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Original Article
Bangladesh Journal of Infectious Diseases
June 2025, Volume 12, Number 1, Page 93-98
ISSN (Online) 2411-670X
ISSN (Print) 2411-4820
NLM ID: 101761093
DOI: https://doi.org/10.3329/bjid.v12i1.83760

Three-Dimensional Quantitative Anatomy of the Arterial Bed and the Renal Pelvis-Calyx System in Women

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Abstract

Background: Understanding the three-dimensional (3D) anatomical relationships of the renal arterial system and the renal pelvis-calyx complex is essential for improving surgical planning and reducing complications in urological procedures. **Objective:** The purpose of the study was to reveal the patterns of the three-dimensional quantitative organization of the branches of the renal artery in relation to the elements of the renal pelvis-calyx system in women. **Methodology:** The study was conducted on 64 corrosion specimens of kidneys from deceased women aged 22 to 75 years who died of causes unrelated to the urinary system. Extra-organ and intra-organ branches of the renal arteries were identified and analyzed in relation to the frontal, horizontal, and sagittal planes. Quantitative-morphological analysis was performed on kidneys with two, three, and four excretory sectors. Data were processed using variation statistics methods with Microsoft Excel. Age-related differences were examined across mature, elderly, and senile groups. **Results:** The renal artery, in the majority of instances, divides into a pair of branches (20, 22.0% of cases across age groups), while it splits into three branches and shows superior/inferior variants with less frequency (3, 5.0%). Across all age demographics, 15.2% of cases systematically manifested both anterior and also posterior pelvic branching. Spatial analysis indicated anterior, posterior branching predominated inside two-sector kidneys (75, 80%), anterior, posterior including upper, lower divisions remained equally represented throughout three-sector kidneys, and anterior, posterior branching prevailed beyond 77.0% of cases throughout four-sector kidneys. Statistically meaningful age-related disparities remained unidentified. **Conclusion:** The study evinces that when one scrutinizes 3D renal artery branching patterns quantitatively, the analysis furnishes clinically valuable preoperative planning information for women as well as strengthens the accurate visualization and modeling tools' development to improve diagnostic precision and surgical safety. [*Bangladesh Journal of Infectious Diseases, June 2025;12(1):93-98*]

Keywords: Kidney; renal artery; renal pelvis; 3D modeling

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Introduction

Literary sources lack a unified approach to the variants of renal artery division, the characteristics of its branches, and their topographic localization[1]. According to these authors, there is a correlation between the shape of the kidney, its mass, and the volumetric structure of its vascular network, which

is of particular clinical interest for operative uronephrology, oncology, and transplantation[2].

Modern diagnostic imaging methods like multislice computed tomography (MSCT) allow the verification of several features characterizing the renal arteries and their relationship with adjacent structures[3-4]. When performing bilateral comparisons of the types of renal artery branching, it was demonstrated that two groups can be distinguished: symmetric and asymmetric division in the ratio of 76.15% and 23.85%, respectively[5-6].

For the correct diagnosis and further development of a patient management algorithm, it is necessary to analyze tomographic images[7-8]. It is also important to monitor the dynamics of changes before and after surgery. Therefore, the implementation of an algorithm for creating virtual models in clinical practice is considered promising[9-10]. Their detailed analysis will help predict possible changes in the patient's condition.

The emergence of modern research methods and new computer 3D technologies can contribute to the creation of algorithms for preoperative patient examination and planning of the proposed surgical intervention[11-12]. As mentioned above, knowledge of the anatomy of the variants and types of intra-organ structure of the renal arteries, the distribution of their basins, zones of blood supply, and their relationship to the renal pelvis-calyx system is also of practical importance in nephrolithotomy. This can be achieved by improving imaging techniques during diagnostic studies[13-14].

Improving the effectiveness of planning surgical interventions on the renal cavity system to remove stones while reducing the frequency of postoperative bleeding can be achieved with a three-dimensional representation of the renal arteries and the excretory sectors of the kidney on the organ surface[3,15-16]. The purpose of the study was to investigate the 3D anatomy of the branches of the renal artery in relation to the excretory sectors of the kidneys in women.

Methodology

Study Settings and Population: The study was conducted on 64 corrosion specimens of the arterial vessels and renal pelvis-calyx system of human kidneys. The specimens were made from the kidneys of deceased female individuals aged 22 to 75 years who died from diseases unrelated to the urinary system, obtained as part of the implementation of a grant from the Russian Foundation for Basic Research No. 18-29-09118 from 2018.

Study Procedure: On the corrosion specimens of the renal arteries and renal pelvis-calyx system, the extra-organ branches of the renal arteries (RA) were identified, with a study of their number, division variants in relation to the pelvis, course, and characteristics at the kidney hilum. The three-dimensional (3D) anatomy of the renal arteries was studied relative to the frontal, horizontal, and sagittal planes; topographic-anatomical relationships of the renal arteries and pelvis were also examined.

On the corrosion specimens, a quantitative analysis of the intra-organ branches of the renal artery was conducted in relation to the sectors of the renal pelvis-calyx system which were quantitative-morphological analysis of the branches of the renal artery in kidneys with two sectors; Quantitative-morphological analysis of the branches of the renal artery in kidneys with three sectors; Quantitative-morphological analysis of the branches of the renal artery in kidneys with four sectors.

Statistical Analysis: All obtained digital material and data from instrumental research methods were processed using variation statistics. A workstation with an Intel Core2Duo T5250 1.5 GHz processor and up to 2 GB RAM on the Windows 7 platform was used. The Microsoft Office 2007 Excel application package was employed for statistical calculations. Descriptive statistics were used to summarize frequency distributions, while comparative analysis between age groups applied significance testing ($p < 0.05$).

Ethical Clearance: The study was carried out in compliance with ethical principles for medical research involving human material. Since the kidneys were obtained from deceased individuals, no informed consent was applicable; however, institutional approval was secured. The research protocol followed the Declaration of Helsinki and local ethical guidelines.

Results

Depending on the division variants of the main renal artery - "A. renalis" (I) at the kidney hilum relative to the frontal, sagittal, and horizontal planes into second-order vessels, that is, zonal arteries - "A. (zonal)" (II), where they have their specific

arterial basins in the kidneys, corresponding groups were identified in different age periods.

It was established that in the first period of mature age, the division of the renal artery - "A. renalis" into 2 branches was found in 13 cases, which constituted 20.31%. In the second period of mature age, this variant of the renal artery division was found in 14 observations, which constituted 21.87% of cases. In the elderly, this variant of division was also found in 14 specimens, which also constituted 21.87% of cases. In the senile age period, this variant of the renal artery division was found in 13 corrosion specimens, which constituted 20.31% of cases.

Further research established that the division of the renal artery - "A. renalis" into 3 branches in the first period of mature age was found in 2 specimens, which constituted 3.13% of cases. In the second period of mature age, this variant of the division was found in 3 corrosion specimens, which constituted 4.69% of cases. In the elderly, this variant of division was also found in 3 specimens, which also constituted 4.69%. In the senile age period, this variant of the renal artery division was found in 2 specimens, which constituted 3.13% of cases.

Furthermore, from this quantity, it was established that the division of the renal artery - "A. renalis" into upper and lower branches in the first period of mature age was identified in three specimens, which constituted 4.69% of cases. In the second period of mature age, this division variant was found in 3 specimens, which constituted 4.69% of cases. In the elderly, this division variant was also found in 3 specimens, which constituted 4.69% of cases, and in the senile period, this variant was found in two specimens, which constituted 3.13% of cases, respectively (Figure I).

Further research established that the division of the RA - "A. renalis" into anterior and posterior pelvic branches in the first period of mature age was found in 10 specimens, which constituted 15.63% of cases. In the second period of mature age, this variant was found in 11 specimens, which constituted 17.19% of cases. In the elderly, this variant was found in 11 specimens, which also constituted 17.29% of cases, and in the senile period, this variant was also found in 11 specimens, which also constituted 17.29% of cases.

Further research established that the division of the RA - "A. renalis" into 2 anterior and 1 posterior branch was not found in the first and second periods of mature age and in senile age, except for the elderly period, where it was found in one specimen and constituted 1.56% of cases.

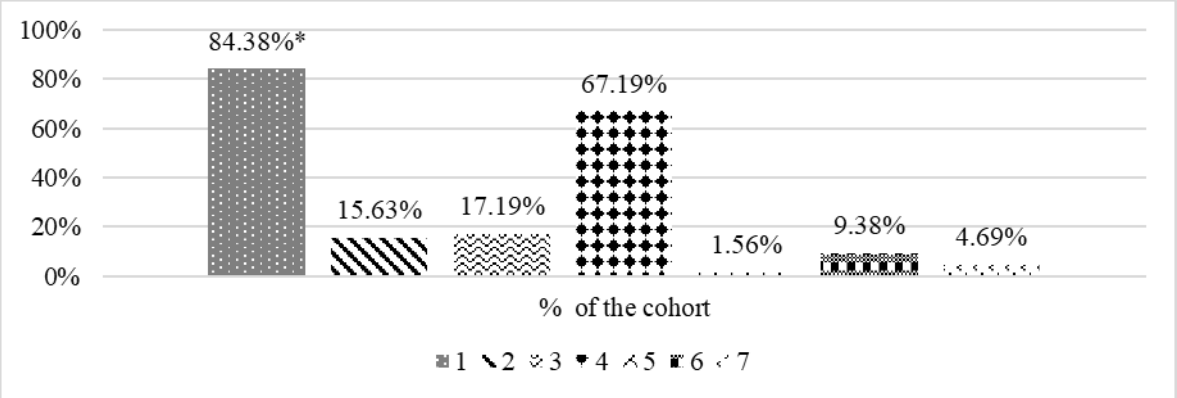

Figure I: Comparative characteristics of the variant anatomy of the extra-organ segment of the renal arteries in the area of the hilum based on corrosion specimens of the right and left kidneys in women of mature, elderly, and senile age; Notes: 1. 2 branches of the renal artery (RA); 2. 3 branches of the RA; 3. Upper and lower branches of the RA; 4. Anterior and posterior pelvic branches of the RA; 5. 2 anterior and 1 posterior branches of the RA; 6. Upper, anterior, and posterior branches of the RA; 7. Anterior, posterior, and lower branches of the RA; *$p < 0.05$ - significance of the difference between groups.

Next, the division of the RA - "A. renalis" into upper, anterior, and posterior branches in the first period of mature age was found in one specimen, which constituted 1.56% of cases.

In the second period of mature age, this variant was found in two specimens, which constituted 3.13% of cases. In the elderly, this variant of the division was also found in two specimens, which constituted 3.13% of cases. In the senile period, this variant of the RA division was found in one specimen, which constituted 1.56% of cases.

The next variant of the RA division into anterior, posterior, and lower branches was found equally in the first and second periods of mature age, in one specimen each, which constituted 1.56% of cases, respectively. This variant was not found in the elderly period, and in the senile period, it was found in one specimen, which constituted 1.56% of cases.

Next, a three-dimensional quantitative analysis of the variants of renal artery division relative to the excretory sectors of the renal pelvis-calyx system was conducted separately for the left and right kidneys in women. Thus, the research revealed that among 9 left two-sector kidneys, in seven specimens, the RA - "A. renalis" divided into anterior and posterior branches, which constituted 75.0% of cases. In one corrosion specimen, the RA divided into upper and lower branches, which constituted 25.0% of cases. And in one two-sector kidney specimen, the RA divided into three branches, which constituted 3.23% of cases.

Further, it was found that among 8 three-sector corrosion specimens of kidneys, in 5 specimens, the RA divided into anterior and posterior branches, which constituted 83.33% of cases. In one case, the division of the RA into upper and lower branches was identified, which constituted 16.7% of cases. In two three-sector kidney specimens, the RA divided into three branches, which constituted 6.5% of cases.

The analysis of 10 four-sector left corrosion kidney specimens established that in 7 specimens, the RA - "A. renalis" divided into anterior and posterior branches, which constituted 77.8% of cases. In two specimens, the RA divided into upper and lower branches, which constituted 22.2% of cases, and in one four-sector kidney specimen, the RA divided into three branches, which constituted 3.2% of cases.

A three-dimensional quantitative analysis of the variants of renal artery division relative to the excretory sectors of the renal pelvis-calyx system of the right kidneys in women showed that among 11 right two-sector kidneys, in eight specimens, the RA - "A. renalis" divided into anterior and posterior branches, which constituted 80.0% of cases. In two corrosion specimens, the RA divided into upper and lower branches, which constituted 20.0% of cases. And in one two-sector kidney specimen, the RA divided into three branches, which constituted 2.9% of cases.

Further, it was found that among 10 three-sector kidney specimens, in 3 specimens, the RA - "A. renalis" divided into anterior and posterior branches, which constituted 42.9% of cases. In four specimens, the division of the RA into upper and lower branches was identified, which constituted 57.1% of cases. In three-sector kidney specimens, the RA divided into three branches, which constituted 8.6% of cases.

The analysis of 14 four-sector right corrosion kidney specimens established that in 10 specimens, the RA - "A. renalis" divided into anterior and posterior branches, which constituted 83.33% of cases. In two corrosion specimens, the RA divided into upper and lower branches, which constituted 16.67% of cases. In two four-sector kidney specimens, the RA divided into three branches, which constituted 5.71% of cases.

Discussion

We studied corrosion specimens of the arterial vessels of the kidneys and the renal pelvis-calyx system, where the specimens were divided into three groups based on the number of excretory sectors with different variants of arterial vessel division. Our analysis confirmed that anterior, posterior branching remains the predominant pattern, also that pattern accords throughout sectoral classifications across age groups. Contemporary studies also stress that these branching patterns are stable: donor-based angiographic analyses identified early-branching renal arteries in roughly 17% of cases, male donors did not diverge substantially from female donors, and this mirrored our observations inside female specimens[17]. Furthermore, a morphometric investigation presented the replicability of dual and triple renal artery bifurcation as the principal anatomical arrangements. Operative security hinges greatly upon these arrangements, underscoring their salience[18].

The analysis of the distribution of specimens of right kidneys in women by the number of excretory sectors and the number of branches of the renal artery participating in their blood supply indicates that two excretory sectors were found in 11

specimens: 10 specimens with two supplying arteries: 8 specimens with anterior and posterior arteries, 2 specimens with upper and lower arteries, and 1 specimen with three renal arteries. Three excretory sectors were found in 10 specimens of right kidneys: 7 specimens with two supplying arteries: 3 specimens with anterior and posterior arteries, and 4 specimens with upper and lower arteries, and 3 specimens with three renal arteries. Four excretory sectors were found in 14 specimens: 12 specimens with two supplying arteries (10 specimens with anterior and posterior branches of the renal artery and 2 specimens with upper and lower branches of the renal artery) and 2 specimens with three renal arteries.

These findings highlight the predominance of two-artery supply in most right kidneys, with three-artery divisions being relatively rare. Similar distributions were reported in a 2023 morphometric analysis of renal artery branching, where two-artery configurations were identified in more than 75% of cases, confirming their surgical relevance in donor nephrectomy and endovascular procedures[19]. A recent 2023 imaging-based study also emphasized that variations in excretory sector supply strongly influence vascular access routes, suggesting that preoperative recognition of such variants can reduce intraoperative risks[20]. Furthermore, advances in artificial intelligence–assisted CT angiography published in 2023 support the use of automated 3D mapping to predict arterial dominance and optimize individualized surgical planning[21].

The analysis of the distribution of specimens of left kidneys in women by the number of excretory sectors and the number of branches of the renal artery participating in their blood supply indicates that two excretory sectors were found in 9 specimens: 8 specimens with two supplying arteries: 7 specimens with anterior and posterior arteries, 1 specimen with upper and lower arteries, and 1 specimen with three renal arteries.

Three excretory sectors were found in 8 specimens of left kidneys: 6 specimens with two supplying arteries: 5 specimens with anterior and posterior arteries, 1 specimen with upper and lower arteries, and 3 specimens with three renal arteries. Four excretory sectors were found in 10 specimens: 9 specimens with two supplying arteries (7 specimens with anterior and posterior branches of the renal artery and 2 specimens with upper and lower branches of the renal artery) and 1 specimen with three renal arteries.

Conclusion

In our work, sufficient attention was paid to the three-dimensional (3D) analysis of intra-organ renal arteries and elements of the renal pelvis-calyx system in accordance with the excretory sectors of the kidneys in women. A detailed analysis of the structure of variants of renal artery division in women according to age indicators indicates the comparability of the results obtained within the groups. Thus, in the analysis of the variants of renal artery division between the corrosion specimens of the right and left kidneys in women of mature, elderly, and senile age, no statistically significant differences were found in the respective age ranges. The results were comparable. The obtained data formed the basis for creating a model of arterial blood supply to the excretory sectors of the human kidney and contributed to the development of an algorithm for creating 3D software for preoperative three-dimensional (3D) visualization of the renal pelvis-calyx system and arterial vessels using augmented reality elements (VAMR).

Acknowledgements
None

Conflict of Interest
We declare that we have no conflict of interest.

Financial Disclosure
The authors received no specific funding for this work.

Authors' contributions
Shamil Akbaev: conceptualization, specimen preparation, data collection, drafting of the manuscript; Islam Vagabov: methodology design, statistical analysis, interpretation of results, manuscript editing; Edgar Kafarov: supervision, validation, critical revision of the manuscript, final approval. All authors read and approved the final version of the manuscript.

Data Availability
Data are available from the corresponding author upon reasonable request and subject to approval by the relevant institutional authorities.

Ethics Approval and Consent to Participate
Ethical approval for the study was obtained from the Institutional Review Board. As this was a prospective study the written informed consent was obtained from all study participants. All methods were performed in accordance with the relevant guidelines and regulations.

How to cite this article: Akbaev S, Vagabov I, Kafarov E. Tree Dimentional Quantitative Anatomy of the Arterial Bed and the Renal Pelvis-Calyx System in Women. Bangladesh J Infect Dis 2025;12(1):93-98

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Article Info
Received on: 1 March 2025
Accepted on: 20 April 2025
Published on: 1 June 2025

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