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Original Article

Anatomy Section

Anatomical Variations of Renal Arteries: A Cross-sectional Cadaveric Study from Rajasthan, India

NIKHIL SHARMA[1], HINA SHARMA[2], VIJAY KUMAR DAYMA[3], RASALIKA MIGLANI[4]

ABSTRACT

Introduction: Kidneys are retroperitoneal organs normally supplied by the paired renal arteries. Variations in renal arterial anatomy are clinically significant for renal transplantation, angiographic interventions, and urological procedures.

Aim: To evaluate the morphological patterns, incidence, and side-specific distribution of anatomical variations in renal arteries among the Rajasthan population.

Materials and Methods: The present cross-sectional cadaveric study was conducted at Pacific Medical University, Udaipur, Rajasthan, India, from March 2024 to April 2025. The study was conducted on 50 human anatomical embalmed kidney specimens of unknown age and sex. To assess variations in renal arterial branching, the Sampaio FJ and Passos MA (1992) classification was used. Specimens free from pathological changes, trauma, surgery, or malformations were dissected to expose renal arteries and pre-hilar branches without the use of dyes or imaging; observations were recorded separately for each side. The proportions of the different variations were calculated as frequency and percentages by using the Epi Info software,

Results: Out of 50 kidneys, a Single Renal Artery (SRA) was present in 11 cases (22.0%), whereas Multiple Renal Arteries (MRA) originating from the abdominal aorta was observed in 25 cases (50.0%). Double Hilar Arteries (DHA) was identified in 9 cases (18.0%), while no instances of triple hilar arteries were encountered. A combination of a hilar artery with a Superior Polar Artery (SPA) was recorded in 2 cases (4.0%), and a hilar artery with an Inferior Polar Artery (IPA) was noted in 3 cases (6.0%).

Conclusion: Knowledge of the differences in renal artery anatomy is essential for surgical procedures related to renal transplantation, abdominal aorta aneurysm repairs, urological operations, and angiographic interventions.

Keywords: Dissection, Kidney transplantation, Retroperitoneal organs

INTRODUCTION

The renal artery is the main artery that provides blood to the kidneys. It emerges as a lateral branch from the abdominal aorta at the level of the L1 vertebra, situated just below where the superior mesenteric arteries originate [1]. Once it arrives at the renal hilum, it splits into anterior and posterior branches, which subsequently divide into segmental arteries. Variations in the origin, quantity, branching patterns, and route of the renal arteries are quite common [2,3].

Renal artery variations are classified as aberrant, supernumerary, supplementary, accessory, and perforating. As noted by Sampaio FJ and Passos MA these arteries should be referred to as multiple, as they are segmental vessels that lack anastomoses among themselves [4].

Polar arteries supply either the superior or inferior poles of the kidneys without entering the renal hilum, while the hilar arteries pass through the hilum to provide blood to the kidney. Variations in renal arteries are frequently observed in the population, revealing social, ethnic, and racial differences in the prevalence of these variations [5,6]. A SRA is present in approximately 70% of individuals, while accessory renal arteries are found in around 30% of individuals; these can originate from the abdominal aorta either above or below the main renal artery and may occasionally arise from the coeliac plexus, superior mesenteric artery, or common iliac arteries [7].

An accessory renal artery supplying the inferior portion of the kidney may exert pressure on the ureter, resulting in obstruction and hydronephrosis. Variations in renal arteries are significant for surgical procedures such as renal transplants, urological and radiological interventions, management of renovascular hypertension, treatment for renal trauma, and cases of hydronephrosis [8,9]. Research has indicated that the human kidney is divided into five segments, each receiving blood from its own end artery, with no collateral circulation between them. A crucial point to consider during renal transplants is that any injury or ligation of the renal artery can cause renal infarction, due to this, proper and complete anastomosis of all the donor kidney's arteries is necessary [10]. The presence of MRA not only alters the kidney's shape but also impacts its blood flow dynamics; therefore, it is crucial to examine them closely for any vascular anomalies to prevent accidental damage [11]. It is important to consider renal artery variations when planning surgical procedures on the kidneys or when performing non-invasive diagnostic tests for renal artery stenosis [12].

Renal artery variations have critical epidemiological implications in India, influencing surgical planning, interventions, and regional health outcomes that may differ among ethnic groups. However, similar research in the Rajasthan population is scarce, making this study relevant given the state's ethnic diversity and potential genetic and environmental influences on vascular anatomy. With this background, the present study was conducted with aim to evaluate the morphological patterns, incidence, and side-specific distribution of anatomical variations in renal arteries among the Rajasthan population.

MATERIALS AND METHODS

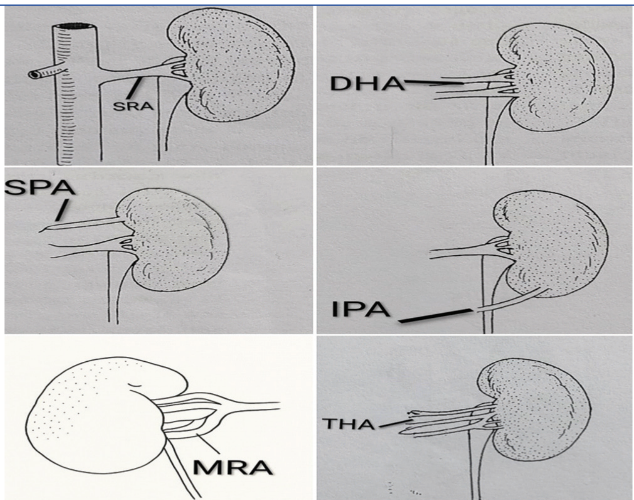
The present cross-sectional cadaveric study was conducted in the Department of Anatomy, Pacific Medical University, Udaipur, Rajasthan, India, from March 2024 to April 2025. A total of fifty human cadaveric kidneys, comprising twenty-five from the right-side and twenty-five from the left, were obtained from embalmed human kidney specimens. Ethical clearance for the study was granted by the Institutional Ethical Committee (PMU/PMCH/IEC/2023/25).

Inclusion criteria: All the kidney specimens of cadavers belonging to both sexes available at the Department of Anatomy, irrespective of age, were included in the study.

Exclusion criteria: Damaged kidneys, kidneys showing gross pathological changes, evidence of traumatic injury, prior surgical intervention, or congenital malformations were excluded from the analysis.

Study Procedure

The renal arteries and their pre-hilar branches were carefully exposed through meticulous dissection. Larger calibre branches arising directly from the abdominal aorta were designated as renal arteries, whereas pre-hilar branches were defined as those originating from the renal arteries before reaching the hilum. The classification system proposed by Sampaio FJ and Passos MA (1992) [4] was employed, wherein the hilar artery is defined as a branch of the abdominal aorta that enters the kidney through the hilum; the SPA as a branch from either the abdominal aorta or the main renal artery entering at the superior pole; and the IPA as a branch from similar origins entering at the inferior pole [Table/Fig-1]. No vascular dyes, contrast injections, or imaging techniques were utilised, so as to preserve the natural anatomical relationships of the specimens.



[Table/Fig-1]: Classification system of renal arteries.
SRA: Single renal artery; DHA: Double hilar arteries; SPA: Superior polar artery; IPA: Inferior polar artery; MRA: Multiple renal arteries; THA: Triple hilar arteries

STATISTICAL ANALYSIS

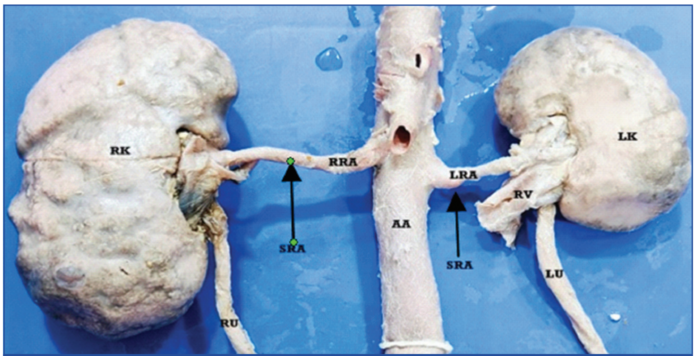
The proportions of the different variations were calculated as frequency and percentages by using the Epi Info software, a database and statistics program for public health professionals. Developed by the CDC, Atlanta, GA, USA (2011).

RESULTS

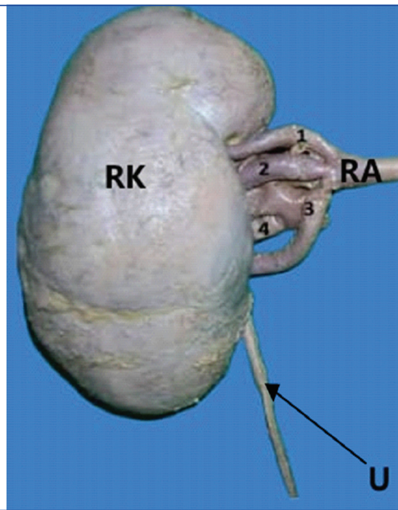
A SRA was noted in 4 out of 25 (16%) on the right-side and in 7 out of 25 (28%) on the left-side [Table/Fig-2,3]. MRA occurred in 11 out of 25 (44%) on the right-side and in 14 out of 25 (56%) on the left-side [Table/Fig-4]. DHA were identified in seven out of 25 (28%) on the right-side and in two out of 25 (8%) on the left-side [Table/Fig-5]. Hilar and superior polar arteries were present in two out of 25 (8%) on the right-side and none on the left-side [Table/Fig-6]. Hilar and inferior polar arteries were found in one out of 25 (4%) on the right-side and in two out of 25 (8%) on the left-side [Table/Fig-2,7], whereas triple hilar arteries were not detected.

Number of renal arteries	Right (N=25)	Left (N=25)	Total (N=50)
Single Renal Artery (SRA)	4 (16%)	7 (28%)	11 (22%)
Double Hilar Arteries (DHA)	7 (28%)	2 (8%)	9 (18%)
Triple hilar arteries	0	0	0
Multiple Renal Arteries (MRA)	11 (44%)	14 (56%)	25 (50%)
Hilar and Superior Polar Artery (SPA)	2 (8%)	0	2 (4%)
Hilar and Inferior Polar Artery (IPA)	1 (4%)	2 (8%)	3 (6%)

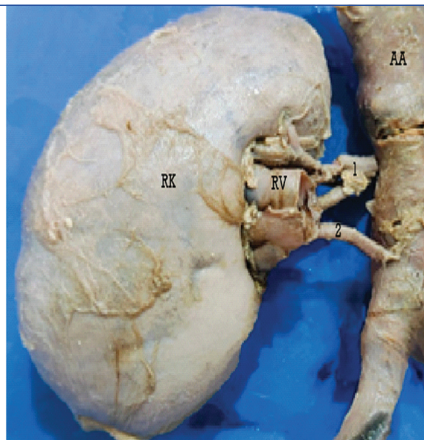
[Table/Fig-2]: Distribution of renal artery.



[Table/Fig-3]: Single Renal Artery (SRA) on right and left-side (Black arrow). SRA: Single renal artery; RK: Right kidney; LK: Left kidney; AA: Abdominal aorta; RV: Renal vein; RRA: Right renal artery; LRA: Left renal artery; RU: Right ureter; LU: Left ureter

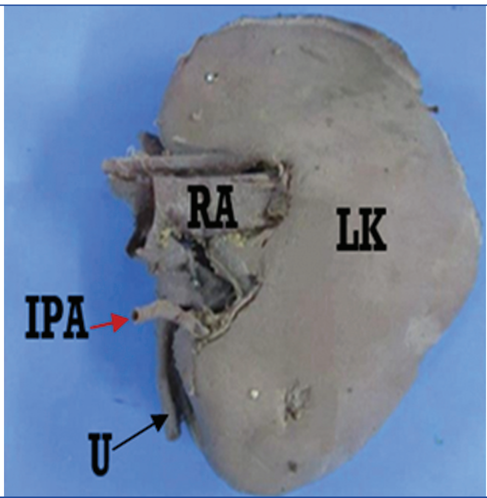


[Table/Fig-4]: 1,2,3,4-Multiple renal arteries on right-side (RK: Right kidney; RA: Renal artery; U: Ureter)



[Table/Fig-5]: 1,2 Double hilar arteries (DHA) on right-side (RK: Right kidney, RV: Renal vain; AA: Abdominal aorta)

[Table/Fig-6]: One Superior Polar Artery (SPA) on right-side (Black arrow). SPA: Superior polar artery; RK: Right kidney; RA: Renal artery; AA: Abdominal aorta, U: Ureter



[Table/Fig-7]: Inferior polar artery on left-side (Red arrow). IPA: Inferior polar artery; LK: Left kidney; RA: Renal artery, U: Ureter

DISCUSSION

During the foetal period, when the embryo is approximately 18 mm in length, the developing metanephros the primordium of the definitive kidney is vascularised by branches of the lateral mesonephric arteries arising from the dorsal aorta. These arteries form a series of transient vessels, of which the caudal branches persist and differentiate into the definitive renal arteries that supply the mature kidney [13]. In this study, the authors found that MRAs were more frequently located on the left-side (56%), whereas a SRA was more common on the right-side (28%). The significance of identifying variations in renal arteries cannot be emphasised enough, especially regarding renal transplantation, angiographic procedures, and urological operations. A thorough understanding of these vascular configurations is essential for enhancing surgical results, reducing vascular complications, and ultimately bettering patient outcomes [14,15].

[Table/Fig-8] provides a comparative analysis of DHA across different international populations [4,14,16-18]. In the present study, the prevalence of DHA was found to be 18%, a figure lower than that reported for the Brazilian population (45.5%) by Palmieri BJ et al., (2011) [16]. However, the findings of the study are comparable to the prevalence rates reported in the Colombian (12.1%) and American (12.3%) populations [14,17]. Furthermore, regarding polar arteries, the prevalence of SPA and IPA in this study was 4% and 6%, respectively. These figures are lower than those reported in the American population (9.6% SPA, 15.1% IPA), but align closely with findings from the Thai study by Khamanrong K et al., (2004), which reported SPA and IPA rates of 7% and 3%, respectively [18].

Authors	Population	Number of kidneys [N]	DHA	THA	SPA	IPA
Sampaio FJ and Passos MA (1992) [4]	Caucasians	266	7.9%	1.9%	6.8%	5.3%
Weld KJ et al., (2005) [14]	American	73	12.3%	-	9.6%	15.1%
Palmieri BJ et al., (2011) [16]	Brazilian	100	45.5%	18.8%	9.4%	3.2%
Saldarriaga B, et al., (2008) [17]	Colombian	196	12.1%	-	4.3%	10.8%
Khamanrong K et al., (2004) [18]	Thai	534	7.0%	1%	7%	3%
Present Study (2025)	Rajasthan	50	18%	0	4%	6%

[Table/Fig-8]: Analysis of data from various arteries across International population groups [4,14,16,17,18].

Such variations suggest that renal vascular anomalies are more frequently observed in South American populations compared to Asian populations, highlighting the influence of ethnic and possibly environmental factors [1,14-16].

[Table/Fig-9] offers insights into renal artery variations within different Indian populations. In the present study conducted on a Rajasthan-based population, a DHA prevalence of 18% was observed. This figure is slightly lower than the 22.6% reported by Budhiraja V et al., (2013) [5] but higher than the prevalence observed in Maharashtra (7%) [19], Karmalkar AS and Durgawale JM, (2019) [15] and Ghaziabad (4.76%) Gupta M et al., (2022) [1]. These discrepancies reinforce the notion that renal artery variations can be significantly influenced by genetic, ethnic, and geographical factors, even within a single country like India. Hence, it is crucial to conduct region-specific studies to better understand these anatomical variations and their clinical implications. Beyond surgical challenges, accessory renal arteries can have pathological consequences. For instance, they may compress the ureter at the ureteropelvic junction, potentially leading to hydronephrosis. Early identification of such variations through preoperative imaging techniques such as Computed Tomography Angiography (CTA) or Magnetic Resonance Angiography (MRA) is essential to avoid intraoperative surprises and postoperative complications. In renal transplantation, accurate mapping of the donor's renal vasculature is critical to ensure proper graft perfusion and function [1,5,13,14,15,20].

Authors	Population	Number of kidneys (N)	DHA	THA	SPA	IPA
Gupta M et al., (2022) [1]	Ghaziabad	108	4.7%	1.5%	12.6%	12.6%
Budhiraja V et al., (2013) [5]	Indian	84	22.6%	11.8%	13.1%	7.1%
Chandrika PV and Jakka LD (2021) [13]	Vijayawada	72	12.5%	-	4.16%	5.6%
Karmalkar AS and Durgawale JM (2019) [15]	Maharashtra	100	7%	2%	9%	1%
Vikram Rao KE and Battula SR (2015) [20]	Hyderabad	64	12%	-	15.6%	6.2%
Present study (2025)	Rajasthan	50	18%	0	4%	6%

[Table/Fig-9]: Analysis of data from various arteries in groups within the Indian population [1,5,13,15,20].

Moreover, in the present study, no instances of triple hilar arteries were observed, suggesting that while multiple arteries are relatively common, higher-order variations are still rare. However, the possibility of encountering triple or even quadruple hilar arteries should not be overlooked during surgical planning [1]. Given the significant clinical impact of these findings, further studies involving larger, diverse populations across various Indian regions are necessary. Such studies could help in forming a comprehensive database that would aid Surgeons, Radiologists, and Clinicians in anticipating and managing renal vascular anomalies more effectively [14,15].

Limitation(s)

The present study did not include morphometric data. It is acknowledged that the sample size in the present study (n=50) is relatively modest compared with certain large-scale anatomical or radiological investigations reported in the literature; this limitation may influence the generalisability of the findings and underscores the need for future studies on larger and more diverse populations. Methodological differences between this dissection-based approach and imaging-based studies are also recognised enabling a more contextual interpretation of the anatomical variations observed.

CONCLUSION(S)

The current analysis highlights the profound changes in the anatomy of renal arteries in the population of Rajasthan, especially with respect to the presence of MRAs and polar arteries. Conducting larger, multicentric studies across various Indian states and ethnic groups would provide a more comprehensive understanding of renal vascular patterns.

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PARTICULARS OF CONTRIBUTORS:

1. Research Scholar, Department of Anatomy, Pacific Medical University, Udaipur, Rajasthan, India.
2. Professor and Head, Department of Anatomy, Pacific Medical University, Udaipur, Rajasthan, India.
3. Research Scholar, Department of Anatomy, Dr. S.S. Tantia Medical College, Sriganganagar, Rajasthan, India.
4. Research Scholar, Department of Anatomy, Dr. S.S. Tantia Medical College, Sriganganagar, Rajasthan, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Nikhil Sharma,
Near Devi Pura Balaji Mandir, Bus Stand, Tiraha, Devipura, Sikar,
Rajasthan-332001, Sikar, Rajasthan, India.
E-mail: nikhilsharma2775@gmail.com

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