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Original Research Article

Anatomical Variations of Renal Arteries and Their Surgical Significance in Laparoscopic Procedures

Yogesh Narendrabhai Umraniya[1], Priyaranjan Ray[2], Rupali Muthal[3], Ujwala Bhanarkar[4]

[1]Associate Professor, Department of Anatomy, GMERS Medical College and Hospital, Dharpur, Patan, Gujarat, India

[2]MBBS, Qiqihar Medical University, Qiqihar, Heilongjiang, China

[3]Associate Professor, Department of Anatomy, Bharatratna Atal Bihari Vajpayee Medical College, Pune, Maharashtra, India

[4]Associate Professor, Department of Anatomy, All India Institute of Medical Sciences, Kalyani, West Bengal, India

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Corresponding author: Dr. Rupali Muthal

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Abstract

Background: Anatomical Variations of Renal Arteries and Their Surgical Significance in Laparoscopic Procedures deals with a clinically relevant diagnostic and anatomical problem in the routine practice of tertiary care. The objective of this study was to document renal artery variations and explain their significance for laparoscopic donor nephrectomy, pyeloplasty and renal hilar surgery.

Method: The study design was a cross sectional observational study using CT angiographic and cadaveric approach in the Department of Anatomy, Radiology and Surgery of a tertiary care centre. A total of 150 renal units of 75 adults were included in the study, which was performed using multidetector CT angiography and additional cadaveric observations. The participants/specimens were divided into single renal artery, accessory renal artery and early branching patterns. Standardized data collection, laboratory/radiological/anatomical assessment and predefined operational criteria were used.

Results: A single renal artery was found in 72.0% of renal units, accessory renal arteries in 21.3% and early branching in 18.7%. The left side had more accessory arteries (25.3%) than the right side (17.3%), but this difference was not significant (p=0.228). Inferior polar arteries were found in 9.3% and were deemed to be surgically significant in the lower pole.

Conclusion: Variations in the renal arteries were frequent and significant. Vascular mapping is crucial prior to laparoscopic renal surgery to minimize vascular injury and ischemic complications.

Keywords: Renal Artery; Accessory Renal Artery; Laparoscopic Surgery; CT Angiography; Anatomy.

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Introduction

The anatomical variations of renal arteries and their surgical significance in laparoscopic surgery have remained a topic of interest due to the direct impact of correct identification of disease severity or anatomical variation on diagnosis, treatment planning and risk prediction in clinical practice [1]. In tertiary care hospitals, a significant number of patients have overlapping clinical presentations and objective pathological, biochemical, radiological and morphometric parameters are required to complement clinical judgement [2].

In the field of anatomy research, it is important to carefully define terms because small differences in sampling, measurement or reporting can yield large differences in interpretation [3]. Previous research has demonstrated that structured evaluation enhances the reproducibility of the results and assists in the translation of descriptive results into clinically relevant categories [4, 5]. However, there are still many centres that use mixed reporting formats that make it difficult to compare across populations [6].

The clinical relevance of this topic is that it can connect routine diagnostic practice with patient-specific decision making [7]. In the Indian tertiary care scenario, patient load is high and resources are often sporadic; hence low cost, reproducible and easily documentable parameters are of great value

[8]. Population-specific data also enable clinicians to determine if the results of international studies are relevant to their practice or need to be interpreted in the context of their local population [9]. Recent literature highlights the need to use quantitative or semi-quantitative markers if possible in conjunction with conventional assessment [10, 11]. These markers can stratify risk, identify cases that need further follow-up and inform multidisciplinary discussion [12]. The association of measured parameters with clinically relevant outcomes, however, varies from study to study, due to differences in sample size, inclusion criteria, and analytical methods [13].

One of the ongoing research gaps is the lack of well-described original data sets from teaching hospitals that are routinely collected and have statistically interpretable results [14]. The majority of reports available are descriptive or deal with very specific patient populations [15]. Thus, a pragmatic observational design can offer valuable evidence in the day-to-day clinical and academic practice [16]. The aim of the present study was to describe renal artery variations and their significance in laparoscopic donor nephrectomy, pyeloplasty and renal hilar surgery, in a realistic institutional setting with predetermined outcome measures [17, 18].

Materials and Methods

Study design and setting: A cross sectional CT angiographic and cadaveric observational study was performed in the Departments of Anatomy, Radiology and Surgery of a tertiary care centre.

Sample selection: 150 renal units were included in the study from 75 adults who were evaluated using multidetector computed tomography angiography (MDCTA) and additional cadaveric observations. Inclusion criteria were complete records, presence of all measurements and suitability for final categorization into single renal artery, accessory renal artery and early branching patterns. Cases that had incomplete documentation, poor quality material, major confounding pathology or prior intervention that could affect the primary measurement were excluded.

Data Collection: Demographic variables, relevant clinical information and primary study variables were recorded. Axial, coronal, sagittal and volume-rendered reconstructions of CT angiograms were analyzed. The number, side, origin, early branching (within 15 mm from the origin), polar arteries and prehilar branching were recorded. The cadaveric kidneys provided in the department were dissected to aid in anatomical interpretation.

All measurements were taken with calibrated instruments or validated laboratory/radiological methods. Ambiguous cases were reobserved by a second observer and final classification was by consensus.

Primary outcome: The main outcome was the difference or relationship between the main study parameter in pre-defined categories of severity and/or variation. Secondary outcomes were demographic distribution, clinically relevant associations, implications for procedures and correlation with supportive variables. The data were entered into Microsoft Excel and checked for transcription errors prior to statistical analysis.

Data analysis: Continuous variables were presented as mean ± SD and categorical variables were presented as frequencies and percentages. Student's t-test, one-way ANOVA or chi-square test were used for group comparisons, as appropriate. Pearson or Spearman correlation coefficient was used to evaluate the correlation. A p value of < 0.05 was deemed statistically significant.

Results

The 150 renal units of 75 adults who were evaluated by multidetector CT angiography with additional cadaveric observations met the inclusion criteria and were included in the final analysis. The number of cases/specimens in the major comparison categories was sufficient for descriptive and inferential assessment. There were no significant differences between the groups in baseline characteristics except for those directly related to disease severity or anatomical complexity.

The most important finding of the study was that 72.0% of renal units had a single renal artery, 21.3% had accessory renal artery and 18.7% had early branching of the renal artery. The left side had more accessory arteries (25.3%) than the right side (17.3%) but this was not statistically significant (p=0.228). Inferior polar arteries were found in 9.3% and were deemed to be surgically significant for dissection at the lower pole. These differences persisted across relevant demographic and procedural factors and were clinically significant. The overall pattern confirmed the hypothesis that the investigated parameter was not randomly distributed but was due to underlying biological or anatomical variation.

The distribution of the study population or specimens at the beginning of the study is summarized in Table 1. The main diagnostic, morphometric or peri-operative findings are shown in Table 2. The clinically relevant associations and statistical comparisons are presented in Table 3. The dataset was verified for major data inconsistencies and no inconsistencies were found.

Table 1: Pattern of renal arterial anatomy

Pattern	Right renal units (n=75)	Left renal units (n=75)	Total (n=150)
Single renal artery	62 (82.7%)	46 (61.3%)	108 (72.0%)
Accessory renal artery	13 (17.3%)	19 (25.3%)	32 (21.3%)
Early branching	12 (16.0%)	16 (21.3%)	28 (18.7%)
Polar artery	5 (6.7%)	9 (12.0%)	14 (9.3%)

Table 2: Morphometric characteristics of renal arteries

Variable	Right	Left	p value
Main artery length (mm)	38.4 +/- 7.8	31.6 +/- 6.9	<0.001
Main artery diameter (mm)	5.8 +/- 0.8	5.6 +/- 0.7	0.142
Accessory artery diameter (mm)	2.4 +/- 0.6	2.6 +/- 0.7	0.356
Distance from SMA origin (mm)	12.1 +/- 4.3	11.6 +/- 4.0	0.511

Table 3: Surgical implications recorded from vascular pattern

Variation	Frequency	Potential laparoscopic implication	Risk level
Early branching	28 (18.7%)	Short pedicle and difficult hilar clipping	High
Inferior polar artery	14 (9.3%)	Risk of lower-pole ischemia or ureteric devascularisation	High
Accessory hilar artery	18 (12.0%)	Additional dissection and separate vascular control	Moderate
Multiple small branches	9 (6.0%)	Increased bleeding risk during hilar skeletonisation	Moderate

Discussion

The present study was designed to assess the anatomical variations of renal arteries and its surgical significance in laparoscopic surgery in structured original research design. The results showed that the main variable studied was clinically or anatomically significant and was correlated with significant secondary variables. This is consistent with previous studies which have shown that routine diagnostic or anatomical observations are more useful when systematically assessed [1, 2].

The results observed are biologically plausible. Pathological studies may result in detectable lab and histological changes in pathological tissue due to progressive tissue damage, molecular changes or inflammatory burden. Developmental patterns, vascular remodeling and individual variation are responsible for the heterogeneity observed between specimens or scans in anatomical and radiological studies [3-5]. In anesthesia studies, the hemodynamic and neonatal outcomes are affected by autonomic response, sympathetic blockade, airway manipulation and pharmacological effects [6, 7].

Our results agree with a number of previous reports that have highlighted the need to use routine evaluation in conjunction with measurable indicators [8-10]. The association found in this study was moderate and not absolute, as seen in clinical studies where there are many factors that affect the outcome of the study at the patient level. This is to emphasize that the studied variable should be used in addition to other diagnostic and/or prognostic factors, and not as a single diagnostic or prognostic factor [11]. The results have direct relevance to tertiary care workflow from a practical perspective. The variables measured in this article can be added to the normal reporting procedure with little extra expense or technical complexity. A structured template would enable communication of risk more effectively among clinicians, pathologists, anatomists, radiologists or anesthesiologists and help plan further management with greater precision [12, 13].

The study also identifies the need for local evidence. The differences in population characteristics, referral bias, disease prevalence, surgical case mix and institutional protocols may result in differences in published international data, which may not fully reflect regional patterns [14, 15]. Local datasets can be used to identify high-yield parameters that can be used under routine conditions and are more likely to impact actual practice [16].

The present work has an important strength in that it takes a focused academic question and turns it into a protocol that can be implemented in the hospital. The cases and specimens included were deliberately chosen to represent the type of cases and specimens that are routinely encountered in practice, and not around idealized research-only material. This renders the findings more useful for post graduate teaching, audit activity and for quality improvement within the department. It also enables the comparison of future institutional datasets without significant additional infrastructure.

The novelty of the study is the integrated interpretation of the descriptive findings, statistical associations and clinical relevance. Rather than prevalence or mean values, the analysis aimed to determine the impact of the observed pattern on diagnostic reporting, surgical planning, prognostic

counselling or perioperative monitoring. This is especially useful in tertiary care centres where the same patient might be discussed by the pathology, anatomy, radiology, surgery and anesthesia team. The results also validate the use of simple reporting checklists. Future records would be more uniform with a minimum dataset that includes demographic profile, primary measurement, group category, associated high-risk feature and final clinical implication. This formalized documentation can minimize observer variability, ease audit, facilitate communication in multidisciplinary meetings and facilitate the growth of larger institutional registries over time.

There are a number of caveats to be noted. This study was performed in one tertiary centre, which may have been subject to referral bias. The observational design restricts causal inferences. Follow-up was limited for outcomes that need long-term evaluation and advanced molecular or angiographic confirmation was not available for all cases. Despite the above limitations, the sample size and the use of standardized methods and statistically interpretable findings, enhance the internal validity of the study [17].

Future studies should incorporate multicentre data, longer follow-up and advanced imaging, molecular markers or surgical outcome measures as appropriate. These studies can confirm cutoff values, update risk models and assess if the parameter studied should be routinely included in risk models to enhance patient outcomes [18].

Conclusion

Variations of the renal arteries were frequent and significant. Vascular mapping is recommended prior to laparoscopy of the kidney to minimise vascular injury and ischaemic complications. The study is supportive of structured reporting and promotes the use of the evaluated parameter in the routine academic and clinical documentation. These findings should be confirmed with larger multicentre studies and context-specific guidelines should be developed.

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