ATLANTIS PRESS
Advances in Health Sciences Research, volume 28
Proceedings of the International Conference "Health and Wellbeing in Modern Society" (ICHW 2020)

Segmental Arteries as Sources of Formation of Arterial Segments of Human Kidney

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ABSTRACT
The purpose of the research was to study the angioarchitecture of kidney in three-dimensional projection with the determination of segmental arteries. A three-dimensional analysis of 116 corrosive preparations of the arterial system of kidney was performed. Corrosion preparations were 3D scanned. In the computer program "Mimics-8.1" and "3D-max", after 3D scanning of corrosive preparations of the arterial vessels of kidneys, the following were determined: fission options, branching types, number of vessels of the 3rd and 4th link. It was revealed that, based on the types of intraorgan branching of the renal artery and the level organization of the links, a quantitative and qualitative difference in the number of vessels of the third and fourth link is observed in kidneys. Based on the principles of fractal structure of the intraorgan blood flow of kidney and the dichotomous decay of its links in kidneys, it is impossible to clearly identify and strictly determine segmental arteries. Therefore, they are not isolated in the International Anatomical Nomenclature, their number depending on the branching of the intraorgan vessels of kidneys, can reach up to 10 or more. In general, this fact is revising the classic five-segmented structure of kidney, which requires further research.

Keywords: *kidney, arteries, segment*

1. INTRODUCTION

Many researchers studied the issues of segmental structure of kidneys [1–7, 9–25]. For the first time, Graves and Samb introduced the concept of a "renal segment" in the mid-1950s [15]. According to these authors, by the renal segment they mean an isolated section of renal parenchyma with its blood supply and urination system [7].

According to S.G. Eremeev (1962) [15] in 88 % of cases, a kidney has 5 segments, in 12 % of cases it has 4 segments. In the case of dividing the kidney into five segments, the upper pole segment, the anterior superior pelvic segment, the lower anterior pelvic segment, the posterior pelvic segment, and the lower pole were distinguished. In the case of four segments in the kidneys, the upper pole segment, the lower pole segment, the anterior pelvic segment and the posterior pelvic segment are distinguished. Regarding the issues of blood supply to kidney segments, the authors note that the upper and lower renal segments are subject to the greatest variability in blood supply sources. According to S.G. Eremeev (1962) [15], the anterior pelvic segment and the posterior pelvic segments were supplied with one segmental artery both in the four and five-segment structure of the organ [7].

As for the poles of kidneys, then of course there are several options. Thus, in 65 % of cases, one artery goes to the upper pole, being a branch of the main renal artery in 22 % of cases. In 34 % of cases, the branch from the anterior pelvic artery goes to the upper pole, and in 9 % – from the posterior pelvic artery. In 33 % of cases, the upper pole was supplied with blood by 2 arterial vessels; in 29 % of cases, these arterial vessels branch from the main renal artery, supplying the ventral and dorsal sections of kidney segment. In 71 % of cases, one arterial vessel approaches the segment of the lower pole of a kidney.

In 53 % of cases, the source of blood supply to this segment was a vessel that departed from the anterior pelvic of the renal artery, and in 18 % of cases, a lower pole vessel. [7]. In the research of Yu.L. Rubinov (1972) [15], similar data were obtained. Thus, in the author's research, a kidney with four segments was detected in 18.4 % of cases, and in 81.6 % of cases – with five [16]. The observations of V.V. Serov (1959) [15], diverge from the studies of the scientists mentioned above, where the author distinguishes five segments of a kidney: this is the upper pole segment, the upper anterior pelvic segment, then the lower anterior pelvic segment, posterior segment and lower segment.

According to this author, a segment of the upper pole is with several options for blood supply sources. In the first case, in 45 % of cases, one vessel is involved in the blood supply to the upper pole, being a branch of the anterior pelvic artery. In the second variant (32 % of cases), the upper segment was supplied with two arteries, being branches of the ventral and dorsal arteries. In 18 % of cases, an artery, a branch of the main renal artery (or a branch of the 2nd order), participated in the blood supply to the segment of the upper pole. In 5 % of cases, the segment of the upper pole of a kidney was supplied with a branch from the dorsal artery.

According to V.V. Serov (1959) in 95 % of cases, the ventral artery gave one branch to supply the middle segment, and in the remaining 5 % of cases, it departed from the main renal artery. The posterior segment was supplied with blood by an artery extending from the dorsal branch. According to the author, several options were identified in the blood supply to the lower segment. They were as follows: option 1 is the blood supply to the lower segment of a kidney with one artery that departed from the anterior pelvic of the kidney, which was found in 47 % of cases; option 2 is a blood supply to the lower segment of a kidney with two arteries from the front and the posterior pelvic of the renal artery (45 % of cases); option 3 is the blood supply to the lower segment due to the lower pole artery, which is a branch of the posterior pelvic artery (8 % of cases) [18].

Ajmani (1983) [15] also studied the variant anatomy of the sources of blood supply to kidney segments. According to the author, the main renal artery in 98 % of cases departed from the abdominal aorta and in most cases was divided into the ventral and dorsal branches before entering hilum of kidney. The author revealed 5 variants of division of the ventral and 3 variants of division of the dorsal branch of the renal artery. The author claims that the upper segment of the kidney (about 7 variants) was the most variable in blood supply [19].

Some authors claim that the number of kidney segments can reach six (L.A. Olofinsky, Sh.R. Sabirov et al.) [15]. Thus, according to L.A. Olofinsky (1970), a kidney has 4 segments in 3.5 % of cases, 5 segments in 72.6 % of cases and 6 segments in 23.9 % of cases. Sh.R. Sabirov (1978) revealed 4 segments of a kidney in 35 % of cases, 5 segments in 38.5 % of cases, and 6 segments in 26.5 % of cases [14, 17]. Both national and international scientists studied the issues of the segmental structure of a kidney.

Thus, according to Longia (1982) [15], a kidney has 5 segments, which was detected in 53 % of cases, 4 segments in 46 % of cases and 3 segments of the kidney in 1 % of cases. Among the identified variants, there were kidneys with less than five kidney segments: in the first variant, there was no upper kidney segment (15 % of cases); in the second case, there was one anterior pelvic segment, consisting of the combined upper and lower (14 % of cases); in the third variant, the lower pole segment was absent (17 % of cases) [21].

Sampaio (1993, 1996) was also involved in variant anatomy of segments [15]. According to him, a kidney had 5 segments in 61.2 % of cases, a kidney had 4 segments in 38.8 %. A kidney had an upper segment in 73.5 % of observations and occupied an area of about 13 %. The upper and lower anterior pelvic segments in a kidney were found in 61.2 % of cases, covering an area of 21.4 and 17.2 %, respectively. The kidneys with one anterior pelvic segment, which were identified in 38.8 % of cases, occupied an area of 28.4 %. In all the observations, the author identified kidneys with the presence of the lower pole and posterior pelvic segments, occupying an area of 22.2 and 33.8 %, respectively [23, 24].

As it can be seen, many researchers studied the issues of the number of kidney segments and their blood supply sources [1–7, 9–25]. According to literature sources, the kidney is divided into segments relative to the branching of the segmental arteries, that is, the branches of the renal artery system [6–10]. From a review of the literature, the number of segments in kidneys varies from 3 to 6, and according to some scientists it even reaches 10 [6–8, 17, 18]. There is a well-known classical division of kidneys into five segments: upper, upper front, lower front, lower and rear segments.

Segmental arteries, namely their pools, supplying the isolated areas of kidney parenchyma determine the renal segment, which is mentioned in a review of the literature. In the International Anatomical Nomenclature (2003), segmental arteries were not distinguished in the angioarchitecture of kidneys. According to this nomenclature, the angioarchitecture of the arterial bed of a kidney is presented as follows: “main renal artery” (I) “interlobar artery” (II) “arc artery” (III “interlobular artery” (IV) “afferent artery” (V). Let us suppose that these segmental arteries are branches of the third order.

In this case, this is the third division level and these vessels are called "interlobar" according to the nomenclature. The interlobular arteries are vessels located in the organ parenchyma and in quantitative terms, their number can reach from 10 to 16. According to the literature review, only the pole segments can have two sources of blood supply [18].

If we assume that in most cases a kidney has 5 segments, then taking into account the presence of two sources of blood supply in the pole segments, such a kidney has 7 segmental arteries. The question arises, what is the fate of the remaining 9 arteries. Even if two arteries are directed to each segment of a kidney, 10 segmental arteries are obtained, and the other 6 remain. There is a certain misconception, which arteries should be called segmental, what is their number and sources of blood supply. The search for the answer for these questions presents the purpose of our study.

2. METHODS AND MATERIALS

A three-dimensional analysis of 116 corrosive preparations of the arterial system of a kidney was performed. Corrosion preparations were 3D scanned.

1) In the computer program "Mimics-8.1" and "3D-max" after 3D scanning of corrosive preparations of the vessels of kidneys the following was determined:

- Three-dimensional (3D) projection of the arterial vessels of kidneys with respect to the frontal, horizontal and sagittal planes;

2) On corrosive preparations of the arterial vessels of kidneys in three-dimensional (3D) projections the following was revealed:

- Extraorgan branches of the renal artery in three-dimensional (3D) projection

- the number of renal arteries in the hilum of kidney
- kidney artery topography in the hilum of kidney

3) Renal artery division options in the kidney hilum in three-dimensional (3D) projection

- extraorgan division of renal artery
- intraorgan division of renal artery

4) Types of branching of the renal artery inside kidney, depending on the division in the hilum of each branch in three-dimensional (3D) projection

- with magisterial type of branching
- with loose type of branching
- with mixed type of branching

5) The number of arterial vessels of the renal artery of different orders depending on the types of intraorgan branching of each branch of the renal artery in three-dimensional (3D) projection:

- the number of vessels of the first order (I)
- the number of vessels of the second order (II)
- the number of vessels of the third order (III)
- the number of vessels of the fourth order (IV)
- the number of vessels of the fifth order (V)
- the number of vessels of the sixth order (VI)

6) The number of segmental arteries in kidneys depending on the types of intraorgan branching of the branches of the renal artery in (3D) projection:

- in magisterial type of branching
- in loose type of branching
- in mixed type of branching

The morphometric analysis data were processed by methods of variation statistics on a personal computer using the Exel (Ver.10.2701) and Statwin (Ver.5.1) programs.

3. RESULTS

A three-dimensional analysis of the division of the main renal arteries relative to the frontal, horizontal and sagittal planes was carried out. It was revealed that in 69.8 % of cases (81 corrosive preparations of renal arteries out of 116), the main renal artery branched into two branches. Moreover, relative to the frontal plane, the main renal artery was divided into ventral and dorsal (84.6 % of cases, 73 of 116 corrosive preparations). In 8 corrosion preparations (9.8 % of cases), the renal artery divides into the upper and lower pole branches.

Further research revealed options for the division of the renal artery into 3 branches (35 corrosive preparations of renal arteries out of 116), which revealed 30.1 % of cases. In 15 preparations out of the 35 (42.8 % of cases), the renal artery was divided into ventral, dorsal and upper pole branches. In 11 preparations (31.4 % of cases), it was divided into ventral, dorsal and lower pole arteries relative to the frontal and horizontal plane. In 6 preparations (17.1 % of observations), the renal artery was divided relative to the frontal plane into two ventral arteries and one dorsal. In 3 preparations (8.5 % of cases), the renal artery branched into the superior pole artery, central and lower pole.

It was noted that in 73 preparations out of 116, the main (90.1 % of cases) renal artery branched relative to the frontal plane into the ventral and dorsal arteries. At the same time, in 19 preparations out of 73, the renal artery was divided at the hilum, that is, laterally from the sagittal plane, the tangent of the medial edge of the kidney (intrarenal variant), which accounted for 26.1 % of cases. In 73.9 % of cases, (54 drugs), the main renal artery was divided at a distance from the portal of kidneys, that is, more medially from the sagittal plane, tangent to the medial edge of kidneys (extrarenal variant).

1. It is worth noting the group of preparations of the arterial vessels of kidneys, where the main renal artery was divided into two arteries (ventral and dorsal), relatively far from hilum of kidney (54 drugs, 73.9 % of cases), that is, the extrarenal variant. Moreover, in 24 corrosive preparations, the ventral branch of the main renal artery was divided into 4 ± 1 vessels of the 3rd order and from 4 to 6 vessels of the 4th order, and the dorsal branch was divided into 3 ± 1 and from 4 to 8 vessels of the 4th order fan-shaped diverging from the place of its formation. The kidney parenchyma was distributed in the ventral and dorsal sections, which was found in 32.8 % of cases.

In 18 corrosive preparations, the ventral branch of the main renal artery was divided into 3 ± 1 vessels of the 3rd order and from 4 to 7 vessels of the 4th order, and the dorsal branch into 2 ± 1 and from 4 to 6 vessels of the 4th order, which was found in 24.6 % of cases. In 12 corrosion preparations, both the ventral and dorsal branches of the renal arteries were divided into 3 ± 1 vessels of the 3rd order and from 5 to 7 vessels of the 4th order, which was found in 16.4 % of cases.

2. As it was mentioned above, in 19 out of 73 corrosive preparations, the main renal artery divided at the hilum of kidney, that is, lateral from the sagittal plane, tangent to the medial edge of kidneys (intrarenal variant), which amounted to 26.1 %. In this case, in 11 corrosive preparations out of 19, the ventral branch of the main renal artery was divided into 3 ± 1 vessels of the 3rd order and from 4 to 8 vessels of the 4th order, and the dorsal branch into 2 ± 1 and from 7 to 6 vessels of 4 of the first order, which were distributed in the ventral and dorsal departments of the renal parenchyma, that was found in 15.1 % of cases.

In 5 corrosive preparations out of 19, the ventral branch of the main renal artery was divided into 4 ± 1 vessels of the 3rd order and from 5 to 8 vessels of the 4th order, and the dorsal branch into 2 ± 1 and from 4 to 6 vessels of the 4th order, that was found in 6.8 % of cases. In 3 corrosive preparations out of 19, the ventral and dorsal branches of the main renal artery were divided into 4 ± 1 vessels of the 3rd order and from 3 to 6 vessels of the 4th order, which we found in 6.8 % of cases.

3. As it was mentioned above, in the second variant, that was found in 9.8 % of cases (8 preparations), the main renal artery was divided into the upper pole and lower pole branches relative to the horizontal plane. Moreover, in 4 corrosive preparations, both the upper and lower pole branches of the main renal artery were divided into 2 ± 1 vessels of the 3rd order and from 4 to 5 vessels of the 4th order, which was found in 4.9 % of cases.

In 3 corrosive preparations, the upper pole branch of the main renal artery was divided into 3 ± 1 vessels of the 3rd order and from 5 to 6 vessels of the 4th order, which were distributed in the ventral and dorsal sections of the upper pole of the kidney, and the lower pole into 2 ± 1 vessels of 3- order and from 4 to 7 vessels of the fourth order, which were also distributed in the ventral and dorsal sections of the lower pole of the kidney, which was found in 3.6 % of cases. On 1 corrosion preparation, the upper pole branch of the main renal artery gave 2 ± 1 vessels of the 3rd order and from 3 to 5 vessels of the 4th order, and the lower pole branch of 3 ± 1 and from 3 to 6 vessels of the 4th order, which we met 1, 2 % of cases.

4. In addition, 35 out of 116 corrosive preparations of the arterial vessels of the kidney, divided the renal artery into 3 branches (30.1 % of cases). In turn, in 15 out of 35 corrosive preparations, the division of the main renal artery occurred relative to the frontal and horizontal plane into the ventral, dorsal and upper pole branches (42.8 % of cases). In 8 corrosive preparations out of 15, the division of the ventral branch of the main renal artery occurred on 3 ± 1 vessels of the 3rd order and from 3 to 6 vessels of the 4th order, which were distributed in the ventral sections of the lower pole of the kidney, the dorsal – 2 ± 1 and from 4 to 8 vessels of the 4th order, which were distributed in the dorsal sections, and the upper pole was divided into 3 ± 1 vessels of the 3rd order and from 4 to 6 vessels of the 4th order, which were distributed in the ventral and dorsal sections of the upper pole of kidney, which was found in 22.8 % of cases.

In 4 corrosive preparations out of 15, the ventral branch of the main renal artery was divided into 3 ± 1 vessels of the 3rd order and from 3 to 5 vessels of the 4th order, the dorsal branch into 3 ± 1 and from 4 to 7 vessels of the 4th order, and the upper pole was divided into 3 ± 1 vessels of the 3rd order and from 3 to 6 vessels of the 4th order, which was found in 11.4 % of cases. In 3 corrosive preparations out of 15, the ventral branch of the main renal artery divided 4 ± 1 vessels of the 3rd order and from 4 to 6 vessels of the 4th order, the dorsal branch into 3 ± 1 and from 4 to 7 vessels of the 4th order, and the upper pole divided into 2 ± 1 vessels of the 3rd order and from 3 to 5 vessels of the 4th order, which was found in 8.5 % of cases.

In 31.4 % of cases, the division of the main renal artery relative to the frontal plane and horizontal occurs on the ventral artery, dorsal and lower pole (11 of 35 preparations). The ventral branch of the main renal artery was divided into 2 ± 1 vessels of the 3rd order, and these vessels branched from 3 to 6 vessels of the 4th order, supplying the ventral part of the upper pole of kidney.

The dorsal artery branched into 3 ± 1 vessels of the 3rd order, and these vessels branched from 4 to 6 vessels of the 4th order, supplying the dorsal part of the upper pole of the kidney and the lower pole was divided into 2 ± 1 vessels of the 3rd order and from 3 to 5 4th-order vessels, which were distributed in the ventral and dorsal sections of the lower pole of the kidney, which was found in 8.5 % of cases.

In 31.4 % of cases (8 preparations out of 35) the ventral branch of the main renal artery was divided into 2 ± 1 vessels of the 3rd order and from 4 to 8 vessels of the 4th order, the dorsal branch was divided into 3 ± 1 and from 4 to 5 vessels of the 4th order, and the lower pole was divided by 2 ± 1 a vessel of the 3rd order that was found in 7.1 % of cases. In addition, 16 out of 35 preparations, where the main branch of the ventral renal artery was divided into 3 ± 1 vessels of the 3rd order, the dorsal branch was also divided into 3 ± 1 vessels of the 3rd order, and the lower pole was divided into 2 ± 1 vessels of the 3rd order and from 4 up to 5 vessels of the 4th order, which was found 14.1 % of cases.

5. Further, it was found that in 17.1 % of cases (6 preparations), the main renal artery relative to the frontal plane was divided into two ventral and one dorsal branches. The ventral branches of the main renal artery were divided into 3 ± 1 vessels of the 3rd order and from 5 to 6 vessels of the 4th order, distributed in the ventral sections of the upper and lower poles of the kidney, the dorsal branch was divided into 2 ± 1 vessels of the 3rd order and from 5 up to 7 vessels of 4th order distributed throughout the posterior surface of a kidney.

6. During the division of the main renal artery into the upper pole, central and lower pole branches located in the same frontal plane, which was found in 8.5 % of cases (3 preparations), all branches were divided into 2 ± 1 vessels of the 3rd order and from 4 up to 7 vessels of the 4th order. The upper pole branch was distributed in the ventral and dorsal sections of the upper pole of kidney, the central branch was distributed in the corresponding sections of the central part of kidneys and the lower pole branch was distributed in its lower pole.

In the process of a detailed analysis of the links and dichotomies of the arterial bed of kidney, taking into account the branching types of intraorgan vessels, it was revealed that 84.6 % of cases are more likely to show the distribution of the main renal artery into the ventral and dorsal.

It was noted that in the first type of branching of the intraorgan arterial vessels of a kidney of the renal artery system, the ventral branch was loose, and the dorsal branch was main, which was detected in 46.2 % of cases.

The level organization of the links of the renal artery system was presented in the following order: A.renalis (I), A.ventralis (II), Aa.interlobares – 1 (III), – Aa.interlobares – 2" (IV), – "Aa.arcuatae" (V), – "Aa.interlobulares" (VI), – "A.afferentis" (VII). A.dorsalis (II), Aa.interlobares – 1 (III), Aa.arcuatae (IV), Aa.interlobulares (V), A.afferentis (VI) .

In 23.8 % of cases, the second branching type of the intraorgan arterial system was revealed, where both branches were with a loose branching type. The structural organization of all links was presented as follows: “A.renalis” (I), – “A.ventralis” (II), “Aa.interlobares – 1” (III), – “Aa.interlobares – 2” (IV), – "Aa.arcuatae" (V), – "Aa.interlobulares" (VI), – "A.afferentis" (VII). "A.dorsalis" (II), – "Aa.interlobares – 1" (III), – "Aa.interlobares – 2" (IV), – "Aa.arcuatae" (V), – "Aa.interlobulares" (VI), – "A.afferentis" (VII).

In 19.4 % of cases, a third type of vascular branching was revealed, where both branches of the renal artery system were of the main type. The hierarchy in this case was represented as follows: "A.renalis" (I), – "A.ventralis" (II), – "Aa.interlobares" (III), – "Aa.arcuatae" (IV), – "Aa.interlobulares" (V), – "A.afferentis" (VI). A.dorsalis (II), Aa.interlobares (III), Aa.arcuatae (IV), Aa.interlobulares (V), A.afferentis (VI).

In the fourth type of branching of the renal artery system, the ventral branch had the main branch type, and the dorsal branch was loose (11.1 % of cases). The structural organization of the links of the renal artery system was presented as follows: A.renalis (I), A.ventralis (II), Aa.interlobares (III), Aa.arcuatae (IV), – "Aa.interlobulares" (V), – "A.afferentis" (VI). "A.dorsalis" (II), – "Aa.interlobares – 1" (III), – "Aa.interlobares – 2" (IV), – "A.dorsalis" (V), – "Aa.interlobares" (VI), – "A.afferentis" (VII).

A three-dimensional analysis of the architectonics of the arterial bed of a kidney, as well as a detailed analysis of the level and links of the dichotomies of the remaining branching and distribution options of the main renal artery system was identical. However, with some branching options, the branches of the second link were called upper-pole or lower-pole. It means that spatial organization and level hierarchy of the structure of various links and dichotomies of the entire renal artery system depends both on the division options renal artery at the hilum of a kidney, and from the types of intraorgan branching of the main branches of renal artery.

4. CONCLUSION

As a result of the studies, it was found that regarding the types of intraorgan branching of individual branches of the renal artery and the level hierarchy of its individual links and dichotomies, in the kidneys with different types of branching, we observe a quantitative and qualitative difference in the number of vessels of the third and fourth link (interlobular vessels the 1th and 2nd order), if these vessels are called “segmental”.

Thus, the number of these vessels in most cases can reach up to 10 or more, if we consider the 3rd level of dichotomies, that is, the division of the ventral, dorsal or upper – and lower pole. That is, in the same kidney, with different types of branching of individual taken intraorgan arterial vessels from the renal artery system, “segmental” arteries can be vessels of either the third or the fourth link, depending on the level of dichotomies. As we can see, the variant anatomy of the segmental structure of kidneys, that is, the number of renal segments, their topography, and area in different kidneys will depend on the presence or absence of these particular links in its intraorgan arterial bloodstream. In kidneys, depending on the level of dichotomy, each particular segmental artery, and maybe two segmental arteries, has its own vascular pool, which supplies this segment of kidney.

Thus, it can be concluded that, based on the principles of the fractal structure of the intraorgan vascular bed of a kidney and the dichotomous decay of its links in kidneys, it is impossible to identify clearly and strictly segmental arteries. Therefore, they are not distinguished in the International Anatomical Nomenclature and the number of them, depending on the branching of the intraorgan vessels of kidneys, can reach up to 12–15. In general, this fact revises the classical five-segment structure of kidney, which requires further research.

ACKNOWLEDGMENT

The article is published as a psrt of a RFBR grant project 19-315-90033.

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