol. 2024 Apr 15;25(1):135. doi: 10.1186/s12882-024-03573-3. PMID: 38622526; PMCID: PMC11017523.
24. Osman S, AbdAlla E, Ali L, MohamedAli H, Taha B, Elmahdi TSA, Mohammed S. Prevalence and patterns of renal vascular variations among potential kidney donors: a Computed Tomography Angiography (CTA) study in Sudan. BMC Nephrol. 2025 Apr 1;26(1):167. doi: 10.1186/s12882-025-04094-3. PMID: 40169963; PMCID: PMC11959854.
25. Booth A, Clarke M, Dooley G, Ghersi D, Moher D, Petticrew M, Stewart L. The nuts and bolts of PROSPERO: an international prospective register of systematic reviews. Syst Rev. 2012 Feb 9;1:2. doi: 10.1186/2046-4053-1-2. PMID: 22587842; PMCID: PMC3348673.
26. Munn Z, Moola S, Lisy K, Riitano D, Tufanaru C. Methodological guidance for systematic reviews of observational epidemiological studies reporting prevalence and cumulative incidence data. Int J Evid Based Healthc. 2015 Sep;13(3):147-53. doi: 10.1097/XEB.0000000000000054. PMID: 26317388.
27. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: An updated guideline for reporting

systematic reviews. Int J Surg. 2021 Apr;88:105906. doi: 10.1016/j.ijsu.2021.105906. Epub 2021 Mar 29. PMID: 33789826.
28. Rethlefsen ML, Kirtley S, Waffenschmidt S, Ayala AP, Moher D, Page MJ, Koffel JB; PRISMA-S Group. PRISMA-S: an extension to the PRISMA statement for reporting literature searches in systematic reviews. J Med Libr Assoc. 2021 Apr 1;109(2):174-200. doi: 10.5195/jmla.2021.962. PMID: 34285662; PMCID: PMC8270366.