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Analysis of Arterial Basins and Venous Drainage Zones in Kidneys with a Two-zone Blood Supply System

Edgar Sabirovich Kafarov[1]*, Oleg Konstantinovich Zenin[2], Khizir Mukhidinovich Bataev[3]

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

ABSTRACT

To review zonal features of the blood supply to the kidneys and to identify the venous basins, depending on the options for the structure of the arterial and venous bed of the kidney. The study was carried out on 124 polychrome corrosive preparations of the arterial and venous systems of the human kidney. For digitization, the preparations were subjected to 3D scanning. The authors identified the zones of local blood supply to the areas of the renal parenchyma and venous drainage depending on the variants of the division of the renal artery and the fusion of the renal vein in a 3D projection in a computer program.
It has been established that the features of the local regional blood supply to the kidney zones and venous outflow from its parenchyma have a dependence associated with the variants of the division of the main renal artery in the renal hilum on the 2nd order arteries, that is, zonal arteries, A. zonal (II), which have their own quantitative and topographic characteristics in the hilum of the kidney, and later in the parenchyma of the organ, where they form the corresponding vascular basins. The structure of the vascular basins will depend on the loose or magistral types of intra-organ branching of the zonal arteries, A. zonal (II) into the arteries of the 3rd, 4th, etc. order. The system of venous outflow from the kidney has a similar structure, except for the absence of zones or regions of isolated venous outflow from the kidney.

Keywords: Kidney, Renal artery, Renal vein, 3D-analysis.

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Corresponding author: Edgar Sabirovich Kafarov
E-mail ✉ kafarov.e.s@mail.ru
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INTRODUCTION

Recently, more and more attention is paid to the morphology of renal vessels using modern methods of radiation research and 3D analysis [1, 2]. The role of renal vessels has also increased in terms of performing surgical interventions. This information is especially necessary when performing segmental resections or organ-preserving kidney operations using modern 3D technologies [2, 3]. According to some authors, for the successful performance of surgical interventions, clinicians pay close attention to the structural features of the renal arteries and veins, as well as to the topographic and anatomical features of their position in the renal hilum related to the pelvis [3, 4]. Particular attention in clinical practice is paid to the questions concerning the variants of the division of the renal arteries at the hilum of the kidney, their intra-organ branching in the parenchyma of the organ, and the structural features of the venous link of the vascular bed of the kidney involved in the processes of drainage of the parenchyma, thereby maintaining normal hemodynamics in the kidney, metabolic processes, etc. [4-6]. The physiological role of these vessels is important in maintaining trophic and drainage functions where conditions such as hypertension and congestive kidney may develop in pathology [7-10]. According to some authors, when performing surgical interventions, information about the peculiarities of the blood supply to the kidney zones, the branching of the vascular basins in the organ parenchyma is very important, and information about the venous drainage of the organ is very important as well because metastases spread through these vessels from tumor foci [11-13].

The literature contains conflicting information about the structural features of these arteries and veins, their intra-organ branches, and the distribution of venous vessels [13]. All these determine the need for further morphological studies using modern classical methods, the results of which could clarify the morphology of these vessels.

The study aimed to review the zonal features of the blood supply to the kidneys and to identify the venous basins depending on the variants of the structure of the arterial and venous bed of the kidney.

MATERIALS AND METHODS

This study was carried out on 124 polychrome corrosive preparations of the arterial and venous system of the human kidney made from the kidneys of corpses of people of both sexes, in the age range from 22 to 75 years, who had died from diseases not related to the pathology of the urinary system. The preparations had been acquired within the framework of RFBR grant No. 18-29-09118 obtained in 2018. Since the study involved the topographic and anatomical features of the structure of the arterial and venous bed of the human kidney, the variants of intra-organ branching of the arterial vessels of the kidney in the parenchyma of the organ and the types of fusion of venous vessels that do not change at the stages of ontogenesis and are genetically determined, we did not study these vessels in the age aspect.

Research algorithm

1. Polychrome corrosive preparations of the arterial and venous system of the human kidney for digitization were subjected to 3D scanning using a 3D microcomputer tomographic digital system *RayScan 130* (Germany) (current rate: 132 mAs, voltage: 140 kV, helix pitch: 1.0 mm), and subsequent 3D modeling (Agreement No. 5 dated 18.07.2020).
2. On polychrome corrosion preparations of arterial and venous vessels of the kidney, intra-organ branches of the renal artery and vein were identified, noting the following: a) the number of intra-organic arteries and veins of the kidney; b) the topography of the renal arteries and veins inside the kidney.
3. In a computer program in a 3D projection, the zones of local blood supply to the areas of the renal parenchyma and venous drainage were identified depending on the variants of the division of the renal artery and the fusion of the renal vein, as well as on the types of intra-organ division of the branches of the renal artery and the fusion of the branches of the renal vein in 3D projection with di- and trichotomous variants of the division of the arteries, and the fusion of the veins.

All the obtained digital materials 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 *2 GB* on the *Windows 7* platform. In the course of the work, we used the *Excel* application package from *Microsoft Office 2007*.

RESULTS AND DISCUSSION

During the study, depending on the dichotomous and trichotomous variants of the division of the main renal artery, A. renalis (I) in the hilum of the kidney in relation to the frontal, sagittal and horizontal plane into the vessels of the 2nd order, that is, the zonal arteries, A. (zonal) (II), having their own specific arterial pools in the kidneys, we identified the corresponding groups of preparations: 1) the first group of preparations with a dichotomous division was made up of the kidneys with a two-zone blood supply system (the ventral and dorsal zones of the kidney, or the superior and inferior polar zones of the kidney); 2) the second group of preparations with a trichotomy variant of division consisted of the kidneys with a three-zone blood supply system (the inferior polar, superior anterior and superior posterior zones of the kidney; the superior polar, inferior anterior and inferior posterior zones of the kidney; the superior polar, inferior polar and central zones of the kidney).

In the study, we identified venous vessels involved in the drainage of the corresponding zones of the kidney with individual characteristics of their arterial blood supply and different zonal structure.

Thus, with the first dichotomous variant of the renal artery division, A. renalis (I), in two-zone kidneys, which was observed in 9.2% of cases, the main renal artery, A. renalis (I), is divided into the ventral, A. ventralis (zonal) (II) and dorsal zonal arteries, A. dorsalis (zonal) (II) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the loose type of vascular branching is divided on average into (X ± m) 4 ± 1 interlobar arteries of the 1st order, which supply blood to the parenchyma of the ventral zone of the kidney. In particular, the arteries branch in the anteroposterior and anterior inferior segments, touching on the segments of the superior and the inferior poles, pass to the dorsal surface of the same poles. With this variant and type of branching, the dorsal zonal artery with the loose type of intra-organ branching also participates in the blood supply to the ventral zone of the kidney in the region of its poles, dividing on average into (X ± m) 2 ± 1 interlobar arteries of the 1st order.

The blood supply to the dorsal zone of the kidney involves the branches of the dorsal zonal artery with the loose type of vascular branching, dividing on average into (X ± m) 3 ± 1 interlobar arteries of the 1st order that supply the parenchyma of the dorsal zone of the kidney, in particular, the areas of the posterior and dorsal parts of the superior polar and inferior polar segments.

The ventral zonal artery with loose branching in the region of the kidney poles is also divided on average into (X ± m) 2 ± 1 interlobar arteries of the 1st order for blood supply to the dorsal zone of the kidney in the region of its poles. The venous system in this group of kidneys is represented by the superior polar vein, V. superius polus (II) and inferior polar vein, V. inferior polus (II) merging in the hilum of the kidney relative to the horizontal plane and forming the main renal vein, V. renalis (I). The venous outflow from the ventral zone of the kidney is performed through the superior and inferior polar veins with loose types of vascular fusion. The superior polar vein drains the ventral sections of the superior and superior anterior segments, and the inferior polar vein drains the parenchyma of the ventral sections of the inferior and inferior anterior segments. Each polar vein, on average, has (X ± m) 4 ± 1 interlobar veins of the 1st order flowing into it. Venous drainage from the dorsal zone of the kidney is also performed through the superior and inferior polar veins. Moreover, (X ± m) 2 ± 1 interlobar veins of the 1st order flow into the superior polar vein on average, and (X ± m) 3 ± 1 interlobar veins of the 1st order with loose types of vascular fusion flow into the inferior polar vein, draining the dorsal zone of the kidney, and in particular, the posterior segment and dorsal sections of the polar segments.

In the second variant of two-zone kidneys, which we observed in 8.3% of cases, the main renal artery, A. renalis (I) is divided into the ventral, zonal branch A. ventralis (zonal) (II), and dorsal zonal branch, A. dorsalis (zonal) (II) (dichotomous variant) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the loose type of vascular branching is, on average, divided into (X ± m) 4 ± 1 interlobar arteries of the 1st order, which supply blood to the ventral zone of the kidney, in particular, the parenchyma of the superior anterior and inferior anterior segments, as well as the ventral sections of the polar segments. The dorsal zonal artery in this group of kidneys with this variant and type of branching of intra-organ arterial vessels does not participate in the blood supply to the ventral zone.

It was found that the dorsal zonal artery with the magistral type of vascular branching was involved in the blood supply to the dorsal zone of the kidney, dividing on average into (X ± m) 3 ± 1 interlobar arteries that supplied the parenchyma of the dorsal zone of the kidney and, in most of its arteries, branched in the posterior segment. The ventral zonal artery with loose branching is also involved in the blood supply to the dorsal zone of the kidneys, namely in the area of its pole segments, where it is divided on average into (X ± m) 2 ± 1 interlobar arteries of the 1st order in the area of the poles. The venous system in this group of kidneys is represented by the superior polar vein, V. superius polus (II), and inferior polar vein, V. inferior polus (II), which merge at the hilum of the kidneys relative to the horizontal plane, forming the main trunk of the renal vein, V. renalis (I). The venous outflow from the ventral zone of the kidney is performed through the superior and inferior polar veins with loose types of vascular fusion. An average of (X ± m) 4 ± 1 interlobar veins of the 1st order flows into each polar vein, thereby draining the parenchyma of the anterior superior and anterior inferior segments, as well as the ventral sections of the polar segments. The venous drainage from the dorsal zone of the kidney is also performed through the superior polar and inferior polar veins, and, on average, (X ± m) 2 ± 1 interlobar veins of the 1st order flow into the superior polar vein, and (X ± m) 3 ± 1 interlobar veins of the 1st order flow into the inferior polar vein also with loose types of vascular fusion, draining the dorsal zone of the kidney, and in particular, the parenchyma of the posterior and dorsal sections of the polar segments.

It was found that in the third variant in the two-zone kidneys, which we observed in 7.1% of cases, the main renal artery, A. renalis (I) was divided into the ventral zonal artery, A. ventralis (zonal) (II), and dorsal zonal artery, A. dorsalis (zonal) (II), (dichotomous variant) relative to the frontal plane in the hilum of the kidney. Moreover, the ventral zonal artery with the magistral type of vascular branching is divided, on average, into (X ± m) 4 ± 1 interlobar arteries supplying the parenchyma of the ventral zone of the kidney, in particular, the anteroposterior, anterior inferior segments, and the ventral sections of the polar segments.

In the dorsal zone of the kidney, the dorsal zonal artery is divided with the magistral type of branching of arterial vessels, dividing on average into (X ± m) 3 ± 1 interlobar arteries that supply the parenchyma of the dorsal zone of the kidney, in particular, the posterior segment and dorsal sections of the polar segments. The ventral zonal artery with the magistral type of vascular branching also participated in the blood supply to the dorsal zone of the kidney, dividing in the polar region on average into (X ± m) 1 ± 1 interlobar artery for blood supply to the parenchyma of the posterior segments of the polar segments. The venous system in this group of kidneys is represented by the superior polar vein, V. superius polus (II), and inferior polar vein, V. inferior polus (II), which merge at the hilum of the kidneys relative to the horizontal plane, forming the main trunk of the renal vein, V. renalis (I). Venous outflow from the ventral zone of the kidneys is performed through the superior and inferior polar veins with loose types of vascular fusion. Moreover, (X ± m) 4 ± 1 interlobar veins of the 1st order flow into the superior polar vein with the loose type of vein fusion, and (X ± m) 3 ± 1 interlobar veins of the 1st order flow into the inferior polar vein. The superior polar vein drains the superior anterior and ventral parts of the superior polar segment of the kidney, and the inferior polar vein drains the inferior anterior and ventral parts of the inferior polar segment. Venous drainage from the dorsal zone of the kidney is also performed through the superior and inferior polar veins. Moreover, on average (X ± m) 3 ± 1 interlobar veins of the 1st order flow into the superior polar vein with the loose type of vascular fusion, and (X ± m) 2 ± 1 interlobar veins of the 1st order flow into the inferior polar vein, draining the dorsal zone, and in particular, the parenchyma of the posterior segment and the dorsal sections of the polar segments.

In the bizonal kidneys in the fourth variant, which we observed in 6.2% of cases, the main renal artery, A. renalis (I) is dichotomously divided into the ventral, A. ventralis (zonal) (II), and dorsal zonal arteries, A. dorsalis (zonal) (II), (dichotomous variant) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the loose type of vascular branching is divided on average into (X ± m) 5 ± 1 interlobar arteries of the 1st order, which supply blood to the parenchyma of the ventral zone of the kidney, namely the superior anterior, inferior anterior segments and the ventral sections of the polar segments. The dorsal zonal artery with the loose type of vascular branching also participates in the blood supply to the ventral zone of the kidneys, dividing in the polar region on average into (X ± m) 1 ± 1 interlobar artery of the 1st order, thereby supplying blood to the parenchyma of the ventral zone. As for the blood supply to the dorsal zone of the kidney, the dorsal zonal artery with the loose type of vascular division branches here, dividing on average into (X ± m) 3 ± 1 interlobar arteries of the 1st order that supply the parenchyma of the dorsal zone of the kidney, namely the region of the posterior and polar segments. The ventral zonal artery also participates in the blood supply to the dorsal zone in this type of kidneys, where, in the area of the poles, it is divided on average (X ± m) 2 ± 1 interlobar arteries of the 1st order for the blood supply to the posterior sections of the polar segments.

Unlike other groups, the venous system in these kidneys duplicates the course of the magistral arteries. Thus, with this variant and type of fusion of venous vessels, the ventral zone of the kidney is drained by a ventral vein with the loose type of vessel fusion, into which, on the average, (X ± m) 6 ± 1 interlobar veins of the 1st order flow, draining the superior anterior, inferior anterior segments and ventral divisions of the polar segments. The dorsal vein with the loose type of vascular fusion is also involved in the drainage of the ventral zone of the kidney. On average, (X ± m) 3 ± 1 interlobar veins of the 1st order flow into it, in particular, the dorsal vein draining the ventral sections of the polar segments.

The dorsal vein with the loose type of vascular fusion is involved in the drainage of the dorsal zone of the kidney. On average (X ± m) 4 ± 1 interlobar veins of the 1st order flow into it, draining the posterior and dorsal sections of the polar segments. Venous outflow from the dorsal zone of the kidney is also performed into the ventral vein with the loose type of vascular fusion, where, on average, (X ± m) 2 ± 1 interlobar veins of the 1st order flow from the parenchyma of the polar segments.

In the fifth variant, in two-zone kidneys, which we observed in 5.2% of cases, the main renal artery, A. renalis (I), is dichotomously divided into the ventral zonal artery, A. ventralis (zonal) (II), and dorsal zonal artery, A. dorsalis (zonal) (II), (dichotomous variant) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the magistral type of vascular branching is divided, on average, into (X ± m) 4 ± 1 interlobar arteries that supply blood to the parenchyma of the ventral zone of the kidney, in particular, the superior anterior, inferior anterior segments and the ventral sections of the polar segments. The dorsal zonal artery does not participate in the blood supply to the ventral half of the kidney with this type of arterial branching.

The blood supply to the dorsal zone of the kidney involves the branches of the zonal artery with the magistral type of vascular branching, dividing on average into (X ± m) 4 ± 1 interlobar arteries that supply the parenchyma of the dorsal zone of the kidney, located in the posterior segment and the dorsal sections of the polar segments. The ventral zonal artery with the magistral type of vascular branching is also involved in the blood supply, dividing in the region of the poles of the kidneys to the dorsal surface on average into (X ± m) 1 ± 1 interlobar artery.

In this group, venous outflow from the ventral zone of the kidneys is performed into the ventral superior polar vein, A. ventralis polus superior (II) and the ventral inferior polar vein, A. ventralis polus inferior (II) with loose types of vascular fusion, into which, on average, (X ± m) 3 ± 1 and, (X ± m) 4 ± 1 interlobar veins of the 1st order flow, respectively, and the ventral superior polar vein drains the parenchyma of the superior anterior and ventral sections of the superior polar segment. The ventral inferior polar vein drains the anterior inferior parenchyma as well as the ventral parts of the inferior polar segment. Venous drainage from the dorsal zone of the kidney is performed into the dorsal central vein, V. dorsalis, centralis (II) with the magistral type of vascular fusion, where on average (X ± m) 3 ± 1 interlobar veins flow, draining most of the parenchyma of the posterior segment and a smaller part of the parenchyma of the dorsal polar segments. Venous outflow from the dorsal zone of the kidney is also performed into the ventral superior polar and ventral inferior polar veins with loose types of vascular fusion, into which, on average, the, (X ± m) 2 ± 1 interlobar veins of the 1st order flow, draining the dorsal parts of the polar segments.

The next group included two-zone kidneys, which constituted the sixth variant, observed in 3.4% of cases, where the main renal artery, A. renalis (I) is divided into the ventral zonal artery, A. ventralis (zonal) (II), and dorsal zonal artery, A. dorsalis (zonal) (II), (dichotomous variant) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the loose type of vascular branching is divided on average into (X ± m) 4 ± 1 interlobar arteries of the 1st order, which supply blood to the parenchyma of the ventral zone of the kidney, in particular, the superior anterior, inferior anterior segments and the ventral sections of the polar segments. The dorsal zonal artery with this variant and type of vascular branching does not participate in the blood supply to the ventral zone of the kidney.

It was found that the dorsal zonal artery with the magistral type of vascular branching was involved in the blood supply to the dorsal zone of the kidney, dividing on average into (X ± m) 3 ± 1 interlobar arteries that supply the parenchyma of the dorsal zone, namely, the posterior segment and the dorsal sections of the polar segments. The ventral zonal artery with loose branching in the region of the kidney poles is divided on average into (X ± m) 2 ± 1 interlobar arteries of the 1st order, participating in the blood supply to the dorsal zone of the kidney in the region of its poles.

The study showed that in this group of corrosive kidney preparations, the venous outflow from the ventral zone was performed into the ventral vein, V. ventralis (II) with the loose type of vascular fusion, into which, on average, (X ± m) 6 ± 1 interlobar veins of the 1st order flowed, draining the parenchyma of the superior anterior and the inferior anterior segments, as well as the ventral sections of the polar segments. The dorsal vein, V. dorsalis (II) does not participate in the drainage of the ventral zone of the kidneys in this variant. Venous drainage from the dorsal zone of the kidney is performed into the dorsal vein with the magistral type of vascular fusion, into which, on average (X ± m) 3 ± 1 interlobar veins flow, participating in the drainage of the parenchyma of the posterior segment and posterior sections of the polar segments. Besides, the ventral vein with the loose type of vascular fusion is also involved in the venous outflow from the dorsal zone of the kidneys. On average, (X ± m) 3 ± 1 interlobar veins of the 1st order flow into it, draining the dorsal sections of the polar segments.

In two-zone kidneys in the seventh variant, which was found in 3.2% of cases, the main renal artery, A. renalis (I) is divided into the ventral zonal artery, A. ventralis (zonal) (II), and dorsal zonal artery, A. dorsalis (zonal) (II), (dichotomous variant) in the hilum of the kidney relative to the frontal plane. Moreover, the ventral zonal artery with the loose type of vascular branching is divided, on average, into (X ± m) 4 ± 1 interlobar arteries of the 1st order, which supply blood to the parenchyma of the ventral zone of the kidney, in particular, the anterior superior, anterior inferior segments and the ventral sections of the polar segments.

The dorsal zonal artery is not involved in the blood supply to the ventral zone of the kidneys. As for the blood supply to the dorsal zone of the kidney, here the dorsal zonal artery is divided with the magistral type of vascular branching, dividing on average into (X ± m) 3 ± 1 interlobar arteries that supply the parenchyma of the dorsal zone of the kidney, in particular, the posterior segment and the dorsal sections of the polar segments. The ventral zonal artery with loose branching in the region of the kidney poles branches on average into (X ± m) 2 ± 1 interlobar arteries of the 1st order for blood supply to the dorsal zone of the kidney.

Thus, our experimental morphological study is based on a 3D analysis of variants of the intra-organ division of the magistral branches of the renal arteries and the fusion of the magistral renal venous vessels with the identification of topographic and anatomical features of the structure of the arterial vessels of the kidneys related to the venous ones, which would be of great clinical significance for identifying the zones of local venous drainage and metastasis in the kidneys with tumors or for ligating the vascular bundle when performing a kidney resection, mainly in organ-preserving operations [13-15].

Besides, during the study, we have established di-, and trichotomic variants of the division of the renal artery into zonal arteries, A. (zonal) (II), forming 3 groups of arterial basins in the kidneys. Thus, the 1st group, which amounted to 11 variants, (51.8% of cases) included kidneys with a dichotomous type of renal artery division, forming 2 basins in the kidney in the ventral and dorsal zones, that is, a two-zone blood supply. Group 2, which comprised 4 variants (27.1% of cases), included kidneys with a dichotomous type of renal artery division, forming 2 basins in the superior and inferior poles of the kidney (a two-zone blood supply as well). The 3rd group, which amounted to 4 options (17.3% of cases) included the kidneys with a trichotomous type of division of the renal artery, forming the following arterial basins: a) inferior polar, superior anterior, and superior posterior; b) superior polar, inferior anterior and inferior posterior; d) superior polar, central and inferior polar. That is, we are talking about a three-zone blood supply to the kidney, which is also very important to take into account in a clinical setting [15, 16].

Further, during the study, we identified 3 groups of kidneys with ventral and dorsal arterial basins [16], but with 3 variants of venous outflow. Thus, in the 1st group (24.6% of cases), the veins drained the superior and inferior polar zones of the kidney. At the same time, the superior polar vein participated in the drainage of the superior polar, superior anterior, dorsal segments, the inferior polar vein drained the inferior polar, inferior anterior, and dorsal segments [16]. In the 2nd group (19.7% of cases), the veins drained the ventral and dorsal zones of the kidney. The ventral vein was involved in the drainage of the superior anterior, inferior anterior, and polar segments, while the dorsal vein was involved in the drainage of the posterior and dorsal polar segments. In the 3rd group (7.5% of cases), the kidney zones were drained by 3 veins. Thus, the ventral superior polar vein drained the superior anterior and superior polar segments. The inferior polar vein was involved in the drainage of the anterior inferior and inferior polar segments, and the dorsal vein drained the posterior and polar segments of the kidneys.

CONCLUSION

The peculiarities of the local regional blood supply to the kidney zones and venous outflow from its parenchyma have a dependence associated with the variants of the division of the main renal artery at the renal hilum on the 2nd order arteries, that is, the zonal arteries, A. zonal (II), which have their own quantitative and topographic characteristics in the hilum of the kidney, and later in the parenchyma of the organ, where they form the corresponding vascular basins. The structure of the vascular basin itself will also depend on the loose or magistral type of intra-organ branching of the zonal arteries, A. zonal (II) into the arteries of the 3rd, 4th, etc. order. The system of venous outflow from the kidney has a similar structure, except for the absence of zones or regions of isolated venous outflow from the kidney, which is important when performing segmental resections of the kidney.

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