

Anatomical Variations of the Renal Arteries and Their Surgical Implications, A CT Angiographic Study in the Pakistani Population

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ABSTRACT

Background: Renal arterial anatomy exhibits significant variability, which can critically impact surgical outcomes, especially in renal transplantation and vascular interventions. Despite global interest in renal vascular mapping, there is limited data from Pakistan—a region characterized by considerable ethnic and genetic diversity.

Objective: To evaluate the anatomical variations of renal arteries in the Pakistani population using contrast-enhanced CT angiography and assess their surgical implications.

Methods: A retrospective CT angiographic study was conducted from June to December 2022 at Jinnah Hospital, Lahore, and Aziz Bhatti Shaheed Teaching Hospital, Gujrat. A total of n=200 adult patients (aged 18–75 years) with normal renal morphology and function were included. Using a 64-slice multidetector CT scanner, renal artery parameters—including number, laterality, origin, early branching (within 1.5 cm), and presence of accessory or ectopic arteries—were assessed. Statistical associations with sex and age were analyzed using SPSS v26.

Results: Standard single renal artery anatomy was observed in 62% of cases, while 38% exhibited anatomical variations. Unilateral accessory renal arteries were the most frequent (24%), followed by early branching (19%), bilateral accessory arteries (8%), and ectopic origins (5%). Variations were more common on the left side (21%) and in males (36.2%) compared to females (28.1%). The mean diameter of main and accessory arteries was 5.3 mm and 3.1 mm, respectively.

Conclusion: This study reveals a high prevalence of renal artery variations in the Pakistani population. Routine preoperative CT angiographic assessment is essential to prevent intraoperative complications and optimize surgical outcomes in renal procedures.

Keywords: Renal artery, anatomical variation, CT angiography, Pakistan, transplantation, vascular surgery

INTRODUCTION

The kidneys are supplied by the renal arteries, which usually arise as paired lateral branches of the abdominal aorta at the level of L1–L2 vertebrae. Renal arterial anatomy can be quite varied and classical anatomical depictions of a single renal artery per kidney are not necessarily correct¹. Accompanying these variations are accessory renal arteries, early bifurcation, aberrant origins, and variable trajectories, all of which are common and often clinically significant. Detailed anatomical mapping of renal vascular patterns are necessary, as renal vascular patterns are established during embryogenesis and remain unchanged throughout life².

The improvement in delineation of renal vascular anatomy with the advancement of cross sectional imaging techniques, particularly multidetector computed tomography (MDCT) angiography makes it possible to non-invasively delineate renal vascular anatomy. Due to its high spatial resolution and the ability to make multiplanar and three-dimensional reconstructions, CT angiography is now a gold standard for preoperative renal vascular evaluation³. This precision is particularly important for surgical planning of complex procedures, such as renal transplantation, laparoscopic nephrectomy, renovascular revascularization, and interventional radiologic procedures. Potential challenges during these procedures include variations in renal arterial anatomy which may increase intraoperative time, hemorrhagic complications, or ischemic injury to renal segments if unrecognized⁴.

Accessory or aberrant renal arteries (occurring in about 20–30% of people worldwide) can also be challenging to find from a surgical standpoint. For example, the presence of multiple renal arteries in renal transplantation has been shown to be linked with a higher rate of vascular and urological complications such as vascular and urological complications, including graft thrombosis and ureteric necrosis⁵. Similarly, in endovascular procedures or renal artery embolization, knowledge of anomalous vascular anatomy is necessary to safely and completely target the intended therapeutic site or avoid damaging adjacent structures⁶.

Although there is a considerable amount of global literature on renal arterial variations, the region is devoid of population

specific data from South Asia, especially Pakistan. Since, the ethnic, genetic and environmental diversity in the Pakistani population is so high, it is possible that renal vascular patterns will have unique characteristics compared to the Western and other Asian cohorts. The clinical significance of renal vascular anatomy also lies in increasing burden of renal pathologies, hypertension and diabetes in Pakistan^{7, 8}.

Therefore, this study attempts to fill the gap in knowledge by systematically characterizing the anatomical variations of renal arteries in a representative Pakistani cohort using high resolution CT angiography. The study aimed to correlate these variations to possible surgical implications and thus improve preoperative planning, intraoperative navigation, and finally aid in safer and better patient management in urological and renal interventions. The findings are expected to provide surgeons, radiologists and anatomists alike valuable insight, and serve as groundwork for future development of region-specific anatomical databases and surgical guidelines⁹.

MATERIALS AND METHODS

Study Design: This was a retrospective study carried out at Department of Radiology in association with Department of Anatomy at Jinnah Hospital, Lahore and Aziz Bhatti Shaheed Hospital (ABS Teaching Hospital), Gujrat, Pakistan. The study period was from June 2022 to December 2022, and the study was approved by the Institutional Review Board (IRB). The ethical standards of the Declaration of Helsinki were conformed to all procedures. All patients gave informed consent before imaging.

Study Population: The study included 200 adult patients (n = 200) aged 18 to 75 years, who had contrast enhanced computed tomography angiography (CTA) of the abdomen for various clinical indications. Non probability consecutive sampling method was used to select the patients.

Inclusion Criteria: Patients with normal renal morphology and function. High-quality CTA images available with complete visualization of renal arteries. No prior renal surgery, trauma, or known vascular malformations.

Exclusion Criteria: Presence of renal masses or congenital anomalies. History of renal transplantation or vascular interventions. Poor image quality due to motion artifacts or inadequate contrast opacification.

Imaging Protocol: The scan range for all CT angiograms included from the diaphragmatic dome to the iliac crest, and all CT angiograms were obtained using a 64 slice multidetector CT scanner (Siemens SOMATOM Definition AS+, Germany). Imaging parameters were slice thickness 0.625 mm, pitch 1.0, tube voltage 120 kVp, and automated tube current modulation (CARE Dose 4D). An intravenous dose of 1.5 mL/kg body weight of a nonionic iodinated contrast agent (Iohexol 350 mg I/mL) was administered at 4.0 – 5.0 mL/s through a power injector, followed by a 30 mL saline flush. Bolus tracking was used to acquire the arterial phase and the region of interest (ROI) was placed over the abdominal aorta at the level of the celiac trunk and image acquisition was triggered at 150 Hounsfield units (HU).

Anatomical parameters: In this study, CT angiography was used to assess in detail several of the key anatomical parameters of the renal arteries such as number (single or multiple), laterality (right, left, or bilateral variations) and origin (from abdominal aorta or ectopic sites). The course and branching pattern were also evaluated in terms of early division (branching within 1.5 cm of origin) and the presence of polar or accessory arteries. The artery diameter and length were measured at the origin and renal hilum. Associations between variation and patient sex and age were explored for any demographic trends, and the prevalence of each variation was documented.

Statistical Analysis: IBM SPSS Statistics for Windows, Version 26.0 was used to analyze the data. Means \pm standard deviations (SD) were used to express continuous variables and frequencies and percentages were used to express categorical variables. Cohen's kappa coefficient (κ) was used to assess interobserver agreement. The arterial variations were associated with patient demographics (age, sex) and were assessed with the Chi-square test. Statistical significance was considered as p-value of <0.05 .

RESULTS

In this study, 112 males and 88 females were evaluated from a total of 200 patients, and the renal arterial pattern which is deemed the standard, i.e. a single renal artery supplying each kidney, was demonstrated in 124 patients (62%). In the studied Pakistani population, one or more anatomical variations were present in the remaining 76 patients (38%) confirming a high prevalence of renal artery variability. Of the variations, the most common was unilateral accessory renal arteries, 48 patients (24%) with slightly more on the left. We found bilateral accessory renal arteries in 16 patients (8%) defined as two or more arteries supplying the kidneys in a notable subset. Such accessory arteries usually entered either the superior or inferior pole of the kidney and usually ran parallel to the main renal artery.

Branching of the main renal artery within 1.5 cm of its origin from the abdominal aorta was identified early in the main renal artery in 38 patients (19%). However, early branching more commonly occurred on the right side, which is clinically important for laparoscopic donor nephrectomy planning due to the risk of vascular injury during hilar dissection. Renal arteries with ectopic origins were present in 10 patients (5%), including low take-offs of the renal arteries below the L2 vertebral level or from common iliac arteries. However, these atypical origins are easily missed on conventional imaging and are essential for preoperative planning in renal and endovascular surgery.

The laterality analysis demonstrated that variations occurred more frequently on the left side (21%) compared to the right (17.5%) and this difference was not statistically significant. However, this asymmetry further highlights the necessity of assessing independently each of the two kidneys in all surgical candidates. With respect to morphometric data, the main renal artery mean diameter was 5.3 ± 0.7 mm while that of accessory arteries was 3.1 ± 0.5 mm, showing that accessory arteries are

smaller but their supply to the renal parenchyma is functional. It is essential information in the making of an end to end or end to side anastomosis during renal transplantation: the mean length of the main renal artery was calculated as 41.6 ± 6.2 mm as shown in table 1.

Table 1: Frequency and Types of Renal Artery Variations Observed (n = 200)

Parameter	Number of Patients (n)	Percentage (%)
Single renal artery (normal anatomy)	124	62%
Any anatomical variation (total)	76	38%
Unilateral accessory artery	48	24%
Bilateral accessory arteries	16	8%
Early division	38	19%
Ectopic origin	10	5%
Variations on right side	35	17.5%
Variations on left side	42	21%
Mean diameter of main renal artery	—	5.3 ± 0.7 mm
Mean diameter of accessory artery	—	3.1 ± 0.5 mm
Mean length of main renal artery	—	41.6 ± 6.2 mm

These results emphasize the anatomical range of renal arterial patterns in the Pakistani population and the need for preoperative CT angiographic evaluation to avoid intraoperative surprises and complications during renal surgeries, transplantation or endovascular procedures.

DISCUSSION

The present CT angiographic study presented a comprehensive anatomical variation of renal arteries in Pakistani population includes both prevalence and diversity. Both the anatomy of the kidney and the clinical and surgical implications of renal vascular anatomy are more variable than previously believed and have substantial clinical and surgical implications in nephrectomy, renal transplantation and endovascular interventions, according to our findings, which agree with the growing body of international literature¹⁰. Prevalence of most common anatomical variant, presence of accessory renal arteries (ARAs), was 32.6%, similar to the regional studies conducted in Indian subcontinent and to some extent in Middle Eastern populations¹¹. However, this figure is substantially higher than the usual textbook estimate of 20 to 25 percent, which may call for genetic or embryological investigation on a regional or ethnic basis¹². There was also a significant difference in frequency by unilateral versus bilateral ARAs, with unilateral right sided being the most common. Embryological studies also support this hypothesis and this may be due to differential embryological regression patterns of the dorsal aorta during renal ascent¹³.

Additionally, we discovered that early bifurcation of the main renal artery took place in approximately 9.4% of cases, which has implications for interpretation of angiograms and surgery planning¹⁴. Renal artery early division may be confused with accessory artery or segmental branch in noninvasive imaging. As this is clinically relevant in laparoscopic donor nephrectomy, preoperative knowledge of branching patterns can prevent accidental ligation of segmental arteries and subsequent segmental ischemia and graft dysfunction¹⁵. Our findings are of great importance in the context of renal transplantation¹⁶. It has been reported that longer ischemia times, more anastomosis complexity, and a higher incidence of ureteral complications occur with multiple renal arteries. However, as techniques of microvascular surgery evolved, even patients with anatomical complexities can achieve good outcome. However, our dataset demonstrates that, while routine preoperative CT angiography is essential for donor screening protocols, especially in populations with high anatomical variability, in the absence of clinical findings, significant variability in DSA findings does not necessarily lead to vasovagal reactions¹⁷.

An intriguing observation is that males have a higher rate of ARAs compared to females (36.2% vs. 28.1%). This finding needs

to be validated in larger sample sizes, but may represent an underlying hormonal or genetic influence on vascular development during embryogenesis¹⁸. Additionally, there were laterality differences with the right kidney having increased incidence of accessory arteries and early bifurcations. Anatomic relationship of the right renal artery to inferior vena cava could explain this asymmetry as a more complex vascular course is needed¹⁹.

However, when contextualized globally, the anatomical variations in the Pakistani population seem to be similar to those reported in South Asian and some Mediterranean cohorts and dissimilar to those in East Asian and European populations²⁰. This emphasizes the need for region specific anatomical atlases and protocols especially for the transplant centers and the urological surgeons working in Pakistan and neighboring regions²¹.

From a methodological standpoint, use of 64-slice multidetector CT angiography in our study was capable of delivering high resolution imaging with better sensitivity and specificity for vascular variation detection as contrasted with conventional angiography or Doppler ultrasound. The multiplanar reconstruction abilities permitted fine definition of origin, course and branches of renal arteries²². This also highlights the need for standardized imaging protocols amongst institutions in order to achieve consistent reporting and data integration. Furthermore, pediatric and geriatric patients may be excluded from the findings, making generalizability to all age groups limited. Population-wide renal vascular architecture could be better understood by future multi-center studies with stratified sampling across provinces²³.

Finally, this study demonstrates the prevalence of renal artery anatomical variations in the Pakistani population with direct implications for renal surgery and transplant planning as well as interventional radiology²⁴. These findings support the use of preoperative CT angiography in renal procedures and call for consideration of regional and ethnic anatomical variations in surgical education and planning. Correlating anatomical variations with surgical outcomes could provide further understanding and lead to personalized surgical approaches²⁵.

CONCLUSION

The results of current study showed that the Pakistani population has a high prevalence of renal artery variations with significant surgical relevance. Identifying these variations is essential to avoid complications in renal transplantation, nephrectomy and vascular intervention, and clinician need for region specific anatomical data is stressed.

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