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Features of Blood Supply to Four-Segment Kidneys

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ABSTRACT

The study aimed to conduct a 3D quantitative analysis of the arterial bed of four-segment kidneys and to study the characteristics of their blood supply. The authors have investigated 128 corrosive preparations of the arterial system of the human kidney made of fast-hardening polymers. The preparations were subjected to 3D scanning. 3D models were used to study the quantitative characteristics of arterial vessels and segments of the kidney depending on the topography, the number of identified segmental arteries, and arterial basins. It was found that out of 128 investigated corrosive preparations, four-segment kidneys were observed in 10.5% of cases. In those kidneys, one could distinguish the following segments: the superior pole, the inferior pole, the anterior and posterior segments. In four-segmental kidneys, regardless of the type of two-zone blood supply: (the ventral and dorsal zones) or (the superior and inferior polar zones), on average, 1 segmental artery (95.4% of cases), 2 segmental arteries (3.3% of cases), or 1 segmental artery extending from the main renal artery (2.4% of cases) participate in the blood supply of the polar segments. The blood supply to the anterior segment is performed by 1 segmental artery extending from the ventral branch of the RA (96.6%of cases), or by 2 segmental arteries extending from the ventral branch (3.3% of cases). The blood supply to the posterior segment is performed by 1 segmental artery extending from the dorsal branch of the RA (97.5% of cases) or by 2 segmental arteries (2.5% of cases), at p ≤ 0.05.

Key words: Kidney, Renal artery, Kidney segment, 3D modelling

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INTRODUCTION

Today, in urological practice, to perform organ-preserving surgery or segmental resection of the kidney, there is a need for information about the segmental structure of this organ, about the features of the distribution of intra-organ arterial vessels in it, and the features of the individual blood supply to the renal segments [1-5]. The emerging modern methods of 3D radiation diagnostics also require more detailed information about the kidneys, about their tubular structures, and the features of the segmental structure of this organ, where the vessels can have different architectonics, which is very important for ligation of the neurovascular bundle before performing surgery [1,2,6-9]. It is known that according to the International Anatomical Nomenclature, five segments are currently distinguished in the kidney: the superior segment, the superior anterior segment, the inferior anterior segment, the inferior segment, and the posterior segment. Of course, according to literature sources, the five-segment variant of the structure of the kidney is more common, but it has been found that the number of segments in the kidneys ranges from 4 to 12 [10-15]. In terms of the number, it has been found that the superior and inferior segments are the most constant ones, but in 10% of cases they, in turn, are divided into anterior and posterior segments [1,16]. According to other researchers, the frequency of occurrence of 5 segments of the kidney equals 88%, and 4 renal segments are observed in 12% of cases. In observations with five segments, the additional ones were the superior polar segment and the superior segment. If the kidney consists of four segments, it is divided into the following segments: the superior polar segment, the inferior polar segment, the anterior pelvic, and the posterior pelvic segments. It has been established that the most variable parts of the kidney, in terms of sources of blood supply to the segments of the kidney, are its superior and inferior poles. The ventral and dorsal segments (in both four- and five-segment kidneys) are supplied, as a rule, by a single segmental artery [17]. For clarification and detail in this work, we have studied the features of the blood supply to the four-segment kidneys.

Scope of the study

To conduct a 3D quantitative analysis of the arterial bed of four-segment kidneys and study the features of their blood supply.

MATERIALS AND METHODS

The material for the research was 128 corrosive preparations of the human arterial system of the human kidney purchased within the framework of the Russian Foundation for Basic Research (RFBR) grant (Scientific project No. 19-315-90033 dated August 21, 2019).

Algorithm of the study

According to the algorithm of our study, 116 corrosive preparations of the human renal arterial system made of fast-hardening polymers were used to review the spatial organization of the arterial vessels of the kidneys. As an injectable mass, we used Protacryl + lead barium, which makes the preparations X-ray positive when scanning (Patent application No. 202003471 dated 09.06.2020 was filed by ES Kafarov, OK Zenin, IU Vagabov, AZ Vezirkhanov for a "Polymer X-ray contrast composition for the manufacture of corrosive anatomical preparations", 2020). The finished preparations were photographed using a Sony Cyber-shot DSC-RX10M 4 Black digital cameras.

Subsequently, all corrosive preparations of kidney vessels for digitization were subjected to 3D scanning using a 3D microcomputer tomographic system Ray Scan 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 (optional 200 mm/135 mm). After digitization, we performed 3D modeling of the arterial segments of the kidney in the Mimics 8.1 computer program.

In the computer program, we studied the number of renal artery (RA) vessels of different orders depending on the types of intra-organ branching of each branch of the RA in 3D projection: a) the number of order 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 RA branches in 3D projection: a) with the magistral type of artery branching; b) with the loose type of artery branching.

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 artery branching; B) With the loose type of artery branching.

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

RESULTS

In a study of 128 corrosive preparations, four-segment kidneys were found in 10.5% of cases. In four-segment kidneys, the following segments are distinguished: the superior polar segment, the inferior polar segment, the anterior and posterior segments. The superior pole segment occupies the superior medial part of the superior pole of the kidney, both from the ventral and from the dorsal surface. The inferior pole segment is localized in the region of the inferior pole of the kidney, mainly located in the ventral part of the organ. The posterior segment is localized on the dorsal surface of the kidney, occupying its central parts. In the superior sections on the dorsal surface, this segment borders the superior polar segment, and in the inferior sections the inferior polar segment. The anterior segment is localized on the ventral surface of the kidney, occupying its central parts. In the superior sections on the ventral surface, this segment borders the superior polar segment, and in the inferior sections the inferior polar segment.

It was found that the sources of blood supply to the kidney segments, that is, the number of segmental arteries and the places of their discharge, had their differences depending on the variants of RA division and the types of branching of its intra-organ branches. In four-segmental kidneys, when the RA was divided into ventral and dorsal branches (54.2% of cases, at $p \leq 0.05$), where the ventral branch had a loose branching type, and the dorsal branch had the magistral branching type, which was observed in 46.2% of cases, the blood supply to the superior polar segment in the first variant was performed by one segmental artery, A. interlobares-1 (III), extending from the ventral branch, A. Ventralis (zonal) (II), (67.3% of cases, at $p \leq 0.05$), in the second variant by two segmental arteries extending from the ventral and dorsal branches (26.3% of cases) and in the third variant the segment was supplied with blood by one segmental artery extending from the main RA, A. renalis (I), which was observed in 6.4% of cases, with $p \leq 0.05$.

In this variant, the blood supply to the anterior segment was performed by the segmental artery, A. interlobares-1 (III), extending from the ventral branch, A. ventralis (zonal) (II). In the first variant, the inferior polar segment was supplied with blood by one segmental artery extending from the ventral branch, A. ventralis (zonal) (II), (68.3% of cases, at $p \leq 0.05$), in the second variant, it was supplied with blood by two segmental arteries extending from the ventral branch (23.4% of cases) and in the third variant one segmental artery was located in the segment, A. interlobares, 1 (III), departing from the main RA, A. renalis (I), which amounted to 8.3% of cases, with $p \leq 0.05$.

In the posterior segment, with this type of branching, one segmental artery, A. interlobares, 1 (III), was located as a continuation of the dorsal branch of the RA.

With this variant of division, but with the next type of branching, where the ventral and dorsal branches had a loose type of branching (23.8% of cases), the blood supply to the superior polar segment in the first variant was performed by two segmental arteries extending from the ventral branch (46.4% of cases), in the second variant, two segmental arteries were also involved in the blood supply of the segment, but extending from both the ventral and dorsal branches, which was observed in 44.3% of cases, and in the third variant, one segmental artery, A. interlobares, 1 (III), was involved, departing from the main RA, which was observed in 9.3% of cases, with $p \leq 0.05$.

In the first variant, the anterior segment was supplied with blood by one segmental artery, A. interlobares, 1 (III), extending from the ventral branch (66.5% of cases), and in the second variant, by two segmental arteries extending from the ventral branch, A. ventralis (zonal) (II), which accounted for 33.5% of cases, with $p \leq 0.05$. Three variants have been established in the blood supply of the inferior polar segment. Thus, in the first variant, its blood supply was performed by the vessels of the basin of one segmental artery extending from the ventral branch, A. ventralis (zonal) (II), (61.4% of cases, at $p \leq 0.05$), in the second variant, the vessels of the basin of two segmental arteries extending from the ventral branch were located in the segment (35.5% of cases, at $p \leq 0.05$) and in the third variant, one segmental artery, A. interlobares-1 (III), was located in the inferior pole segment, departing from the main RA, A. interlobares-1 (III), which was observed in 3.1% of cases, with $p \leq 0.05$.

In the first variant, the posterior segment was supplied with one segmental artery, A. interlobares, 1 (III), extending from the dorsal branch (78.5% of cases), in the second variant, two segmental arteries were in the segment, extending from the dorsal branch, A. dorsalis (zonal) (II), which was observed in 21.5% of cases.

With this variant of division, but with the next type of branching, where the ventral and dorsal branches had the magistral branching type (19.4% of cases, at $p \leq 0.05$), the blood supply to the superior polar segment in the first variant was performed by one segmental artery, A. interlobares, 1 (III), extending from the ventral branch, A. ventralis (zonal) (II), (84.5% of cases, at $p \leq 0.05$), in the second variant, one segmental artery was located in the segment, extending from the main RA, A. interlobares, 1 (III), which was observed in 15.5% of cases, with $p \leq 0.05$.

One segmental artery, A. interlobares-1 (III), extending from the ventral branch, A. ventralis (zonal) (II), participated in the blood supply of the anterior segment.

As for the inferior polar segment, in the first variant, one segmental artery, A. interlobares – 1 (III), extending from the ventral branch was located there (87.5% of cases, at $p \leq 0.05$), and in the second variant, one segmental artery was also located in the segment, but extending from the main RA, A. renalis (I), which was observed in 12.5% of cases, with $p \leq 0.05$. In the posterior segment, with this type of branching, one segmental artery, A. interlobares – 1 (III). was located, extending from the dorsal branch, A. dorsalis (zonal) (II).

With this variant of division, but with the next type of branching, where the ventral branch had the magistral branching type, and the dorsal branch had loose branching, which amounted to (11.1% of cases, at $p \leq 0.05$), the blood supply to the superior pole segment in the first variant was performed by the vessels one segmental artery, A. interlobares-1 (III), extending from the ventral branch, A. ventralis (zonal) (II), (74.3%, at $p \leq 0.05$), in the second variant, two segmental arteries were located in the segment, extending from the ventral and dorsal branches (21.4% of cases) and in the third variant one segmental artery, A. interlobares-1 (III), was located in the segment departing from the main RA, A. renalis (I), which was observed in 4.3% of cases, with $p \leq 0.05$. In the anterior segment with this type of branching, one segmental artery, A. interlobares – 1 (III), was located extending from the ventral branch, A. ventralis (zonal) (II).

In the first variant, the inferior polar segment was supplied with one segmental artery extending from the ventral branch (79.4% of cases, at $p \leq 0.05$); in the second variant, two segmental arteries were located in the segment extending from the ventral branch, A. ventralis (zonal) (II), (16.5% of cases) and in the third variant, one segmental artery was located in the inferior polar segment, extending from the main RA A. renalis (I), which amounted to 3.1% of cases, with $p \leq 0.05$.

In the posterior segment, in the first variant, one segmental artery, A. interlobares – 1 (III), was located as a continuation of the dorsal branch, A. dorsalis (zonal) (II) (91.5% of cases), and in the second variant, two segmental arteries were in the segment, extending from the dorsal branch, which was observed in 8.5% of cases, at $p \leq 0.05$.

When dividing the RA into the superior polar and inferior polar branches (15.5% of cases), where the superior polar branch had the magistral branching type, and the inferior polar branch had a loose branching type, which we found in 76.4% of cases, the blood supply to the superior polar segment in the first variant was performed by the vessels of the basin of one segmental artery, A. interlobares, 1 (III), extending from the superior polar branch (77.4% of cases, at $p \leq 0.05$), in the second variant, two segmental arteries were located in the segment, extending from the superior polar artery, A. superius polus (zonal) (II), (18.3%, at $p \leq 0.05$) and in the third variant, the vessels of the basin of one segmental artery were located in the segment, extending from the main RA, A. renalis (I), which was observed in 4.3% of cases, with $p \leq 0.05$. In the anterior segment with this type of branching, one segmental artery, A. interlobares – 1 (III), was located extending from the superior polar branch, A. superius polus (zonal) (II).

In the first variant, the inferior polar segment was supplied with blood by one segmental artery extending from the inferior polar branch, A. inferior polus (zonal) (II), (75.3% of cases), in the second variant, two segmental arteries were located in the segment, extending from the inferior polar branch (19.4% of cases), and in the third variant, one segmental artery was located in the segment, extending from the main RA, A. renalis (I), which was observed in 5.3% of cases, with p ≤ 0.05.

In the posterior segment, with this type of branching, one segmental artery was located, A. interlobares (III), extending from the inferior polar branch of the RA.

With this variant of RA division, but with the loose type of branching of the superior polar and magistral type of branching of the inferior polar artery, which was observed in 16.1% of cases, one segmental artery, A. interlobares (III), was located in the superior polar segment in the first variant, extending from the superior polar branch, A. superius polus (zonal), (II) (67.5% of cases), in the second variant, two segmental arteries were located in the segment, extending from the superior polar branch, A. superius polus (zonal) (II), (27.3% of cases) and in the third variant, one segmental artery was distributed in the segment, extending from the main RA, A. renalis (I), which amounted to 5.2% of cases, with p ≤ 0.05.

In the anterior segment, one artery was located, extending from the superior polar branch, A. superius polus (zonal) (II).

In the first variant, the inferior polar segment was supplied with blood by one artery extending from the inferior polar branch, A. inferior polus (zonal) (II), (78.3% of cases), in the second variant, two arteries were located in the segment, extending from the inferior polar branch, A. inferior polus (zonal) (II), (18.5% of cases) and in the third variant, the blood supply of this segment was performed by one artery extending from the main RA, A. renalis (I), which was observed in 3.2% of cases, with p ≤ 0.05.

Two variants were identified in the blood supply to the posterior segment. Thus, in the first variant, one artery, extending from the superior polar branch, A. superius polus (zonal) (II) took part in the blood supply, (88.5 cases, at p ≤ 0.05), and in the second variant, two arteries were in the segment, extending from the superior polar branch of the RA, which was observed in 11.5% of cases, with p ≤ 0.05.

With this variant, but with the next type of branching, where the superior and inferior polar branches had a loose type of branching, which was found in 7.5% of cases, in the first version, one artery was involved in the blood supply of the superior polar segment, extending from the superior polar branch, A. superius polus (zonal) (II), (71.3% of cases, at p ≤ 0.05), in the second variant, two arteries were located in the segment, extending from the superior polar branch (24.4% of cases, at p ≤ 0, 05) and in the third variant, one segmental artery was located in the segment, A. interlobares (III), departing from the main RA, A. renalis (I), which was observed in 4.3% of cases. In the anterior segment, in the first variant, one segmental artery was located, A. interlobares (III), extending from the superior polar branch, A. superius polus (zonal) (II), (89.5% of cases, at p ≤ 0.05), and in the second variant, the segment was supplied with blood by two segmental arteries extending from the superior polar branch, A. superius polus (zonal) (II), which was found in 10.5% of cases, at p ≤ 0.05.

In the first variant, the blood supply to the inferior pole segment was performed by the vessels of the basin of one segmental artery, A. interlobares (III), extending from the inferior polar branch, A. inferior polus (zonal) (II), (65.3% of cases, at p ≤ 0.05), in the second variant, the vessels of the basins of two segmental arteries extending from the inferior polar branch were located in the segment (31.4% of cases, at p ≤ 0.05), in the third variant, the vessels of the basin of one segmental artery were located in the segment, A. interlobares (III), departing from the main RA, A. renalis (I), which was observed in 3.3% of cases, with p ≤ 0.05. In the posterior segment, one segmental artery was located, A. interlobares (III), extending from the superior polar branch, A. superius polus (zonal) (II), (72.5% of cases, at p ≤ 0.05), in the second variant, two segmental arteries were in the segment, extending from the superior and inferior polar branches, which was observed in 27.5% of cases, at p ≤ 0.05.

DISCUSSION

Thus, summarizing all the above, it should be noted that we had 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 arterial bloodstream branching in four-segmental kidneys. The results of the study showed that in the four-segment kidneys, in the presence of a bipolar (ventral and dorsal) blood supply system, the superior polar segment was supplied on average by one artery extending from the ventral branch (56.5%); by two arteries extending from the ventral and dorsal branches (23.0%); by two arteries extending from the ventral branch (11.6%); or by the branch extending from the main RA (8.8%). The blood supply to the anterior segment was performed by one artery extending from the ventral artery (91.6%); or by two arteries extending from the ventral branch (8.3%). The blood supply to the posterior segment was performed by one artery extending from the dorsal artery (92.5%) or by two arteries extending from the dorsal artery (7.5%). The blood supply to the inferior polar segment was performed by one artery extending from the ventral branch (74.1%); by two arteries extending from the ventral branch (18.8%); or by 1 artery extending from the main RA (6.7%), at p ≤ 0.05.

In four-segment kidneys, in the presence of a two-zone (superior and inferior polar) blood supply system, the superior polar segment was supplied on average by one artery extending from the superior polar segment (72.0%); by two arteries extending from the superior polar branch (23.3%); or by one artery extending from the main RA (4.6%). The blood supply to the anterior segment was performed by one artery extending from the superior polar branch (96.5%); or by two arteries extending from the superior polar branch (3.5%). The blood supply to the inferior polar segment was performed by one artery extending from the inferior polar artery (72.9%); two arteries extending from the inferior polar artery (23.1%); or one artery extending from the main RA (3.9%), at $p \leq 0.05$.

CONCLUSION

In a study of 128 corrosive preparations, four-segment kidneys were found in 10.5% of cases. In four-segment kidneys, the following segments are distinguished: The superior polar segment, the inferior polar segment, the anterior and posterior segments. In four-segmental kidneys, regardless of the type of two-zone blood supply: (ventral and dorsal zones) or (superior and inferior polar zones), on average, the following is involved in the blood supply of the polar segments: 1 segmental artery (95.4%), 2 segmental arteries (3.3%), or 1 segmental artery extending from the main RA (2.4%). The blood supply to the anterior segment is performed by 1 segmental artery extending from the ventral branch of the RA (96.6%of cases), or by 2 segmental arteries extending from the ventral branch (3.3% of cases). The blood supply to the posterior segment is performed by 1 segmental artery extending from the dorsal branch of the RA (97.5% of cases) or by 2 segmental arteries (2.5% of cases), at $p \leq 0.05$.

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