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3D Analysis of The Renal Vascular System in a Dichotomous Variant of Renal Artery Division

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Abstract

The authors conducted a quantitative 3D analysis of the arterial and venous kidney beds with the identification of zones of arterial blood supply and venous outflow in the parenchyma with a dichotomous variant of the division of the renal artery. The authors distinguished dichotomous and trichotomous variants of the division of the main renal artery in the frontal, sagittal, and horizontal planes into vessels of the 2nd order (zonal arteries) forming arterial basins in the parenchyma of the organ consisting of three groups. The first group included kidneys with a dichotomous variant of the division of the main renal artery in the frontal plane, forming two arterial basins in the ventral and dorsal halves of the kidney, that is, with a two-zone blood supply (11 variants, 51.8%). The second group consisted of kidneys with a dichotomous division variant forming arterial basins in the parenchyma of the superior and inferior kidney poles (four variants, 27.1%). The sources of blood supply to the kidney zones, that is, the number of zonal arteries, had some differences depending on the variants of the division of the main renal artery and the types of branching of its intra-organ arterial vessels of the kidney. The number of venous vessels involved in the drainage of various zones of the kidney and their confluence at the level of the links of the magistral venous vessels depend on the variants and types of fusion of veins in the intra-organ venous bed.

Keywords: kidney, artery, vein, 3D analysis

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1. Introduction

The widespread introduction of modern radiation research methods in urological practice, namely 3D technologies for performing organ-preserving operations and segmental resections, requires clarifying information about the features of the structure of the kidney arterial and venous bed, the topographic and anatomical features of the structure inside the organ, the zones of arterial blood supply and venous outflow, etc. [1-5]. Many researchers question the degree of correspondence of the course of arterial and venous vessels and how much the veins repeat the course of the arteries, which is important in urological practice for proper ligation of the neurovascular bundle before performing segmental resection to avoid postoperative bleeding [6,7]. Researchers pay special attention to the issue of the discrepancy between the quantitative ratio and the location of venous and arterial vessels inside the kidney. Morphological studies by O. Mochalov [8], K.K. Gubarev et al. [6], A.M. Ali Khussein [9], and D.W. Giel et al. [10] indicate the presence of various topographic and anatomical features of the arteries related to the veins, both inside and outside the organ. Researchers pay special attention to the discrepancy between the number and topography of arterial and venous vessels. This issue of the topographic and anatomical relationship between arteries and veins, their number and ratio is extremely important when performing surgical interventions on the kidneys, for example, organ-preserving operations or segmental resections. This issue has been repeatedly discussed by many researchers [11-13].

According to some researchers, venous vessels predominate over arterial ones, while others claim the opposite and note that the number of arterial vessels is greater than venous vessels [6,8,9,11-13]. The presence of vascular basins inside the kidney parenchyma, their quantitative characteristics, and the degree and distribution zones of the vessels of these basins in various areas of the organ are also important. Researchers also take an interest in the drainage features of the venous bed of the kidney with different variants of the distribution of arteries and their vessels in the areas of the kidney parenchyma [6,8,9,11-13].

The generalization of existing data and the development of new approaches to the analysis of intra-organ arterial and venous kidney beds is of paramount importance for the creation of a personalized approach in clinical practice [14,15, 16]. We conducted a 3D anatomical analysis of the renal vascular bed with the identification of zones of arterial blood supply and venous drainage in the parenchyma.

2. Materials and methods

124 polychrome corrosive preparations of the arterial and venous bed of the kidney were used in the study. They were made from the kidneys of corpses of people of both genders aged 22 to 75 who had died from diseases unrelated to the pathology of the urinary system. The preparations were purchased as part of the implementation of the grant of the Russian Foundation for Fundamental Research in the Graduate Students program for project No. 20-315-90008/20. The polychrome corrosive preparations of the renal vascular bed were photographed using a Sony Cyber-shot DSC-RX10M4 Black digital camera. All kidney preparations were subjected to 3D scanning using a RayScan 130 3D digital microcomputer tomography system (Germany), at a current strength of 132 mAs, voltage of 140 kV, with a spiral pitch of 1.0 mm and subsequent 3D modeling (Agreement No. 5 dated 18.07.2020).

The data obtained from the scans of polychromic corrosive renal vascular bed preparations were imported into special modules of the IntelliSpase Portal and Synapse 3D workstations for automatic calculation of the volume of vascular basins of the arterial and venous renal bed, expressed as a percentage (X±m)%, where the basins of the venous bed and basins of the renal arterial bed were taken as 100%. In the calculations, we used the Excel application from the Microsoft Office 2007 application package.

The accuracy of the study was determined by the probability of an error-free forecast less than or equal to 0.95% with the level of statistical significance $p \leq 0.05$.

3. Results and Discussions

Depending on the variants of the division of the main trunk of A. renalis (I) in the renal hilum in the frontal, sagittal, and horizontal planes into vessels of the 2nd order (zonal arteries, A. (zonal) (II)), the dichotomous and trichotomous variants of their intra-organ branching were established, which had their specific arterial basins in different areas of the kidney. By the kidney zone, we understand the section of the renal parenchyma where the arterial vessels of A. (zonal) (II)). As a result of the studies of corrosive preparations, we identified the corresponding kidney groups. The first group was represented by kidneys with a dichotomous division of A. renalis (I) (these are kidneys with a two-zone blood supply system). They participated in the following types of blood supply: the first one was the distribution of arterial vessels in the parenchyma of the ventral and dorsal kidney zones and the second one was the distribution of arterial vessels in the parenchyma of the superior and inferior polar zones of the kidney. In the first dichotomous variant of the division of A. renalis (I) in kidneys with a bi-zonal blood supply system, which was observed in 9.2% of cases, at $p<0.05$, A. renalis (I) in the renal hilum relative to the frontal plane branched into the ventral zonal branch, A. ventralis (zonal) (II), and dorsal zonal branch, A. dorsalis (zonal) (II). The ventral zonal artery (VZA), A. ventralis (zonal) (II), with a dispersed type of branching, was divided on average into (X±m) 4±1 interlobar arteries of the 1st order, A. interlobares-1 (III), which fed the parenchyma of the ventral zone of the superior and inferior poles of the kidney, amounting to 50±2% of the volume of blood supply to the entire organ. The kidney arteries branched in the parenchyma of the anterior superior and anterior inferior segments, also supplying blood to the segments of the superior and inferior poles, smoothly passing to the dorsal surface of the same poles of the kidney (Table 1, Figures 1 and 2).

In this variant of the division of A. renalis (I) and the type of intra-organ branching, the DZA with dispersed branching, on average, branched into (X±m) 3±1 A. interlobares-1 (III) supplying blood to the parenchyma of the dorsal zone of the kidney. These vessels were distributed in the posterior segment and dorsal parenchyma of the superior polar and inferior polar segments, averaging 40±2% of the volume of blood supply to the entire organ. The VZA with a dispersed type of branching of arterial vessels on average gave (X±m) 2±1 A. interlobares-1 (III) for blood supply to the parenchyma of the dorsal zone of the kidney in the area of its poles, averaging 10±1% of the volume of blood supply to the parenchyma of the kidney. On average, in this group of kidney preparations, the number of interlobar arteries equaled (X±m) 7±1.

When examining the venous system in this group of kidneys, we found that it was represented by the SPV, V. superius polus (II), and the IPV, V. inferior polus (II), merging in the renal hilum relative to the horizontal plane, forming the main renal vein, V. renalis (I). In this case, on average (X±m) 4±1 interlobar veins of the 1st order, V. interlobares-1 (III), flowed into the SPV with dispersed venous vessel fusion. Furthermore, on average (X±m) 4±1 V. interlobares-1 (III) flowed into the IPV with dispersed fusion. Venous outflow from the parenchyma of the ventral zone was carried out along the SPV and IPV with dispersed venous vessel fusion. The SPV drained the parenchyma of the ventral sections of the superior and superior anterior segments, averaging 25±1% of the volume of venous outflow from the entire kidney. The IPV drained the parenchyma of the ventral parts of the inferior and inferior anterior segments, also averaging 25±1% of the volume of venous outflow from the entire kidney. On average, (X±m) 4±1 V. interlobares-1 (III) flowed into each polar vein. Venous drainage from the parenchyma of the dorsal zone of the kidney was also carried out through the SPV and IPV. On average (X±m) 2±1 V. interlobares-1 (III) with dispersed types of vascular fusion flowed in the SPV and (X±m) 3±1 V. interlobares-1 (III) with dispersed types of vascular fusion flowed in the IPV draining the parenchyma of the dorsal zone of the kidney, and in particular, the posterior segment and dorsal parts of the pole segments, averaging 50±3% of the volume of venous outflow from the entire parenchyma of the kidney. On average, in this group of kidneys, the number of interlobar veins was (X±m) 8±1. In the second variant of the kidneys with a bi-zonal blood supply system, which we found in 8.3% of cases, at $p<0.05$, A. renalis (I) in the renal hilum relative to the frontal plane was divided into the ventral zonal branch, A. ventralis (zonal) (II), and dorsal zonal branch, A. dorsalis (zonal) (II), demonstrating a dichotomous variant. In this case, the VZA, A. ventralis (zonal) (II), with a dispersed type of branching, was divided on average into (X±m) 4±1 A. interlobares-1 (III) supplying blood to the parenchyma of the ventral zone of the kidney, in particular, parenchyma of the superior and inferior anterior segments, as well as the ventral parts of the polar segments, averaging 50±3% of the volume of blood supply to the entire kidney (Table 2 and Figure 3).

Table 1. Variants of venous outflow from the kidney with its bi-zonal blood supply (ventral and dorsal halves), (total: 9.2% of cases, at p<0.05)

Variant (%) at p≤0.05	**Arteries**	**Artery branching types**	**Volume of blood supply (%) Number of interlobar arteries of the 3rd order (X±m)**	**Veins**	**Vein fusion types**	**Volume of venous outflow (%), Number of interlobar veins of the 3rd order (X±m)**
Variant I (9.2%)	Ventral half					
	VZA	Dispersed type	50±2%	SPV	Dispersed type	25±1%
			4±1			4±1
	DZA	Dispersed type	0%	IPV	Dispersed type	25±1%
			3±1			4±1
	Dorsal half					
	VZA	Dispersed type	10±1%	SPV	Dispersed type	25±1%
			4±1			4±1
	DZA	Dispersed type	40±2%	IPV	Dispersed type	25±1%
			3±1			4±1

IPV: inferior polar vein; SPV: superior polar vein; DZA: dorsal zonal artery; VZA: ventral zonal artery

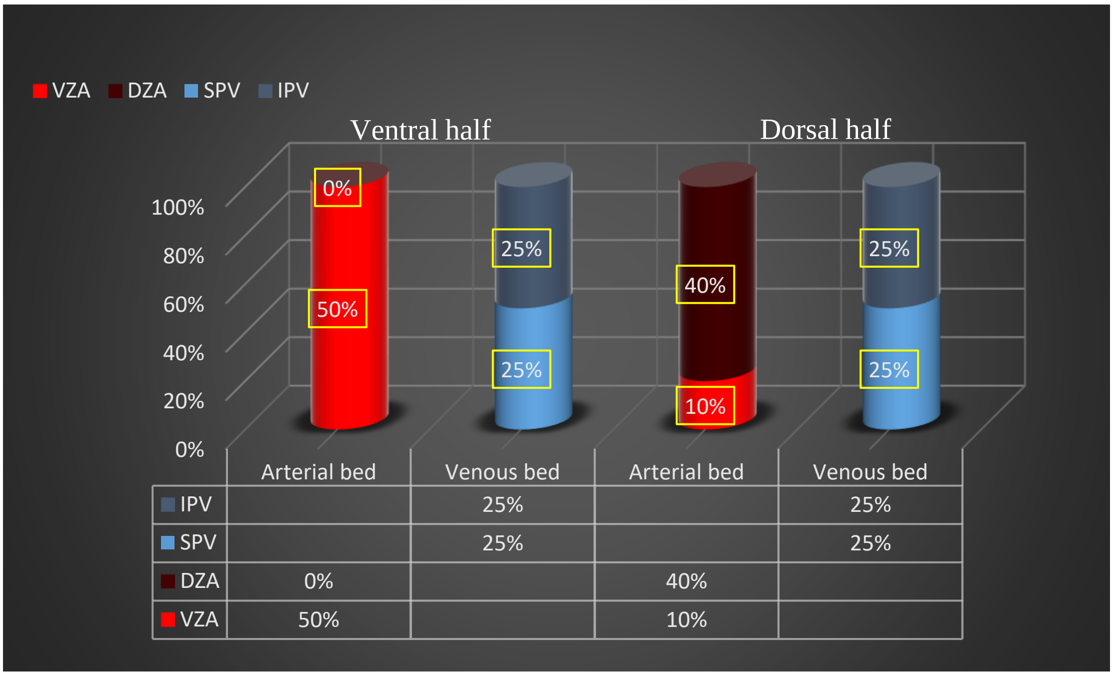


Figure 1. Variant I of venous outflow from the kidney with its bi-zonal blood supply (ventral and dorsal halves). IPV: inferior polar vein; SPV: superior polar vein; DZA: dorsal zonal artery; VZA: ventral zonal artery.

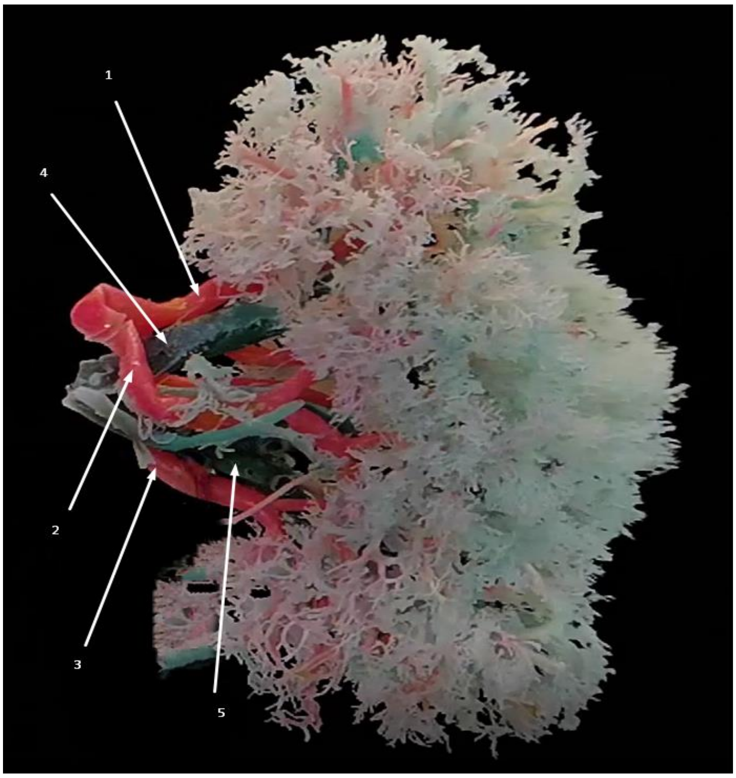
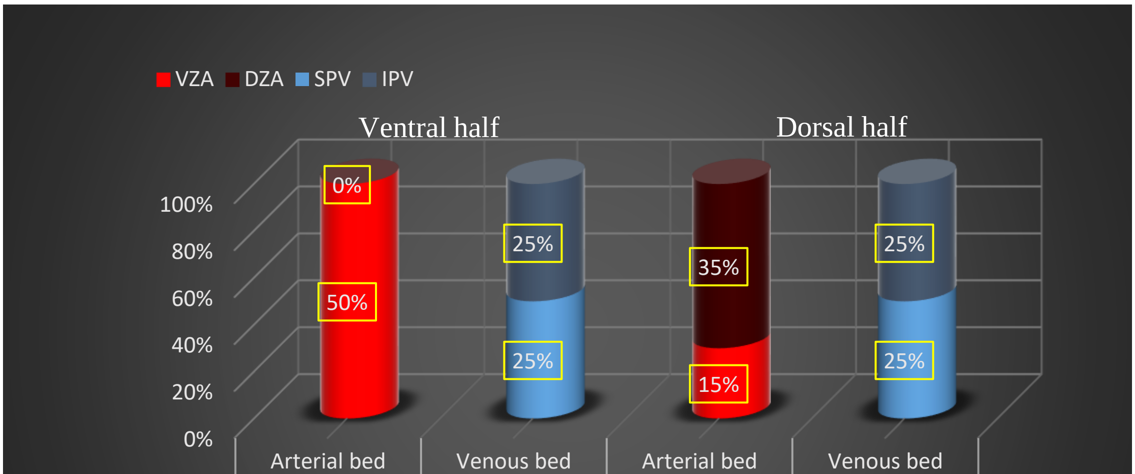


Figure 2. Variant I of venous outflow from the kidney with its bi-zonal blood supply (ventral and dorsal halves) (male, 53 years old). 1: DZA; 2: VZA; 3: branch of the dorsal artery; 4: SPV; 5: IPV.

Table 2. Variants of venous outflow from the kidney with its bi-zonal blood supply (ventral and dorsal halves), (total: 8.3% of cases, at p<0.05)

Variants (%) at p≤0.05	**Arteries**	**Artery branching types**	**Volume of blood supply (%) Number of interlobar arteries of the 3rd order (X±m)**	**Veins**	**Vein fusion types**	**Volume of venous outflow (%) Number of interlobar veins of the 3rd order (X±m)**
Variant II (8.3%)	Ventral half					
	VZA	Dispersed type	50±3%	SPV	Dispersed type	25±2%
			4±1			4±1
	DZA	Magistral type	0%	IPV	Dispersed type	25±1%
			3±1			4±1
Variants (%) at p≤0.05	Arteries	Artery branching types	Volume of blood supply (%) Number of interlobar arteries of the 3rd order (X±m)	Veins	Vein fusion types	Volume of venous outflow (%) Number of interlobar veins of the 3rd order (X±m)
Variant II (8.3%)	Dorsal half					
	VZA	Dispersed type	15±1%	SPV	Dispersed type	25±1%
			4±1			4±1
	DZA	Magistral type	35±2%	IPV	Dispersed type	25±2%
			3±1			4±1



	Arterial bed	Venous bed	Arterial bed	Venous bed
IPV		25%		25%
SPV		25%		25%
DZA	0%		35%	
VZA	50%		15%	

Figure 3. Variant II of venous outflow from the kidney with its bi-zonal blood supply (ventral and dorsal halves). IPV: inferior polar vein; SPV: superior polar vein; DZA: dorsal zonal artery; VZA: ventral zonal artery.

The DZA, A. dorsalis (zonal) (II), with the magistral type of branching, participated in the blood supply of the parenchyma of the dorsal zone of the kidney, which was divided into average into (X±m) 3±1 interlobar arteries, A. interlobares (III), supplying blood to the parenchyma in most of its the posterior segment, averaging 35±2% of the volume of blood supply to the entire parenchyma. We observed that the VZA, A. ventralis (zonal) (II), with a dispersed type of vascular branching, participated in the blood supply of the parenchyma of the dorsal zone of the kidneys, namely in the area of its polar segments, giving on average (X±m) 2±1 A. interlobares-1 (III) in the area of the polar segments, amounting to 15±1% of the volume of blood supply to the parenchyma of the entire kidney. On average, in this group of kidneys, the number of interlobar arteries was (X±m) 7±1. The venous system in this group of kidneys is represented by the SPV and the IPV that merge in the renal hilum relative to the horizontal plane, forming the main trunk of V. renalis (I). The venous outflow from the parenchyma of the ventral zone of the kidney is carried out through the SPV and IPV with dispersed types of vascular fusion, averaging 50±3% of the volume of venous outflow from the entire parenchyma of the kidney.

On average (X±m) 4±1 V. interlobares-1 (III) flowed in the SPV with a dispersed type of vascular fusion. On average (X±m) 4±1 V. interlobares-1 (III) flowed the inferior polar vein, V. inferior polus (zonal) (II), also with a dispersed type of vascular fusion, draining thereby the parenchyma of the anterior superior and anterior inferior segments, as well as the parenchyma of the ventral divisions of the polar segments. The venous drainage from the dorsal zone of the kidney was also carried out by the SPV and IPV. On average (X±m) 2±1 V. interlobares-1 (III) flowed into the SPV, and (X±m) 3±1 V. interlobares-1 (III) flowed into the IPV. They also had dispersed types of vascular fusion and drained the dorsal zone of the kidney, and in particular, the parenchyma of the posterior and dorsal divisions of the polar segments, averaging 50±2% of the volume of venous outflow from the entire renal parenchyma. On average, in this group of kidneys, the number of V. interlobares-1 (III) was (X±m) 8±1. The second group, which amounted to four variants, i.e. 27.1% of cases, included kidneys with a dichotomous variant of the division of A. renalis (I), but forming two arterial basins already in the superior and inferior poles of the kidney, also related to the bi-zonal blood supply. Further, during the study of preparations, a third group was identified, which amounted to four variants. These were 17.3% of cases where kidneys with a trichotomous variant of the division of A. renalis (I) forming basins were included. These were the inferior polar, superior middle, and superior posterior basin; superior polar, inferior middle, and inferior posterior basin, and finally, superior polar, central, and inferior polar basin, i. e. the three-zone blood supply to the kidneys. Thus, when identifying the distribution zones of arterial basins in the kidneys, we established bi- and trichotomic variants of the division of A. renalis (I) into A. (zonal) (II), forming the following three groups of arterial basins in the kidneys.

The first group consisted of 11 variants of polychromic corrosive preparations of arterial and venous vessels of the kidneys with a dichotomous variant of the division of A. renalis (I), forming two arterial basins in the ventral and dorsal zones of the kidney (bi-zonal blood supply to the kidney), which was observed on average in (X±m) 51.8% of cases. The second group consisted of four variants of polychromic corrosive preparations of the renal vessels, with a dichotomous variant of the division of A. renalis (I), forming two arterial basins in the superior and inferior poles of the kidney (bi-zonal blood supply to the kidney), which was observed on average in (X±m) 27.1% of cases.

There were three groups of kidneys with ventral and dorsal arterial basins but with three variants of venous outflow. In the first group (24.6%) veins drained the superior and inferior polar zones of the kidneys. The SPV drained the superior polar, superior anterior, and dorsal segments, and the IPV drained the inferior polar, inferior anterior, and dorsal segments of the kidneys. In the second group (19.7%), veins drained the ventral and dorsal zones of the kidneys. The ventral vein drained the superior and inferior anterior and polar segments, and the dorsal one drained the posterior and dorsal polar segments of the kidneys. In the third group (7.5%), the zones were drained by three veins: the ventral SPV drained the superior anterior and superior polar segment, the IPV drained the anterior and inferior polar segment and the dorsal vein drained the posterior and polar segments of the kidneys.

4. Conclusions

Our analysis showed that the sources of blood supply to the zones and segments of kidneys, their topography, and the number of zonal and segmental arteries have differences depending on the variants of the division of the main trunk of A. renalis (I) in the renal hilum in the horizontal and frontal plane, as well as the branching types (magistral or disperse) of intra-organ vessels. In the renal venous bed, the number of veins involved in the drainage of various zones and segments of the kidney and their confluence at the level of the links of the magistral venous vessels also depend on the variants and types of fusion of both intra- and extra-organ renal vessels. They have certain topographic and anatomical features, which is very important to consider in urological practice when ligating the neurovascular bundle during the segmental kidney resection.

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