ORIGINAL SCIENTIFIC ARTICLE

THE ANATOMY OF RENAL ARTERIES IN ADULTS

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ABSTRACT

Detailed extraparenhymal renal hilar dissection was performed on 110 fixed cadaveric kidneys (60 from male cadavers and 50 from female cadavers). We analyzed the number of renal arteries, angles between renal arteries and abdominal aorta, length and diameter of the renal arteries. Multiple renal arteries were present in 20.9% of cases, with a slightly higher incidence on the right side (21.8%: 20.0%). The angle between the aorta and the RRA varied from 30° to 100° with a mean of 64.1°, while the angle between the abdominal aorta and the LRA was 40° to 115°, with a mean of 67.3°. The external caliber of the RRA at the point of origin from the abdominal aorta was 5 mm to 9.1 mm, with a mean of 6.8 mm. The same caliber of the LRA was 3.7 to 9.6 mm with a mean of 7.0 mm. The average length of the renal artery from the point of origin from the abdominal aorta to the branching point was 36.2 mm for the right renal artery and 30.7 mm for the left renal artery. The average length of the renal artery from the point of origin from the abdominal aorta to the renal hilum was 65.1 mm for the right one and 54.7 mm for the left one. Knowledge of the number of renal arteries, their mode of entry into the kidney, the angles they build with the abdominal aorta, their diameter and length has practical applications in interventional radiology and surgery of the kidney and its environment.

Keywords: *renal artery, accessory artery, polar artery.*

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INTRODUCTION

Usually, each kidney is supplied by a single artery which is named the main renal artery. It has relatively constant position and path from the site of origin to the hilum of the kidney. Renal arteries are located in the vascular pedicle behind renal veins. They arise from the abdominal aorta below superior mesenteric artery, between the first and the third lumbar vertebra (1). Graves (1956) described renal vessels, defining normal segmental vessels, accessory artery and aberrant renal artery. He states that accessory arteries enter the kidney through the hilum and aberrants not through it, but usually through the upper and the lower pole of the kidney (2). In 70% of cases, there is a single renal artery (3). The right renal artery often leaves the aorta at a slightly higher level than the left one. It usually passes behind the inferior vena cava, but rarely, it could be found in front of it. Renal arteries are also the origin of inferior adrenal artery and small inferior branches that feed the renal pelvis and upper ureter. Tiny branches for the renal capsule and perinephric fat may also stem from the main renal artery.

The pronephros, mesonephros and metanephros are the basic stages in embryonic kidney development. The metanephros is formed at level of the bifurcation of the aorta. The mesonephros develops between the fifth week and the sixteenth week of the embryological development (4). Then it is supplied by temporary aortic branches, even up to thirty mesonephric arteries (5). With complete mesonephros degeneration only nine mesonephric arteries remain, from the tenth thoracic to the third lumbar segment (6). Between the sixth and the ninth week the metanephros ascends from the pelvis to the retroperitoneal space. During the ascent, the metanephros receives vascularization from the surrounding arteries, first from the iliac and then from the abdominal aorta. Lumbar mesonephros vessels form the rete arteriosum urogenitale which connects the vessels of the metanephros with the mesonephric arteries and the aorta abdominalis. Mesonephric arteries slowly disappear and only one artery remains, which is the future renal artery. If more than one artery remains at this stage of transition from mesonephros to metanephros then multiple renal arteries are formed (7).

Variations of the main renal artery and vein are common, due to existence of several mesonephric arteries during fetal life. These arteries develop from aorta between C6 and L3 vertebrae and are divided into cranial, middle and caudal arteries. Only one of the mesonephric arteries will later transform to main renal artery (8). If the fusion of the rete arteriosum urogenitale is not fully completed, two variations could occur: 1) short stem of renal artery and its early division and 2) multiple renal arteries. There are many names in the references for multiple renal arteries such as: accessory, aberrant, additional, supernumerary, supplementary arteries, etc. Glodny et al. (2009) divided the multiple renal arteries into additional renal arteries arising from the abdominal aorta, and accessory renal arteries arising from branches of the abdominal aorta. He found additional and accessory renal arteries with frequency of 14.6% up to 56% (9). Other study describes accessory renal arteries, as one with the hilar renal entrance that more often arise below the main renal artery. They cross ureter anteriorly and have the potential to cause obstruction. If an accessory artery is damaged, the part of kidney supplied by it is likely to become ischaemic. Aberrant renal arteries enter into the kidney extrahilary, through the capsule, usually through the lower or upper pole (10). If renal artery in a patient originates above the celiac trunk, it is consequence of the persistent mesonephric vessel (11). Bayramoglu et al. (2003) described bilateral accessory renal arteries stemming from abdominal aorta; the right one was accompanied by the vein (12). Merklin and Michels (1958) classify accessory arteries as follows: 1) accessory renal arteries originating from the aorta, 2) accessory renal arteries originating from the main renal artery, 3) accessory renal arteries originating from other sources. They use terms the main renal, aortic superior/inferior polar and renal inferior polar arteries (13). Poisel and Spangler (1969) described accessory, supplementary, supernumerary and aberrant renal arteries (14) and Stephens (1982) considered that these terms were not adequate because these were segmental and terminal blood vessels (15). Terms as hilar - for the aortic branch penetrating the hilum, extrahilar - for the branch of the renal artery with an extrahilar penetration, superior polar - for the aortic branch penetrating the superior pole and inferior polar - for the aortic or common iliac artery penetrating the inferior pole of the kidney, were also used in references (16). Satyapal et al. (2001) introduced the term additional renal artery for the one that, in addition to main renal artery, exits the aorta and ends in the kidney (17). Vilhova et al. (2001) used the term “accessory” for the segmental polar artery with hilar renal entrance, while the term “perforant” was reserved for segmental polar arteries that entered extrahilary (through the kidney capsule). In both case, those were aortic branches (18). Bordai et al. (2004) described three types of renal arteries: 1) the upper and lower polar arteries that enter through the kidney poles 2) the main renal artery as the largest hilar artery, and 3) the hilar supplementary artery that enters the hilum with the larger, main artery (19). The accessory and aberrant arteries usually originate from the abdominal aorta or iliac arteries and rarely from the thoracic aorta or branches of the abdominal aorta (20). Türkvatan A et al. (2009) divided the additional arteries into the hilar and polar depending on how they enter the kidney (8). Some authors distinguish between two types of additional renal arteries: 1) early division arteries and 2) extra renal arteries, which are classified as hilar (accessory) arteries and polar (aberrant) arteries (17, 21). In 2010, Daescu et al. divided the renal arteries into the hilar and polar (upper and lower polar arteries). They further divided the polar arteries into four groups: 1) solitary 2) pedicular, if the second one is accompanied by a polar vein and a nerve plexus 3) false supernumerary, if it replaces the segmental artery and 4) true supernumerary artery, if the respective segmental artery emerges from the renal artery (22).

In this study, we analyzed the number of renal arteries, their place of origin, length and diameter. We classified the multiples arteries into accessory, if they entered the kidney through the hilum and aberrant (polar) arteries, if they

entered the kidney through his capsule, usually through the upper or lower poles. The aim of the study was to examine the pattern of renal vascularization, describe its prospective anatomical variations and to point out the significance of a good knowledge of renal vascular anatomy, which is of great importance for planning and conducting certain urological and surgical procedures in the abdominal cavity.

MATERIAL AND METHODS

The study was performed in the Department of Anatomy and Department of Pathological anatomy of the Faculty of Medical Sciences of the University of Kragujevac, Serbia. Detailed extraparenhymal renal hilar dissection was performed on 110 fixed cadaveric kidneys (60 from male cadavers and 50 from female cadavers). The kidneys and surrounding tissue were removed within 24 h after death en bloc with adjacent part of the aorta and the vena cava. Cause of death was not related to urinary tract diseases. Any accessory or aberrant renal arteries if they were seen were also preserved. After excision, perirenal fat and surrounding tissue were removed and renal vessels, pelvis and ureter were prepared. The length of the renal artery was measured from the point of origin to the point of branching as well as from the point of origin to the hilum of the kidney. We also measured the external diameter of the renal arteries at the site of their origin. The measurements recorded in the text were made by the Vernier caliper with an accuracy of 0.1 mm. Angles between the lateral side of the abdominal aorta and the lower side of the renal artery were measured by using a protractor. All kidneys were recorded by drawings or photographs. The analysis included descriptive and analytical statistical methods. We used the student's T test in comparison to obtained sizes between the left and right kidneys, as well between male and female sex, in order to see if there was significant difference in the length, diameter and number of renal arteries. The study was performed in the Department of Anatomy and Department of Pathological anatomy of the Faculty of Medical Sciences of the University of Kragujevac, Serbia. Detailed extraparenhymal renal hilar dissection was performed on 110 fixed cadaveric kidneys (60 from male cadavers and 50 from female cadavers). The kidneys and surrounding tissue were removed within 24 h after death en bloc with adjacent part of the aorta and the vena cava. Cause of death was not related to urinary tract diseases. Any accessory or aberrant renal arteries if they were seen were also preserved. After excision, perirenal fat and surrounding tissue were removed and renal vessels, pelvis and ureter were prepared. The length of the renal artery was measured from the point of origin to the point of branching as well as from the point of origin to the hilum of the kidney. We also measured the external diameter of the renal arteries at the site of their origin. The measurements recorded in the text were made by the Vernier caliper with an accuracy of 0.1 mm. Angles between the lateral side of the abdominal aorta and the lower side of the renal artery were measured by using a protractor. All kidneys were recorded by drawings or photographs. The analysis included descriptive and analytical statistical methods. We used the student's T test in comparison to obtained sizes between the left and right kidneys, as well between male and female sex, in order to see if there was significant difference in the length, diameter and number of renal arteries.

RESULTS

The number of renal arteries

A single renal artery was present in 79.1% cases of 110 dissected kidneys: on the right side in 78.2% and on the left side in 80.0%. Multiple renal arteries were present in 20.9% of cases, with a slightly higher incidence on the right side (21.8%: 20.0%). We found two arteries in 18.2% and three in 3.6% of the observed right kidneys. The same arteries in the left kidney existed in 20.0% of cases: two arteries in 16.4%, three in 1.8% and four arteries in 1.8% of the kidneys (Table 1).

Table 1. The number and frequency of the renal arteries of the right and left kidneys in males and females

Material	Number	Gender	1 artery		2 arteries		3 arteries		4 arteries	
			right	Left	right	left	right	left	right	left
The dissected kidneys	60	**male**	22 73.3%	25 83.3%	7 23.3%	4 13.3%	1 3.3%	--- ---	--- ---	1 3.3%
			47 **78.3%**		11 **18.3%**		1 **1.7%**		1 **1.7%**	
	50	**female**	21 84%	19 76%	3 12%	5 20%	1 4%	1 4%	--- ---	--- ---

Material	Number	Gender	1 artery		2 arteries		3 arteries		4 arteries	
			right	Left	right	left	right	left	right	left
The dissected kidneys			40 **80%**		8 **16%**		2 **4%**		--- ---	
The dissected kidneys	110	**total**	43 78.2%	44 80%	10 18.2%	9 16.4%	2 3.6%	1 1.8%	-- --	1 1.8%
			87 **79.1%**		19 **17.3%**		3 **2.7%**		1 **0.9%**	

Angles between renal arteries and abdominal aorta

The angle between the aorta and the RRA varied from 30° to 100° with a mean of 64.1°, while that angle on the left side was from 40° to 115°, with a mean of 67.3°. The difference in the angle values between the right and the left side was a statistically significant, with smaller angle on the right side ($DF = 108$, $p < 0.01$).

The diameter of the renal arteries

The external caliber of the RRA at the point of origin from the abdominal aorta was 5 mm to 9.1 mm, with a mean of 6.8 mm. The same caliber of the LRA was 3.7 to 9.6 mm with a mean of 7.0 mm. At the branch point, the diameter of the RRA was 4.0 mm to 8.1 mm with a mean value of 5.5 mm, while on the left it was 2.4 mm to 8.0 mm with a mean of 5.8 mm. The difference in the diameter of renal arteries was not statistically significant between the left and right arteries in males ($t = 0.75$, $p > 0.05$) and females ($t = 0.75$, $p > 0.05$). Diameters of renal arteries are shown in Tables 2 and 3.

Table 2. Diameters of the renal arteries in mm

Gender	Site	Renal artery diameter- mm.					
		At the beginning of RA			At the branching point of the RA		
		min-max		SD	min-max		SD
Male	**RRA**	5.0 - 9.1	**7.02**	0.95	4.0 - 8.1	**5.71**	0.97
	LRA	3.7 - 9.6	**7.23**	1.22	2.4 - 8.0	**6.18**	1.13
Female	**RRA**	5.0 - 8.4	**6.63**	1.05	4.0 - 8.0	**5.40**	0.98
	LRA	5.2 - 9.0	**6.82**	1.01	4.0 - 7.0	**5.39**	0.94

Length of renal arteries

The length of the RRA from the point of origin to the branching point was 5 mm - 60 mm with an average value of 36.2 mm. The length of the RRA from the point of origin to the hilum of the kidney was 45mm - 88 mm, with an average value of 65.1 mm. The length of the LRA from the point of origin to the branching point was 3 mm - 50 mm with the average value of 30.7 mm. The length of the LRA from the point of the origin to the hilum of the kidney was 35 mm - 82 mm with average value of 54.7 mm. If the renal artery was divided up to 15 mm from the aorta, we considered it as early branching (early division). Early division of the renal artery was in 5.5% in the RRA and in 7.3% in the LRA. Early branching of the renal artery was considered as a consequence of the unfinished embryonic development of the kidney that is, the remains of mesonephrotic vessels. There is no statistically significant difference in the length of the left and right renal arteries from the point of origin to the point of branching ($t = 2.52$, $0.05 < p < 0.01$). The statistically significant difference was found in the length of renal arteries from the point of origin to the renal hilum, with the right renal artery longer than the left ($t = 5.179$, $p < 0.001$), as expected considering the sinistroposition of abdominal aorta. Lengths of the renal arteries are shown in Table 3.

Table 3. The length of renal arteries in mm

Renal artery	Number	The length of the renal arteries - mm	
		To the branching point	To the renal hilum
RRA	**55**	5 - 60 ± SD = 36.24 ± 12.15	45 - 88 ± SD = 65.01± 10.15
LRA	**55**	3 - 50 ± SD = 30.74 ± 10.75	35 - 82 ± SD = 54.69 ± 10.87

DISCUSSION

If there is another artery in addition to the main renal artery then it is a multiple renal artery. The percentages of multiple renal arteries described in references varied and depended on the author, type of study and the studied population. Tardo et al. (2017) discovered multiple renal arteries in 22% of subjects and 12.12% of kidneys. There was no significant difference between left- and right-sided kidneys (13.8% vs. 12.5%). Unilateral additional renal arteries were in 16.7% but bilateral in 3.4% of cases. Variations among males were more than females (27.2% vs. 15.2%) (23). Apisarnthanarak et al. (2012) found the supernumerary renal arteries in 18.5% and early branching in 12.8% at the right side and 27.7% and 22.4% respectively at the left side (24). In another large angiographic series, additional renal arteries were found in 18.2% of cases. One additional artery was found in 8.9% of cases, two in 5.0%, three in 1.6%, four in 0.35%, five in 0.2% and six in 0.1% cases. In 6.6% of cases there was bilateral symmetry in the number of the additional renal vein (bilateral double in 6.3%, bilateral triple in 0.2% and bilateral quadruple in 0.1% of cases (7, 25).

Palmieri et al. (2011) found a high percent of multiple renal arteries of 61.5% in the angiographic study conducted in Brazilian population (56% in the right and 67% in the left kidney) (26). Contrary, Hlaing et al. (2012) found only 4% of accessory arteries in an anatomical study in Malaysian population (27). In another angiographic study, multiple renal arteries were found in 31.3% of cases (two arteries in 22.2%, three in 7.5%, four in 1.4%, five in 0.2% of cases) and prehilar branching in 6.5% cases (1).

In our study multiple renal arteries were found in 20.9% of cases, at the right side in 21.8% and at the left side in 20.0% of cases. Multiple arteries were slightly more often in males than in females (21.7%: 20.0%). Our findings are in agreement with the studies conducted in other populations (Table 4).

Table 4. The frequency of multiple renal arteries (different studies)

Studies	MA %	2 arteries %	3 arteries %	4 arteries %	5 arteries %
Çınar C, Türkvatan A, 2016 (1)	31.3	22.2	7.5	1.4	0.2
Tardo DT et al., 2017 (23)	6.9	5.6	1.4	--	--
Zăhoi DE et al., 2015 (35)	23.2	19.6	3.6	--	--
Matusz P et al., 2011 (25)	18.2	8.9	5.0	1.6	0.35
Natsis K et al., 2014 (36)	17.3	13.0	4.3	--	--
Our study, 2019	20.9	17.3	2.7	0.9	--

The existence of accessory renal arteries is most often without clinical symptoms. Usually, these arteries are detected by random radiographic examinations. If the accessory artery vascularizes the lower pole of the kidney, it often passes in front of the ureteropelvic junction or ureter and performs external compression leading to hydronephrosis (15). The existence of accessory renal vessels (arteries or veins) leading to ureterohydronephrosis must be surgically resolved either by the open surgery or laparoscopy. Simphoroosh et al. (2005) presented the laparoscopic management of ureteropelvic junction obstruction by division of the aberrant vein and cephalad relocation of the crossing artery (28).

Life-threatening bleeding may result from accessory artery injury during percutaneous renal biopsy for diagnostic or other purposes (29). The existence of accessory renal arteries impairs renal transplantation and can lead to pyeloureteral necrosis of the graft due to damage of the artery that vascularizes it (30). The exact number of arteries and their arrangement is especially important in the kidney transplantation. These findings are necessary to avoid undesirable injuries to these arteries during the explantation of the kidney and to prepare for their microsurgical reconstructions.

Unlike the renal veins, the RRA is slightly longer than the LRA. Palmieri et al. (2011) found that the average length of the main renal artery to its first branch was 3.96 ± 0.13 cm on the right and 3.41 ± 0.11 cm on the left side (26). Mohiuddin et al. (2017), found a significant difference in the caliber and length of the right (diameter was 6.66 ± 0.39 mm; length was 44.69 ± 2.48 mm) and left renal arteries (diameter was 6.79 ± 0.36; length was 35.10 ± 2.86 mm) (31). We found no significant difference in caliber between the right and left renal arteries. A significant difference in the length of the right and left renal arteries was found when we measured the length from their origin to the hilum of the kidney. The clinical relevance of the knowledge of the size of renal arteries is reflected in the evaluation of renovascular hypertension. Tortuous shape and small caliber of accessory arteries can lead to arterial hypertension (17). Knowledge of the size of the renal arteries is important for interventional radiologists in procedures such as angioplasty and arterial catheterization (32). Small caliber of renal arteries can lead to arterial stenosis which can cause renal hypertension and ischemic nephropathy (33). Renal artery stenosis is treated by percutaneous stenting and requires knowledge of the caliber and length of the renal artery (34). The larger length of the renal artery allows greater mobility of the kidney during the intervention on it. The short renal artery (early branching) can cause difficulty during a nephrectomy and kidney transplantation. In our study, early branching of the renal artery (15 mm from the aorta) was found in 5.5% on the RRA and in 7.3% on the LRA. Knowing the length and caliber of the renal artery is important before the kidney transplantation. Successful transplantation requires a renal artery of sufficient length and diameter. The transplant kidney with the appropriate vascular loop should be selected to minimize microsurgical vascular reconstruction and to make transplantation more successful.

CONCLUSION

Multiple renal arteries were present in 20.9% of cases of our study, with a slightly higher incidence on the right side. Knowledge of the number of renal arteries, their origin, course, and mode of entry into the kidney is of great importance for the successful conduct of radiological and surgical procedures. Multiple renal arteries can be injured during surgery and lead to bleeding of a life-threatening patient. They complicate kidney surgery as well as interventions in its environment such as in the case of retroperitoneal lymphadenopathy, surgery of aneurysm of the abdominal aorta and others. Multiple kidney arteries make it difficult and, in some cases, prevent kidney transplantation.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by Ethical comittee of the Clinical Centre Kragujevac, Serbia, No. 01-19/3542. Voluntary written and informed consent was obtained from each participant prior to enrollment in the study.

COMPETING INTERESTS

There are no conflicts of interest.

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