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Variants of Blood Supply to Kidney Segments According to 3D Anatomical Analysis

Islam Uzgenbayevich Vagabov[1]*, Edgar Sabirovich Kafarov[1], Oleg Konstantinovich Zenin[2]

[1] Department of Normal and Topographical Anatomy with Operational Surgery, Chechen State University, Grozny, Russia.
[2] Department of Human Anatomy, Penza State University, Penza, Russia.

ABSTRACT

The study aimed to conduct a 3D anatomical analysis of corrosive preparations to identify the sources of blood supply to the kidney segments in the most common variant of the division of the main renal artery, A. renalis (I). The authors have studied 116 corrosive preparations of the human kidney arterial system made of fast-hardening polymers. On 3D models, the authors have determined the number and topography of arterial segments in the kidney depending on the number of identified segmental arteries (as sources of arterial segments) in a 3D projection: a) with the magistral type of arterial branching; b) with the loose type of arterial branching. The study has shown that the sources of blood supply to the kidney segments and the number of segmental arteries supplying the segments, as well as the places of their discharge and topography, have their differences depending on both the variants of the division of the main renal artery and the types of branching of its intra-organ branches. Consequently, in the kidneys, depending on the types of intra-organ branching (magistral or loose) and the level of di- or trichotomy, each specific segmental artery has its place, localization, source of discharge, and arterial basin, branching in the segments of the kidney. In one segment of the kidney, basins can be distributed on average (X ± m) from 1 to 3 segmental arteries, at p ≤ 0.05. It has been found that the polar and dorsal segments of the kidney more often have more segmental arteries.

Keywords: *Kidney, Renal Artery, Kidney Segment, 3D Modeling.*

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Corresponding author: Islam Uzgenbayevich Vagabov
E-mail ✉ vagabov.i.u @ mail.ru
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INTRODUCTION

Today, in urological practice, with the advent of modern methods of radiation research and the development of modern innovative medical and computer technologies, for the successful performance of organ-preserving operations on the kidneys or their segmental resections, there is a great need for information not only about the segments of the kidneys but also the features of their blood supply, as it is very important for ligation of the vascular nerve bundle before performing surgery [1-11]. 3D presentation of arterial segments of the kidney and topographic visualization of their boundaries on the surface of the organ increases the efficiency of preoperative planning, thereby reducing the number of possible postoperative bleeding [8-10]. However, for a 3D representation of kidney segments and their boundaries on the surface of an organ, accurate knowledge of the quantitative anatomy of the renal vessels and especially their intra-organ architectonics is necessary, and the question of the sources of blood supply to the renal segments, their place of origin, topography, the number and characteristics of nutrition in renal segments remains especially important. This is the most difficult issue of morphological research, which is of great importance in urological practice in connection with the problems of performing reconstructive and organ-preserving operations [10-15].

In this regard, the need to know the intra-organ architectonics of the arterial bed of the kidney and the peculiarities of its segmental structure when performing nephrotomy or segmental resection make surgeons and morphologists perform a more detailed study of the anatomical structure of arterial vessels of the kidney and its segments [2, 3, 16, 17].

To conduct a 3D anatomical analysis of corrosive preparations to identify the sources of blood supply to the kidney segments in the most common variant of the division of the main renal artery (RA), A. renalis (I).

MATERIALS AND METHODS

The material for the research consisted of 116 corrosive preparations of the human renal arterial system purchased under the Russian Foundation for Basic Research (RFBR) grant (Scientific project No. 19-315-90033 of August 21, 2019).

Algorithm of the study

1. According to the algorithm of our actions, 116 corrosive preparations of the human renal arterial system made of fast-hardening polymers were used to study the spatial organization of the arterial vessels of the kidneys. As an injectable mass, we used Protacryl + lead barium, which gives the preparations X-ray positivity during scanning (Patent application No. 202003471 dated 09.06.2020 for a "Polymer X-ray contrast composition for the manufacture of corrosive anatomical preparations" was filed by E. S. Kafarov, O. K. Zenin, I. U. Vagabov, A. Z. Vezirkhanov, 2020). The finished preparations were photographed using a Sony Cyber-shot DSC-RX10M 4 Black digital camera.
2. Subsequently, all corrosive preparations of kidney vessels for digitization were subjected to 3D scanning using a 3D microcomputer tomographic system RayScan 130 (Germany). Technical characteristics: Sources of X-ray radiation: Microfocus 130 kV; focal spot from 5 microns; X-ray detector: flat-panel 3-megapixel detector; measuring range (horizontal/vertical): 160 mm/175 mm (optionally 200 mm/135 mm). After digitization in the Mimics 8.1 computer program, 3D modeling of the arterial segments of the kidney was performed.
3. The computer program studied the number of arterial vessels of the RA of different orders depending on the types of intra-organ branching of each branch of the RA in 3D projection, including a) the number of vessels of the first order (I); b) the number of vessels of the second-order (II); c) the number of vessels of the third-order (III); d) the number of vessels of the fourth-order (IV). The number of segmental arteries in the kidneys was determined depending on the types of intra-organ branching of the branches of the RA in 3D projection: a) with the magistral type of arterial branching; b) with the loose type of arterial branching.
4. On 3D models, the number and topography of arterial segments in the kidney were determined depending on the number of identified segmental arteries (as sources of arterial segments) in 3D projection: a) with the magistral type of arterial branching; b) with the loose type of arterial branching.
5. All the obtained digital material and the data of instrumental research methods were processed by the methods of variation statistics using a workstation with an *Intel Core2Duo T5250 1.5 GHz processor*, RAM up to *2GB* on the *Windows 7 platform.* In the course of the work, we used the *Excel* application package from *Microsoft Office 2007*.

RESULTS AND DISCUSSION

We found that on 81 corrosive preparations of arterial vessels of human kidneys out of 116 in this group, the main a. renalis divided into two branches, which was observed in 69.8% of cases. In this case, the division of a. renalis relative to the frontal plane to the ventral and dorsal branches was found in 54.2% of cases (63 out of 81 preparations). In 15.5% of cases (18 preparations), the main RA was divided relative to the horizontal plane into the superior polar and inferior polar branches. Subsequently, we found variants, where on 35 corrosive preparations of arterial vessels of the kidneys out of 116 the main a. renalis divided into 3 branches, which was observed in 30.1% of cases. At the same time, out of 35 corrosive preparations in 12.9% of cases (15 preparations), a. renalis was divided into the ventral, dorsal, and superior polar branches relative to the frontal and horizontal planes; in 9.4% of cases (11 preparations) a. renalis was divided into the ventral, dorsal and inferior polar branches relative to the frontal and horizontal planes; in 5.1% of cases (6 preparations) a. renalis was divided into two ventral and one dorsal branch relative to the frontal plane, and in 2.5% of cases (3 preparations) a. renalis was divided into the superior polar, central and inferior polar branches.

In the above material, we found that out of 116 corrosive preparations of human renal arterial vessels on 63 preparations, the main RA, a. renalis was divided into the ventral and dorsal branches relative to the frontal plane (54.2% of cases). At the same time, on 19 preparations out of 63 a. renalis branched at the hilum of the kidney, that is, lateral to the sagittal plane, tangent to the medial edge of the kidney (intrarenal variant), which accounted for 30.1% of cases. In 69.8% of cases, (44 preparations) a. renalis was divided at a distance from the hilum of the kidneys, that is, medial to the sagittal plane, tangent to the medial border of the kidneys (the extrarenal variant).

For comparison, later a 3D analysis of the branching types of the intra-organ arterial bed of the kidney was carried out with a quantitative identification of arteries of the 3rd and 4th order and their distribution zones in the renal parenchyma, considering the gender characteristics and the side of the body.

First of all, as one of the observed conclusions, it can be noted that in 54.2% of cases, we found a variant of the division of the main a renalis into the ventral and dorsal branches. Subsequently, a 3D analysis of the links of the arterial bed of the kidney, considering the types of branching of its intra-organ vessels, showed that in the first case, the ventral branch of a. renalis was divided according to the loose type on average into (X ± m) 5 ± 1 third-order arteries, and the dorsal branch was divided according to the magistral type, branching on average into (X ± m) 3 ± 1 third-order arteries, which was found in 46.2% of cases. With all this, in males, this type of branching of intra-organ arterial vessels of the kidneys was found in 7.3% of cases in the right kidney and 6.2% of cases in the left one, at $p \leq 0.05$. In females, the intra-organ arterial vessels of the kidneys with this type of branching were found on the right side in 4.5% of cases, and on the left side in 5.4% of cases, at $p \leq 0.05$.

As a logical conclusion of the carried out multidimensional (3D) analysis of the intra-organ arterial bed of the kidney, we can state that the level organization of the links of the organization of the arterial system of the kidney is represented by the RA, A. renalis (I), with its division into the ventral and dorsal branches. The ventral artery, A. ventralis or zonal (zonal) (II), with loose branching, on average, was divided into (X ± m) 4 ± 1 third-order arteries, A. interlobares - 1 (III), located in the parenchyma of the ventral half of the kidney and the area of its poles. Subsequently, each artery was, on average, divided into (X ± m) 2 ± 1 fourth-order arteries, A. interlobares - 2 (IV), with further branching in the area of the cortico-medullary zone into the arcuate arteries, A. arcuatae (V). Interlobular arteries, A. interlobulares (VI), went from the arcuate arteries into the cortical substance of the kidney. Compared with the ventral branch, the dorsal branch of the RA, A. dorsalis (zonal) (II), was divided according to the magistral type, with a departure of (X ± m) 3 ± 1 interlobar vessels of the third order, A. interlobares (III), from the main artery. The original arteries for the most part were divided in the parenchyma of the central zone of the dorsal half of the kidney and in the area of the cortico-medullary zone they branched out into arcuate arteries, A. arcuatae (IV), from which the interlobular arteries, A. interlobulares (V), branched off in the kidney cortex. With this type of branching, the number of vessels of the third-order (III) averaged (X ± m) 7 ± 1, and the number of vessels of the fourth-order (IV) reached up to (X ± m) 12 ± 2.

According to the study, in this group of corrosive preparations of renal arterial vessels with this variant and type of branching, the average number of segmental arteries in men and women equaled (X ± m) 7 ± 1.

It was found that with a five-segmental structure of the kidney with this variant and the type of branching of its intra-organ arteries, the superior pole segment was supplied with blood in the first variant by one segmental artery, A. interlobares 1 (III), extending from the ventral branch, A. ventralis (zonal) (II), (41.2% of cases), which was mostly located in the ventral half of the superior pole of the kidney and less in the dorsal half. In the second variant, this segment was supplied with blood by two segmental arteries extending from the ventral and dorsal branches (32.3% of cases, at $p \le 0.05$), with their branches located in the ventral and dorsal parts of the superior pole of the kidney. In the third variant, one segmental artery was distributed in the superior pole segment, extending from the main RA, A. renalis (I), (21.2%), and in the fourth variant, that segment was supplied with blood by one segmental artery at $p \le 0.05$, extending from the dorsal branch, A. dorsalis (zonal) (II), which was found in 5.3% of cases, with $p \le 0.05$. At the same time, its branches in the greater part were distributed in the dorsal half of the superior pole segment. With this variant and type of branching of intra-organ arteries, the kidneys were directed to the superior anterior and inferior anterior segments along one segmental artery from the ventral branch of the main RA, evenly distributed with their branches in the superior and inferior parts of the central part of the renal parenchyma. In the first variant, the inferior pole segment was supplied with one segmental artery, A. interlobares 1 (III), extending from the ventral branch (68.3% of cases), located with its branches mostly in the ventral part and less in the dorsal parts of the inferior pole of the kidney. In the second variant, the blood supply to the inferior pole segment involved two segmental arteries extending from the ventral and dorsal branches (27.4% of cases), located in the ventral and dorsal parts of the inferior pole of the kidney. In the third variant, this segment was supplied by one segmental artery extending from the main RA, A. renalis (I), which was found in 4.3% of cases.

The blood supply to the posterior segment was provided by one segmental artery, which was a continuation of the dorsal branch, A. dorsalis (zonal) (II) of the main RA, located with its branches in the parenchyma of the posterior segment.

Thus, summarizing all of the above, it should be noted that we carried out a 3D quantitative analysis of the sources of segmental arteries depending on the number and topography of zonal branches with different variants of division and types of branching of the vessels of the arterial bed of the kidney. The results of the study showed that in the five-segmental kidney, in the presence of a two-zone (ventral and dorsal) blood supply system (considering the magistral and/or the loose type of branching), the superior pole segment was supplied by 1 segmental artery extending from the ventral branch (41.2% of cases, at $p \le 0.05$). In the second variant, the segment was supplied on average ($X \pm m$) by 2 segmental arteries extending from the ventral and dorsal branches (32.3% of cases). In the third variant, 1 artery was located in the segment, extending from the main RA, A. renalis (I), (21.2% of cases, at $p \le 0.05$), and in the fourth variant, the segment was also supplied with one artery extending from the dorsal branch, which was found in 5.3% of cases, at $p \le 0.05$.

Further, it was found that the supply of the superior anterior segment of the kidney was carried out by 1 segmental artery extending from the ventral branch of the RA (83.3% of cases, at $p \le 0.05$) or by 2 segmental arteries, also extending from the ventral branch, which was observed in 16.6% of cases. The inferior anterior segment of the kidney was supplied with blood by 1 segmental artery extending from the ventral branch (68.3% of cases, at $p \le 0.05$) or by 2 segmental arteries also extending from the ventral branch of the main RA, which was found in 27 4% of cases.

As for the inferior pole segment, with this blood supply system, it was supplied by 1 segmental artery extending from the ventral branch of the RA (68.3% of cases). In the second variant, the segment was supplied on average ($X \pm m$) by 2 segmental arteries extending from the ventral and dorsal branches of the main RA (27.4% of cases, at $p \le 0.05$). In the third variant, the blood supply was performed by 2 segmental arteries, also extending from the ventral branch (16.4% of cases, at $p \le 0.05$.). In the fourth variant, the segment was supplied by 1 branch extending from the main RA, which was found in 4.3% of cases, at $p \le 0.05$. It was found that in these kidneys, the posterior segment was supplied by 1 segmental artery, as a continuation of the dorsal branch (86.7% of cases) or by 2 segmental arteries, also extending from the dorsal branch, which was observed in 13.2% cases, at $p \le 0.05$. With the loose type of branching of the ventral branch and the main type of branching of the dorsal branch, 1 segmental artery participated in the blood supply of the posterior single segment of the kidney, as a continuation of the dorsal branch.

CONCLUSION

In the arterial bed of the kidney, regardless of the types of branching, the role of segmental arteries is played by interlobar vessels of the 3rd order, which are the main sources of blood supply to the renal segments. In the kidneys, depending on the variants of the division of the RAs, as well as the types of loose or magistral branching of intra-organ arteries, there are levels of di- or trichotomy, which form their hierarchy of links and the number of segmental arteries supplying the renal segments. Moreover, basins of several segmental arteries can be located in one segment of the kidney. The sources of blood supply to the segments of the kidney and the number of segmental arteries supplying the segments, as well as the places of their origin and topography, have their differences depending on both the variants of the division of the main RA and the types of division of its intra-organ branches. Consequently, in the kidneys, depending on the types of intra-organ branching (magistral or loose) and the level of di- or trichotomy, each specific segmental artery has its place, localization, source of discharge, and arterial basin, branching in the segments of the kidney. In one segment of the kidney, basins can be distributed on average (X ± m) from 1 to 3 segmental arteries, at $p \leq 0.05$. It has been found that the polar and dorsal segments of the kidney more often have more segmental arteries.

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