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Anatomical Variations of the Branching Pattern of Renal Vessels: A Cadaveric Study

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ABSTRACT

Background: The renal arteries and veins exhibit considerable anatomical variability, which may influence surgical and radiological procedures involving the kidneys. Variations in the branching pattern of renal vessels are particularly important in renal transplantation, nephrectomy, urological surgeries, and interventional radiology. Cadaveric studies provide reliable anatomical evidence of such variations and help in understanding their frequency and clinical relevance.
Aim: To identify and document anatomical variations in the branching pattern of renal arteries and renal veins in adult cadavers and to emphasize their surgical significance.
Materials and Methods: This retrospective observational cadaveric study was conducted over a period of three years in the Departments of Anatomy at Sidhartha Medical College, Vijayawada, and Government Medical College, Rajamahendravaram. A total of 30 formalin-fixed adult cadavers were examined. Cadavers with damaged kidneys or congenital renal anomalies were excluded. The renal arteries and veins were carefully dissected to observe their number, course, and branching pattern. Findings were recorded and expressed as percentages to determine the frequency of variations.
Results: Normal renal vascular anatomy was observed in 70% of cadavers, while variations were identified in 30%. Renal arterial variations were more common than venous variations. Accessory renal arteries constituted the most frequent arterial anomaly, followed by polar arteries and early division of the renal artery. Lower polar arteries were more common than upper polar arteries. Renal venous variations were less frequent, with multiple renal veins being the predominant finding.
Conclusion: Renal vascular variations are relatively common, with arterial anomalies occurring more frequently than venous anomalies. Awareness of these variations is essential to reduce intraoperative complications and improve outcomes in renal surgical and radiological procedures.

Keywords*: Renal artery, Renal vein, Anatomical variation, Accessory renal artery, Cadaveric study.*

INTRODUCTION

The kidneys play a crucial role in maintaining fluid, electrolyte, and acid–base homeostasis, and their physiological function is highly dependent on an adequate and uninterrupted vascular supply [1]. Conventionally, each kidney is supplied by a single renal artery arising from the abdominal aorta and drained by a single renal vein that empties into the inferior vena cava [2]. At the renal hilum, the classical anterior–posterior arrangement consists of the renal vein, renal artery, and renal pelvis. However, deviations from this standard anatomical pattern are frequently observed [3].

From an embryological perspective, the kidneys ascend from the pelvic region to their definitive retroperitoneal position, receiving successive arterial supplies from transient lateral splanchnic branches of the aorta [4]. Persistence of these

embryonic vessels leads to the formation of accessory or aberrant renal arteries and veins. These vessels may enter the kidney through the hilum or directly at the upper or lower poles as polar arteries, contributing to the wide spectrum of renal vascular variations reported in anatomical and radiological studies [6].

Anatomical variations of renal vessels are of considerable clinical importance, particularly in renal transplantation, partial nephrectomy, pyeloplasty, and endourological interventions. Accessory renal arteries are functionally end arteries, and inadvertent injury or ligation can result in segmental renal ischemia or postoperative complications. Similarly, variations in renal venous drainage may complicate vascular control and increase the risk of intraoperative haemorrhage [3–5]. Therefore, detailed knowledge of renal vascular anatomy and its variations is essential for surgeons and radiologists to ensure safe and effective renal procedures.

Despite advances in imaging techniques, cadaveric studies remain the gold standard for detailed anatomical assessment of renal vasculature. Understanding the frequency and patterns of renal vascular variations is essential for surgeons, radiologists, and anatomists to minimize operative complications. The present cadaveric study was undertaken to document the anatomical variations in the branching pattern of renal arteries and renal veins and to highlight their clinical and surgical relevance.

METHODOLOGY

Study Design, Setting, and Period

This study was conducted as a retrospective observational cadaveric study in the Departments of Anatomy at Sidhartha Medical College, Vijayawada, and Government Medical College, Rajamahendravaram. The study period extended from January 2023 to 14 November 2025.

Study Material and Sample Size:

A total of 30 formalin-fixed adult human cadavers available in the anatomy dissection halls of the participating institutions were included in the study.

Inclusion Criteria:

Adult cadavers with intact kidneys and renal vessels
Cadavers showing variations in renal vascular anatomy

Exclusion Criteria:

Cadavers with damaged or distorted kidneys
Cadavers with congenital renal anomalies

Method of Dissection:

Routine dissection of the posterior abdominal wall was performed following standard anatomical dissection guidelines. The kidneys were exposed by removing the peritoneum and surrounding connective tissue. Renal arteries and veins were carefully dissected from their origin to their point of entry or exit at the renal hilum. The number, course, branching pattern, and site of entry of renal arteries, as well as the pattern of renal venous drainage, were meticulously observed and documented.

Data Collection and Analysis:

All observations were recorded systematically. The frequency of each anatomical variation was calculated and expressed as percentages. Descriptive statistical analysis was used to present the findings.

Ethical Considerations

The study was approved by the Institutional Ethics Committee (IEC/GMC-RJM/2025/26, Dt.14/11/2025) of Government Medical College, Rajamahendravaram. Informed consent was not applicable, as the research was conducted exclusively on formalin-fixed cadaveric specimens used for educational and research purposes.

RESULTS

The present cadaveric study evaluated the branching pattern and anatomical variations of renal vessels in 30 adult cadavers. Normal renal vascular anatomy, characterized by a single renal artery and a single renal vein entering the kidney through the hilum, was observed in 21 cadavers (70%), whereas variations in renal vascular anatomy were identified in 9 cadavers (30%) (**Table 1**).

Table 1. Overall Distribution of Renal Vascular Anatomy (n = 30)

Renal Vascular Pattern	Number of Cadavers	Percentage (%)
Normal renal artery and vein anatomy	**21**	**70.0**
Presence of any renal vascular variation	**9**	**30.0**
Total	**30**	**100**

Renal arterial variations constituted the majority of anomalies. Accessory renal arteries were the most frequently observed arterial variation, detected in 8 cadavers (26.7%). Among these, unilateral accessory renal arteries were more common, present in 5 cadavers (16.7%), while bilateral accessory renal arteries were identified in 3 cadavers (10.0%). In addition, polar arteries supplying the kidney outside the hilum were noted in 4 cadavers (13.3%). Early division of the main renal artery before entering the hilum was observed in 3 cadavers (10.0%). It was noted that some specimens exhibited more than one arterial variation (**Table 2**).

Table 2. Variations in Renal Arterial Anatomy (n = 30)

Type of Renal Arterial Variation	Number of Cadavers	Percentage (%)
Accessory renal artery (overall)	**8**	**26.7**
Unilateral accessory artery	**5**	**16.7**
Bilateral accessory arteries	**3**	**10.0**
Polar arteries (upper or lower pole)	**4**	**13.3**
Early division of renal artery before hilum	**3**	**10.0**

Note: Some cadavers showed more than one arterial variation.

Further analysis of polar arteries revealed a predominance of lower polar arteries, which were observed in 3 cadavers (10.0%), whereas upper polar arteries were identified in only 1 cadaver (3.3%). Overall, polar arteries were present in 4 cadavers, accounting for 13.3% of the study population (**Table 3**).

Table 3. Distribution of Polar Renal Arteries (n = 30)

Type of Polar Artery	Number of Cadavers	Percentage (%)
Lower polar artery	**3**	**10.0**
Upper polar artery	**1**	**3.3**
Total polar arteries	**4**	**13.3**

Renal venous variations were less frequent compared to arterial anomalies. Multiple renal veins draining separately into the inferior vena cava were observed in 3 cadavers (10.0%). An altered course of the renal vein with an abnormal hilar arrangement was documented in 1 cadaver (3.3%). In total, renal venous variations were identified in 4 cadavers (13.3%)

(**Table 4**).

Table 4. Variations in Renal Venous Anatomy (n = 30)

Renal Venous Variation	Number of Cadavers	Percentage (%)
Multiple renal veins draining into IVC	**3**	**10.0**
Altered course / abnormal hilar arrangement	**1**	**3.3**
Total renal venous variations	**4**	**13.3**

Figure 1: Cadaveric specimen showing the kidney with multiple renal arterial branches entering the hilum, demonstrating an accessory renal artery in addition to the main renal artery.

Figure 2. Dissected kidney illustrating variation in renal hilar vascular arrangement, with multiple renal vessels clustered at the hilum instead of the classical vein–artery–pelvis sequence.

Figure 3. Cadaveric kidney specimen showing early division of the renal artery before entry into the renal hilum, resulting in multiple segmental branches supplying the kidney.

Figure 4. Gross specimen demonstrating presence of polar renal arteries, with arterial branches entering the kidney outside the hilum, highlighting a lower polar arterial variation.

DISCUSSION

The present cadaveric study demonstrates that anatomical variations in the branching pattern of renal vessels are relatively common, with variations identified in 30% of the examined specimens. This observation is consistent with contemporary anatomical and imaging-based studies, which have emphasized that deviations from classical renal vascular anatomy represent a frequent finding rather than an exception and must be anticipated during renal surgical and radiological procedures [7,8].

In the current study, renal arterial variations were more prevalent than renal venous anomalies. Accessory renal arteries constituted the most common arterial variation, a finding that aligns well with detailed zonal and segmental analyses of renal arterial vasculature reported in recent literature [7,9]. Large cadaveric series and regional studies have similarly demonstrated a high incidence of accessory renal arteries, particularly in South Asian populations, underscoring their embryological origin and clinical relevance [8]. The persistence of transient mesonephric arteries during renal ascent provides a well-established explanation for these variations.

Polar arteries were identified in a notable proportion of specimens, with lower polar arteries occurring more frequently than upper polar arteries. Previous anatomical and clinical studies have highlighted the importance of lower polar arteries due to their potential to cross the ureteropelvic junction and contribute to obstruction or surgical difficulty during procedures such as pyeloplasty and partial nephrectomy [10,11]. The predominance of lower polar arteries observed in the present study corroborates these findings.

Early division of the renal artery before entering the renal hilum was another significant finding. This variation has been shown to increase technical complexity during hilar dissection and nephron-sparing surgeries, particularly in minimally invasive approaches, where unrecognized branches may lead to vascular injury or incomplete vascular control [9,11].

Renal venous variations were less frequent than arterial anomalies, with multiple renal veins draining independently into the inferior vena cava being the most common finding. Similar venous patterns have been reported in radiological and cadaveric studies, emphasizing the importance of preoperative vascular mapping to prevent unexpected hemorrhage during nephrectomy and transplant surgeries [12].

CONCLUSION

The present cadaveric study demonstrates that anatomical variations in the branching pattern of renal vessels are relatively common, with nearly one-third of specimens showing deviations from the classical anatomy. Renal arterial variations were more frequent than venous anomalies, with accessory renal arteries representing the most prevalent finding, followed by polar arteries and early arterial division. Lower polar arteries were observed more commonly than upper polar arteries, underscoring their potential clinical significance. Although renal venous variations were less frequent, their presence has important surgical implications. Awareness and precise understanding of these variations are essential for anatomists, surgeons, and radiologists to minimize intraoperative complications and improve outcomes in renal surgical and interventional procedures.

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