

MORPHOLOGICAL AND MORPHOMETRIC VARIATIONS OF THE RENAL ARTERIES IN NORTH INDIAN CADAVERS: IMPLICATIONS FOR RENAL SURGERY AND VASCULAR INTERVENTIONS

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Received : 03/08/2026
Received in revised form : 02/09/2026
Accepted : 14/09/2026

Keywords:

Renal artery variation, Renal morphometry, Cadaveric study.

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DOI: 10.47009/jamp.2026.8.5.58

Source of Support: Nil,
Conflict of Interest: None declared

Int J Acad Med Pharm
2026; 8 (5); 370-374



ABSTRACT

Background: Renal arterial anatomy varies in origin, dimensions, branching, and hilar relations. These variations are relevant to renal transplantation, partial nephrectomy, endovascular procedures, and interpretation of vascular imaging. The objective is to describe the vertebral level of origin, length, external diameter, branching pattern, and hilar relations of the renal arteries in adult cadavers from North India. **Materials and Methods:** This descriptive cross-sectional cadaveric study examined 30 well-embalmed adult cadavers (27 male and 3 female) in the Department of Anatomy, Government Medical College, Amritsar. Sixty renal arteries were assessed. Arterial length was measured from the aortic origin to the renal hilum using thread, and external diameter at the aortic origin was measured using Vernier calipers. Categorical observations were summarized as frequencies and percentages, continuous measurements were summarized as mean, standard deviation, and range. **Result:** The renal artery originated most frequently at L1 (35/60, 58.3%). Mean right and left renal artery lengths were 63.0 ± 12.42 mm and 50.0 ± 11.60 mm, respectively. Mean external diameters were 11.0 ± 4.92 mm on the right and 10.0 ± 3.97 mm on the left. The classical hilar arrangement was present in 51/60 hila (85.0%); the renal artery lay anterior to the renal vein in 8/60 (13.3%) and posterior to the renal pelvis in 1/60 (1.7%). Extra-renal branches to the suprarenal gland, ureter, perinephric tissue, renal capsule, and renal pelvis showed variable frequencies. **Conclusion:** Most renal arteries originated at the L1 level, with the right artery being longer and wider than the left. Although the classical hilar arrangement predominated, vascular variations were observed. These findings may aid anatomical teaching, imaging interpretation, and surgical planning.

INTRODUCTION

The kidneys are paired retroperitoneal organs that perform essential homeostatic functions, including regulation of fluid and electrolyte balance, maintenance of acid–base equilibrium, excretion of metabolic waste products, and endocrine functions. The kidneys also contribute to systemic blood pressure regulation through the renin–angiotensin–aldosterone system.^[1] Despite accounting for less than 1% of total body weight, the kidneys receive approximately 20–25% of the resting cardiac output, reflecting their high renal blood flow and the importance of an adequate and uninterrupted renal arterial supply.^[2] The principal vascular supply of each kidney is provided by the renal artery, which usually arises as a paired lateral branch from the

abdominal aorta immediately inferior to the origin of the superior mesenteric artery at the level of the first or second lumbar vertebra. Near the renal hilum, the renal artery typically divides into anterior and posterior divisions, which subsequently give rise to five segmental arteries supplying functionally independent renal segments.^[3] Since these segmental arteries are end arteries with little or no collateral circulation, interruption of their blood supply may result in irreversible ischemic injury to the corresponding renal parenchyma. Therefore, comprehensive knowledge of renal arterial anatomy is indispensable for anatomists and clinicians involved in renal surgery and vascular interventions.^[4,5]

The renal arteries exhibit considerable anatomical variation with respect to their origin, number, length,

external diameter, branching pattern, hilar division, and relationship to adjacent vascular structures.^[6] These variations arise during embryogenesis as a consequence of persistence or regression of the transient lateral mesonephric arteries that supply the developing kidneys during their ascent from the pelvic cavity to the lumbar region.^[7] Failure of regression of these embryonic vessels may result in accessory or multiple renal arteries, early prehilal branching, polar arteries, or anomalous origins from the abdominal aorta or neighboring arteries.^[8] Although many of these variations remain clinically silent, they assume great importance during diagnostic imaging and surgical procedures because inadvertent injury to an accessory or segmental artery may compromise renal perfusion and postoperative renal function. Consequently, detailed morphometric evaluation of the renal arteries has become an integral component of anatomical research and preoperative planning.^[9]

Numerous cadaveric and radiological investigations have examined the morphology and morphometry of the renal arteries in different ethnic populations. Previous studies have demonstrated significant variation in arterial length, external diameter, branching pattern, hilar arrangement, and the prevalence of accessory renal arteries.^[10] The reported incidence of accessory renal arteries varies considerably among different populations and studies, potentially reflecting population-related, developmental, and methodological differences. Variations in renal arterial morphology and morphometry reported across different populations further highlight the importance of population-specific anatomical data rather than universal generalization of these parameters.^[11,12]

Several studies from India have described renal arterial variations; however, most studies have primarily focused on accessory renal arteries and branching patterns rather than detailed morphometric parameters. Moreover, studies conducted in North Indian populations remain relatively limited, and considerable discrepancies exist regarding the reported arterial dimensions. The increasing frequency of renal transplantation, minimally invasive urological procedures, and endovascular interventions in North India highlights the necessity for region-specific anatomical databases. Cadaveric studies continue to serve as the gold standard for evaluating vascular morphology because they permit direct visualization and precise morphometric measurements. Therefore, the present cadaveric study was undertaken to evaluate the morphometry of the renal arteries in adult North Indian cadavers.

MATERIALS AND METHODS

This descriptive cross-sectional cadaveric study was conducted in the Department of Anatomy, Government Medical College, Amritsar. The study included 30 adult human cadavers of known sex

available for undergraduate anatomical dissection. The cadavers were embalmed and assigned identification numbers from 1 to 30, with the suffix “M” or “F” used to denote male and female cadavers, respectively. The study included 27 male and 3 female cadavers.

Inclusion criteria

Cadavers used for undergraduate anatomical teaching, irrespective of age and sex, were eligible for inclusion. Cadavers with intact kidneys and renal vasculature and without previous renal surgery were included.

Exclusion criteria

Cadavers with major congenital renal anomalies, significant damage to the kidneys or renal vessels during dissection, marked postmortem deterioration, or a history of previous renal surgery were excluded.

The morphological characteristics assessed included:

1. Vertebral level of origin of the renal artery from the abdominal aorta.
2. Arrangement of the renal artery in relation to the renal vein and renal pelvis at the renal hilum.
3. Number and distribution of branches arising from the renal artery, including branches supplying the suprarenal region, ureter, perinephric tissue, renal capsule, and renal pelvis.
4. Presence of any other identifiable variation in the renal arterial pattern.

Morphometric assessment: The length of each main renal artery was measured from its origin at the abdominal aorta to the renal hilum. A thread was used to follow the course of the artery, after which the corresponding length was measured.

The external diameter of each renal artery was measured at its origin from the abdominal aorta using Vernier calipers. The caliper jaws were gently positioned against the external walls of the artery without compressing the vessel.

All observations and measurements were recorded systematically on a predesigned proforma.

Data presentation and statistical analysis: The observations were tabulated separately for the right and left renal arteries. Continuous variables were expressed as mean $\pm$ standard deviation (SD) and range, whereas categorical variables were presented as frequencies and percentages.

RESULTS

The present study evaluated the morphological and morphometric characteristics of the renal arteries in 30 well-embalmed adult human cadavers, comprising 60 renal arteries (30 right and 30 left). The cadavers included 27 males and 3 females. The vertebral level of origin, arterial length and diameter, hilar arrangement, and branches arising from the renal arteries were recorded.

The vertebral level of origin of the renal arteries from the abdominal aorta was variable on both sides [Table 1]. On the right side, the renal artery

originated at the T12–L1 level in 1 case (3.3%), at the L1 level in 19 cases (63.3%), between L1 and L2 in 7 cases (23.3%), and at the L2 level in 3 cases (10.0%). On the left side, the renal artery originated at the T12–L1 level in 1 case (3.3%), at L1 in 16 cases (53.3%), between L1 and L2 in 8 cases (26.7%), and at L2 in 5 cases (16.7%). Overall, the L1 vertebral level was the most frequent level of origin, accounting for 35 of 60 renal arteries (58.3%).

Length of the renal arteries: The morphometric measurements of the renal arteries are presented in [Table 2]. The mean length of the right renal artery was 63.0 ± 12.42 mm, with a range of 31–95 mm. The corresponding mean length of the left renal artery was 50.0 ± 11.60 mm, with a range of 39–75 mm. Thus, the right renal artery demonstrated a greater mean length than the left renal artery in the present series.

Diameter of the renal arteries: The mean external diameter of the renal arteries at their origin from the abdominal aorta is presented in [Table 3]. The right renal artery had a mean diameter of 11.0 ± 4.92 mm, with a range of 6–23 mm, whereas the left renal artery had a mean diameter of 10.0 ± 3.97 mm, with a range of 5–21 mm.

Arrangement of renal vessels at the hilum: The arrangement of the renal vessels at the renal hilum was assessed bilaterally [Table 4]. A normal hilar arrangement was observed in 25 right renal hila (83.3%) and 26 left renal hila (86.7%), accounting for 51 of the 60 renal hila examined (85.0%). The renal artery was positioned anterior to the renal vein in 4 cases on the right side (13.3%) and 4 cases on the left side (13.3%), giving an overall frequency of 8 cases (13.3%). On the right side, the renal artery was observed posterior to the renal pelvis in 1 case (3.3%); this arrangement was not observed on the left side.

Branches arising from the renal arteries: The branches arising from the renal arteries were recorded on both sides [Table 5]. An inferior suprarenal branch was identified in all 30 renal arteries on both the right and left sides (100%). A ureteric branch was present in 24 right renal arteries (80.0%) and 26 left renal arteries (86.7%). Branches supplying the perinephric tissue were observed in 27 right renal arteries (90.0%) and 29 left renal arteries (96.7%). Capsular branches were present bilaterally in all specimens (100%). A branch supplying the renal pelvis was identified in 29 right renal arteries (96.7%) and all 30 left renal arteries (100%).

Table 1: Shows the Vertebral level of Renal artery

Vertebral level	Rt (N=30) %	Lt(N=30)	Total (N= 60) %
T12-L1	1 (3.3)	1 (3.3)	2 (3.3)
L1	19 (63.3)	16 (53.3)	35 (58.3)
L1-L2	7 (23.3)	8 (26.6)	15 (25)
L2	3 (10)	5 (16.6)	8 (13.3)

Table 2: Incidence of length of renal arteries

Parameter	Right renal artery	Left renal artery
Number of arteries	30	30
Mean length (mm)	63.0	50.0
Standard deviation (mm)	12.42	11.60
Range (mm)	31–95	39–75

Table 3: External diameter of the renal arteries

Parameter	Right renal artery	Left renal artery
Number of arteries	30	30
Mean diameter (mm)	11.0	10
Standard deviation (mm)	4.92	3.97
Range (mm)	6–23	5–21

Table 4: Arrangement of renal vessels at the renal hilum

Hilar arrangement	Right, n (%)	Left, n (%)	Total, n (%)
Normal arrangement	25 (83.3)	26 (86.7)	51 (85.0)
Renal artery anterior to renal vein	4 (13.3)	4 (13.3)	8 (13.3)
Renal artery posterior to renal pelvis	1 (3.3)	0 (0.0)	1 (1.7)
Total	30 (100)	30 (100)	60 (100)

Table 5: Branches arising from the renal arteries

Branch	Right n, %	Left n, %
Inferior suprarenal branch	30 (100.0)	30 (100.0)
Ureteric branch	24 (80.0)	26 (86.7)
Branch to perinephric tissue	27 (90.0)	29 (96.7)
Capsular branch	30 (100.0)	30 (100.0)
Branch to renal pelvis	29 (96.7)	30 (100.0)

DISCUSSION

The renal arteries demonstrate considerable anatomical variability in their origin, course, branching pattern, length, diameter, and relationship with the other structures at the renal hilum. Such variations are of considerable clinical importance because the renal arterial circulation consists predominantly of end arteries, and interruption of an arterial branch may result in ischemia of the corresponding renal segment. The present cadaveric study evaluated the vertebral level of origin, length and diameter of the renal arteries, hilar arterial arrangement, and branches arising from the renal arteries in 30 adult cadavers.

In the present study, the L1 vertebral level was the most frequent site of origin of the renal arteries, accounting for 58.3% of all renal arteries. On the right side, 63.3% of renal arteries originated at L1, while the corresponding proportion on the left was 53.3%. The remaining arteries originated at T12–L1, L1–L2, or L2 levels. This variation in the level of origin is consistent with the recognized variability of renal arterial anatomy. The predominance of the L1 level in the present study is anatomically relevant because the renal arteries usually arise from the abdominal aorta in the upper lumbar region. However, the presence of arteries originating at T12–L1 and L2 in the present series demonstrates that the vertebral level should not be assumed to be identical in all individuals. Knowledge of this variation may be particularly useful during retroperitoneal surgical approaches and radiological evaluation of the renal vasculature.

The variable vertebral origin of the renal arteries can be explained by the embryological ascent of the kidneys. During development, the kidneys receive a series of transient lateral mesonephric arteries. As the kidneys ascend from the pelvic region to their definitive lumbar position, successive vascular channels are established while earlier vessels usually regress. Budhiraja et al. emphasized the embryological basis of renal arterial variation and its relevance to renal transplantation and vascular procedures.^[8]

The mean length of the right renal artery in the present study was 63.0 ± 12.42 mm, whereas that of the left renal artery was 50.0 ± 11.60 mm. Thus, the right renal artery was longer than the left renal artery. The greater length of the right renal artery in the present study is in agreement with findings reported in previous anatomical investigations. Maurya, in a recent cadaveric study of Indian renal arteries, reported mean renal artery lengths of 3.70 ± 1.34 cm on the right and 2.85 ± 1.29 cm on the left, with the right renal artery being significantly longer than the left ($P < 0.001$).^[13] Similarly, Dhar and Lal, in a cadaveric study of renal arteries in individuals of Indian origin, reported mean lengths of the main renal artery of 31.05 ± 12.0 mm on the right and 25.0 ± 9.5 mm on the left. Both studies demonstrated a longer

right renal artery, which is consistent with the findings of the present study.^[14]

In the present study, the mean external diameter of the right renal artery was 11.0 ± 4.92 mm, while that of the left renal artery was 10.0 ± 3.97 mm, the external diameter was measured at the origin of the renal artery from the abdominal aorta using vernier calipers. The right renal artery therefore demonstrated a slightly greater mean diameter than the left. Variation in renal arterial diameter has practical importance in renal vascular surgery, renal transplantation, endovascular procedures, and the assessment of renovascular disease. The dimensions of the renal artery may influence the selection of vascular instruments and the technical approach during reconstructive or transplant procedures.

The classical arrangement of structures at the renal hilum is generally described from anterior to posterior as renal vein, renal artery, and renal pelvis. In the present study, the normal arrangement was observed in 85.0% of the renal hilum. An arterial position anterior to the renal vein was observed in 13.3% of cases, whereas a renal artery posterior to the renal pelvis was observed in 1.7% of cases. The occurrence of variant hilar arrangements in the present study is consistent with previous anatomical observations. Kumar et al., in a study of 96 renal hilum from South Indian adult cadavers, identified 12 different patterns of hilar arrangement. Such variations in the disposition of renal hilar structures are clinically important, as unexpected vascular relationships may increase the risk of iatrogenic injury during hilar dissection and renal surgical procedures.^[15]

The present study also shows that the renal arteries give rise to several branches supplying structures in and around the kidney. Inferior suprarenal and capsular branches were observed bilaterally in all specimens. Ureteric branches were present in 80.0% of right and 86.7% of left renal arteries, while branches supplying the perinephric tissue were observed in 90.0% and 96.7% of right and left renal arteries, respectively. Trivedi et al. examined kidneys and reported considerable variation in segmental renal arterial patterns and hilar arrangements, emphasizing the importance of recognizing these patterns during renal surgery and radiological evaluation.^[16]

Limitations: An important strength of the present study is the direct assessment of renal arteries through cadaveric dissection, allowing visualization and measurement of the vessels and their relationships at the renal hilum. However, the study has limitations. The sample size was relatively small, and the cadavers were obtained from a single institution. Furthermore, the study population was predominantly male, with only three female cadavers. Therefore, the findings cannot necessarily be generalized to the wider Indian population or to other ethnic groups.

CONCLUSION

The present study demonstrates considerable variation in the morphology and morphometry of the renal arteries. The L1 vertebral level was the most common site of origin, while the right renal artery was longer and had a slightly greater mean diameter than the left. Although the classical hilar arrangement predominated, variant arterial relationships and variable branches were observed. These findings emphasize the importance of detailed knowledge of renal arterial anatomy for anatomical education, radiological interpretation, renal transplantation, and renal and retroperitoneal surgical procedures.

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