Original paper

Analysis of coexistence of multiple renal arteries and veins in 2392 human kidneys based on computed tomography imaging

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Abstract

Introduction: Analysis of the coexistence of multiple renal arteries and veins is a rare subject in the literature. There are few studies in which the arterial and venous systems of the human kidney are evaluated simultaneously.
Aim of the research: The aim of the study was to analyse and correlate variations in the arterial and venous vascularisation of the kidneys in patients diagnosed using computed tomography.
Material and methods: The study group (1196 patients) included women (592) and men (604), aged from 19 to 92 years, who had imaging scans performed using contrast-enhanced computed tomography. The statistical analysis was performed using Statistica 12.0 software. The relationships were verified with the χ^2 test. The level of statistical significance was $p = 0.05$. The mean age of the patients was 58.78 ±15.31 years; the mean age for men was 57.18 ±14.74 years, and for women 60.41 ±15.72 years ($p < 0.001$).
Results and conclusions: As for arterial vascularisation, it was demonstrated that the presence of multiple renal arteries was more common in left kidneys (11.71%) compared with right kidneys (9.95%), whereas multiple renal veins more often occurred in right kidneys (9.03%) than in left kidneys (4.43%). It was generally concluded that there is a correlation between the number of coexisting arteries and veins in the kidneys, which was confirmed statistically ($\chi^2 = 55.47$; $p < 0.001$). In the context of anatomic variation regarding the extrarenal arteriovenous system of the kidneys, there is a statistical relationship between the number of coexisting arteries and veins in the kidneys ($r = 0.9472$; $p < 0.001$), which has been confirmed by the results of this study.

Introduction

The problem of the prevalence of renal vascular anomalies may in fact be related to the characteristics of a given population whose traits result from various factors, such as geographic region or ethnic origin. However, bearing in mind contemporary knowledge regarding intraspecies variation in humans, genetic and molecular studies provide evidence that contemporary populations do not represent separate phylogenetic lines due to a constant and multidirectional gene flow [1]. Nonetheless, the so-called local populations, characterised by a separate geographic distribution, specific biological traits expressed in appearance, and specific environmental conditions, may show certain tendencies to a greater prevalence of given anatomic "variations" in relation to the generally acknowledged (classical) morphology regarding the structure of the human body. In one of the recent reviews on variations in the renal vascularisation, Recto *et al.* [2], who reviewed 64 papers involving the analysis of 20,000 human kidneys from 31 countries (5 continents), estimated that multiple renal arteries were present in 19.95% of all examined kidneys, with the number of these vessels ranging from to 2 to 6. The variation of multiple renal arteries (mRAs) usually involved the presence of 2 renal arteries (89.48%), followed by 3 (9.31%), 4 (1.06%), 5 (0.02%), and 6 (0.005%) renal arteries. The above-mentioned authors were unable to formulate definitive conclusions regarding the side of the body that shows a greater tendency to such variations. Multiple renal arteries were found on the right side in 49.83% of cases, and on the left side in 50.17% of cases, making the difference subtle. The prevalence of multiple renal veins (mRVs), circumaortic left renal vein (C-LRV), and retroaortic left renal vein (R-LRV) was well presented by Hostiuc *et al.* [3]. Based on an extensive literature review, including 105 papers, the authors estimated the overall prevalence of R-LRV at 3% (1–10%), C-LRV at 3.5% (1–15%), and mRVs at 16.7% (2–40%). Is should be added that the authors suggest that venous variations of the kidneys tend to be more common on the right side (16.6%) than on the left (2.1%). Based on the literature data [3] from all the papers, a total of 12,773 kidneys were analysed. Variation of mRVs was identified in 2241 cases, 1762 of which concerned right renal veins and 221 concerned left renal veins. The presence of double renal veins (1450) concerned double right renal veins in 1317 cases and double left renal veins in 133 cases. The presence of triple right renal veins was found in 170 cases, and triple left renal veins in 77 cases. According to Hostiuc *et al.* [3], the most and the least prevalent are double right renal veins (13.8%) and triple right renal veins (0.4%), respectively. In general, the presence of multiple renal veins is relatively common. The literature indicates that the variations in the number of renal veins usually result from developmental defects [4–6]. Nevertheless, renal veins are characterised by a lower level of variation than renal arteries. Other aspects of renal vein variation include, for example, the location or site of venous confluence and the course of these vessels that may be explained by the complexity of the left renal vein development in the embryonic period [7, 8]. The presence of multiple renal arteries may coexist with other anatomic variations, e.g. with multiple renal veins or multiple ureters [9, 10]. As for the prevalence of renal arterial and venous anomalies, the renal arterial variations are much more common than renal venous variations. Bordei *et al.* [10] support this conclusion and report a prevalence ratio for venous to arterial variations of 1 : 8. Nonetheless, it must be noted that renal arterial variation is accompanied by venous variation, which is suggested in the literature data [11–13].

Because the data on the coexistence of multiple renal arteries and veins are scarce and some of them are based on metadata, it was decided to carry out an original study with the aim to determine the relationship between the coexistence of anatomic variations in the arterial and venous systems of the kidneys. Apart from the exploratory character, the results of this study also have practical implications that are significant for abdominal surgery.

Aim of the research

The aim of this study was to evaluate the prevalence of renal vascular variations in patients undergoing computed tomography and to investigate the association between the presence of multiple renal arteries and veins.

Material and methods

The investigation concerned randomly selected results of abdominal imaging examinations performed using computed tomography (CT) with intravenous contrast administration in 1196 patients diagnosed at the Department of Diagnostic Imaging of Swietokrzyskie Oncology Centre in Kielce, Poland, in 2017–2019. The investigations were possible thanks to the appropriate authorisations, for example, for personal data processing with respect to access to medical records, via the hospital IT system CLININET and NETRAAD system. These systems are used for comprehensive computerisation of imaging departments and labs and enable the management of information and digital diagnostic images, their archiving, and creation of complete medical documentation in the form of electronic patient records. Furthermore, the study was approved by the Ethics Committee at the Collegium Medicum of Jan Kochanowski University in Kielce (Resolution No. 1/2019). The study group included women (592) and men (604), aged from 19 to 92 years, who had diagnostic imaging scans performed using contrast-enhanced computed tomography (with iohexol 350 mg I/ml). The mean age of the patients was 58.78 ±15.31 years; the mean age for men was 57.18 ±14.74 year, and for women 60.41 ±15.72 years ($p < 0.001$). The investigation involved computed tomography images (DICOM format) obtained with a 64-slice computed tomography scanner by Siemens (SOMATOM Definition AS) and analysed using a Siemens Syngo Multi-Modality Workplace and Leonardo Workstation.

Statistical analysis

The statistical analysis was performed using Statistica 12.0 software. The normal distribution of data was verified using the Shapiro-Wilk test. Normally distributed data were tested with one- or two-way analysis of variance (main effect ANOVA) and the post-hoc Fisher's LSD test. Homogeneity of variance was verified with the Levene's and Brown-Forsythe tests. In the case of variance non-homogeneity, Welch's test was employed. For data with non-normal distribution, the non-parametric Mann-Whitney *U* test or Kruskal-Wallis test was used, and differences between the individual means were tested using Dunn's multiple comparison test for mean ranks of all samples. The relationships were verified with the chi-square test. The Pearson correlation coefficient (r) was used to assess the relationship between the analysed variables. In all tests used, results with a significance level of $p < 0.05$ were considered statistically significant.

Results

In total, 2392 kidneys of 1196 patients were analysed. To do this, the examined kidneys were divided into 2 anatomic variations: the first group included kidneys with only one renal artery ($n = 1874$; 78.34%), and the other group included kidneys with at least 2 renal arteries ($n = 518$; 21.66%) (Figure 1). As for the arterial vascularisation of each analysed kidney, it was demonstrated that mRAs were more common in left

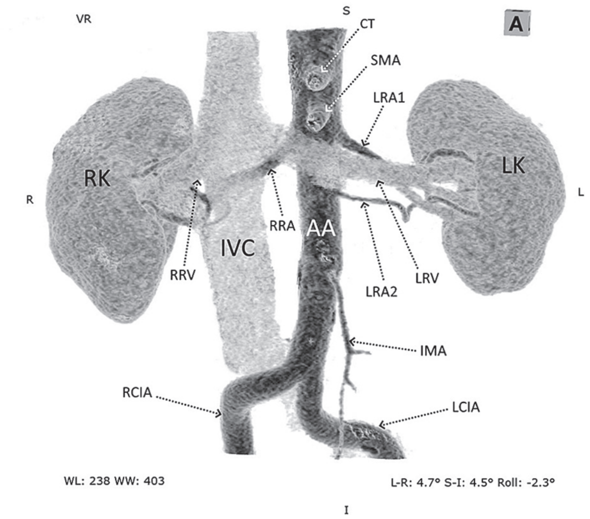

Figure 1. 3D reconstruction showing the presence of two left renal arteries and one right renal artery

RK – right kidney, LK – left kidney, AA – abdominal aorta, IVC – inferior vena cava, CT – celiac trunk, SMA/IMA – superior/inferior mesenteric artery, RCIA/LCIA – right/left common iliac artery, RRV/LRV – right/left renal vein, RRA – right renal artery, LRA1–LRA2 – two left renal arteries.

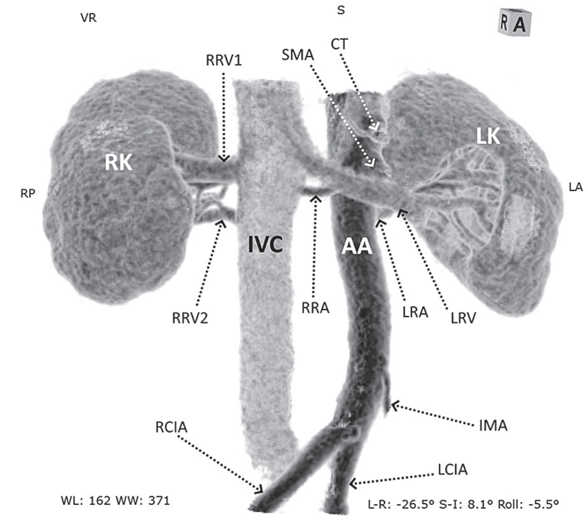

Figure 2. 3D reconstruction showing the presence of two right renal veins and one left renal vein

RK – right kidney, LK – left kidney, AA – abdominal aorta, IVC – inferior vena cava, CT – celiac trunk, SMA/IMA – superior/inferior mesenteric artery, RCIA/LCIA – right/left common iliac artery, RRA/LRA – right/left renal artery, LRV – left renal vein, RRV1–RRV2 – two right renal veins.

kidneys (11.71%) compared with right kidneys (9.95%) ($\chi^2 = 4.35$; $p = 0.0371$). The kidneys were investigated in terms of the multiplicity of arterial vascularisation. This led to the division into 3 groups (anatomic variations). The first group included kidneys supplied by 2 arteries (2RAs), the second group included kidneys supplied by 3 arteries (3RAs), and the third group included kidneys supplied by 4 arteries (4RAs). Of all the kidneys in the mRA group ($n = 518$), most (85.14%) had 2 arteries. The 3RA variation accounted for 10.81% of the cases, while the 4RA variation was found in 4.05% of the cases. There were statistically significant differences between the number of the analysed kidneys and their arterial variation ($H = 8.06$; $p = 0.0178$). The multiple comparison test confirmed that the greatest differences exist between the 2RA variation and the 4RA variation ($Z = 2.75$; $p = 0.0181$). As for the analysis of the number of renal veins in their extrarenal segments, there were multiple vessels in 292 (24.41%) patients, and 904 (75.59%) patients had a single renal vein bilaterally. As in the arterial system, the examined kidneys were divided into 2 anatomic variations: the first group included kidneys with only one renal vein exiting from the renal parenchyma (sRV; $n = 2070$, 86.54%), and the other group included kidneys with at least 2 renal veins exiting from the renal parenchyma and separately entering the inferior vena cava or common iliac vein (mRVs; $n = 322$, 13.46%). As for the venous vascularisation of each analysed kidney, it was found that multiple renal veins were more common in right kidneys (9.03%) compared with left kidneys (4.43%) ($\chi^2 = 44.28$; $p < 0.001$). The kidneys were analysed in terms of the number of veins directly supplying the inferior vena cava. This led to the division into 3 groups (anatomic variations). The first group included kidneys with 2 renal veins (2RVs), the second group included kidneys with 3 veins (3RVs), and the third group included kidneys with 4 veins (4RVs). Of all the kidneys in the mRV group ($n = 322$), most (86.02%) had 2 veins (Figure 2). The 3RV variation accounted for 13.04% of the cases, while the 4RV variation was found in 0.94% of the cases. There were statistically significant differences between the number of the analysed kidneys and their venous variation ($H = 8.31$; $p = 0.0157$). The multiple comparison test confirmed that the greatest differences exist between the 2RV variation and the 4RV variation ($Z = 2.64$; $p = 0.0243$). The comparative analysis of the extrarenal arteriovenous system of the kidneys included the anatomic variations of renal arteries (mRAs: 21.65%, 518 kidneys) and renal veins (mRVs: 13.46%, 322 kidneys) (Table 1).

It was generally concluded that there is a correlation between the number of coexisting arteries (sRA and mRA variations) and veins (sRV and mRV variations) in the kidneys, which was confirmed statistically ($\chi^2 = 55.47$; $p < 0.001$).

A positive correlation was found between the number of kidneys representing a given arterial variation (1RA, 2RAs, 3RAs, and 4RAs) and a venous variation (1RV, 2RVs, 3RVs, and 4RVs) ($r = 0.9472$; $p < 0.001$)

As for the coexistence of renal arteries and veins taking into account the side of the body, it was shown

Table 1. The distribution of the number of kidneys based on the coexistence of renal arteries and veins as well as the presence of anatomic variations (mRAs and mRVs)

Number of veins		Number of arteries				Total	mRAs	
		1	2	3	4		Σ	%
1		1699	331	28	12	2070	371	17.92
2		152	97	22	6	277	125	45.13
3		23	12	5	2	42	19	45.24
4		0	1	1	1	3	3	100
Total		1874	441	56	21	2392	518	21.65
mRVs	Σ	175	110	28	9	322		
	%	9.34	24.94	50.00	42.86	13.46		

that, on the right side, mRAs were the most common (100%) in kidneys with concomitant four renal veins. This was followed by mRAs (45.24%) coexisting with 3 veins. As for the left kidneys, mRAs were the most common (46.41%) in the kidneys with 2 veins. It was also demonstrated that the co-occurrence of mRA kidneys with a single vein depends on the side of the body ($\chi^2 = 4.45$; $p = 0.0348$) (Table 2).

As for the coexistence of renal arteries and veins taking into account sexual dimorphism, it was shown that mRAs were the most common (100%) in male kidneys with concomitant 4 renal veins. This was followed by mRAs (47.88%) coexisting with 2 veins. As for the left kidneys, mRAs were the most common (44.44%) in the kidneys with 2 veins. It was also demonstrated that the co-occurrence of mRA kidneys with a single vein depends on the gender ($\chi^2 = 11.14$; $p < 0.001$) (Table 3).

Discussion

As the literature analysis reveals, the mean prevalence of variations in the human extrarenal arterial system (i.e. the presence of more than one renal artery) is ~25% in the general population, with the values

Table 2. Distribution of the number of kidneys ($n = 2392$) taking into account the side of the body and coexistence of renal arteries and veins including the mRA variation (LZ, number of veins; LT, number of arteries; LN, number of kidneys; mRA%, percentage distribution of multiple arteries in each group for one, two, three, and four veins)

Right					χ^2 value (p)	Left				
LZ	LT	LN	%	mRA %		LZ	LT	LN	%	mRA %
1	1	865	84.23	15.77	4.45 (0.0348)	1	1	834	79.96	20.04
	2	143	13.92				2	188	18.02	
	3	13	1.27				3	15	1.44	
	4	6	0.58				4	6	0.58	
2	1	70	56.45	43.55	0.09 (0.7699)	2	1	82	53.59	46.41
	2	42	33.87				2	55	35.95	
	3	10	8.06				3	12	7.84	
	4	2	1.62				4	4	2.62	
3	1	23	54.76	45.24	–	3	1	0	–	–
	2	12	28.57				2	0	–	
	3	5	11.90				3	0	–	
	4	2	4.76				4	0	–	
4	1	0	0.00	100.00	–	4	1	0	–	–
	2	1	33.33				2	0	–	
	3	1	33.33				3	0	–	
	4	1	33.33				4	0	–	

Table 3. Distribution of the number of kidneys (n = 2,392) taking into account the gender and coexistence of renal arteries and veins including the mRA variation (LZ, number of veins; LT, number of arteries; LN, number of kidneys; mRA%, percentage distribution of multiple arteries in each group for one, two, three, and four veins)

Men (n = 1208)					χ^2 value (p)	Women (n = 1184)				
LZ	LT	LN	%	mRA %		LZ	LT	LN	%	mRA %
1	1	799	78.64	21.36	11.14 (0.008)	1	1	900	85.39	14.61
	2	184	18.12				2	147	13.95	
	3	23	2.26				3	5	0.47	
	4	10	0.98				4	2	0.19	
2	1	86	52.12	47.88	0.48 (0.4900)	2	1	66	58.93	41.07
	2	57	34.55				2	40	35.71	
	3	17	10.30				3	5	4.47	
	4	5	3.03				4	1	0.89	
3	1	13	54.17	45.83	0.00 (0.9561)	3	1	10	55.56	44.44
	2	7	29.16				2	5	27.78	
	3	3	12.50				3	2	11.11	
	4	1	4.17				4	1	5.55	
4	1	0	0.00	100.00	–	4	1	0	–	–
	2	1	33.33				2	0	–	
	3	1	33.33				3	0	–	
	4	1	33.33				4	0	–	

reaching over 30% in certain populations [14]. Abuelnour [15] conducted a meta-analysis of 21 reviews (in total 11,563 analysed kidneys) and concluded that the prevalence of multiple renal arteries reached 19%. In the meta-analysis of 64 papers (in total 20,782 analysed kidneys) performed by Recto *et al.* [2], multiple renal arteries were found in 4146 kidneys, which represents the prevalence of 19.95%, where 3710 kidneys (17.85%) had 2 arteries, 386 kidneys (1.86%) had 3 arteries, 44 kidneys had 4 arteries (0.21%), 5 kidneys had 5 arteries (0.02%), and one kidney had 6 arteries (0.005%). In the studies on the Polish population, Sośnik and Sośnik [16] demonstrated a considerable prevalence of mRAs at the level of 41% (133 of 324 patients). In other studies performed by the same authors [17], the (renal) prevalence of mRAs was 23.3% (256 of 1100 kidneys), and in yet another study Sośnik and Sośnik [18] reported the mRA prevalence at the level of 38.3% (354 of 924 patients).

In the present study, multiple arteries represented 21.66% of the cases in the study population, which makes this value similar to the mean values found in the literature, but slightly lower than the one reported by Sośnik and Sośnik [16–18].

As the literature data show, the mean prevalence of variation in the human extrarenal venous system (i.e. the presence of more than one renal vein) is ~15% in the general population, with the values reaching over 20% in certain populations [3]. In one of the recent reviews on the prevalence of renal venous variations, Hostiuc *et al.* [3] demonstrated that the overall prevalence of multiple renal veins was 16.7% in the range from 14.3% to 19.2%.

Based on the studies carried out by Sośnik and Sośnik [19], the prevalence of mRVs in the Polish population reaches 29.6%, and mRVs are more common on the right side (27.5%) than on the left side (9.3%). The present study revealed that multiple renal veins were found in 24.41% of the cases and were also more common on the right side.

As has previously been suggested, the literature usually contains studies that focus either on renal arterial variation or renal venous variation, but there are fewer reports regarding the coexistence of arterial and venous variations. Moreover, these are usually case reports [20–24]. Stojadinovic *et al.* [25] stated that anatomic variations regarding arterial and venous vessels are relatively common, but their coexistence is a rare phenomenon and is reported as isolated cases. Recently, some interest has been noted in this subject matter among researchers. In one of the most recent publications regarding the Polish population, Sośnik and Sośnik [17] demonstrated a statistically significant relationship between the coexistence of anatomic variations concerning renal vascularisation. Moreover, the authors also showed that this is more common for males than for females. The authors reported a statistically significant relationship between the coexistence of a single renal artery and 2 renal veins ($p < 0.001$), single renal artery and 3 renal veins ($p < 0.001$), as well as single renal artery and 4 renal veins ($p < 0.001$), and between the occurrence of 2 arteries and 3 veins ($p < 0.001$). They also noted a statistically significant correlation ($p < 0.001$) between venous variation and coexisting arterial variants. In other studies, Staśkiewicz *et al.* [26] performed a correlation analysis of the number of renal vessels (arteries and veins) to evaluate for a potential correlation (tendency) in the coexistence of accessory vessels. The authors noted significant positive correlations, thus confirming the tendency for the coexistence of accessory arteries and veins. Moreover, the authors compared the number of renal vessels in patients with accessory vessels and without them. This demonstrated that there were more vessels on the right side in patients with an accessory left renal artery, whereas the mean number of all the remaining vessels was significantly higher in patients with an accessory right renal vein. The present study has demonstrated a relationship between the number of arteries and the number of veins that coexisted in the kidneys, which was verified statistically ($\chi^2 = 55.47$; $p < 0.001$).

The presence of multiple renal arteries may be linked with persistent primary vessels. In his research, Cieśliński [27] demonstrated that, from week 8 of the embryonic development, the kidney is supplied by the renal artery that originates from the anterolateral segment of the aorta. Moreover, the above-mentioned author states that the renal artery, which enters the renal hilum, is one of the upper arteries of the mesonephros. As for the embryonic development of renal veins, attention should be paid to the transformations observed then in the cardinal veins. Unlike the arterial system, the renal venous system develops by anastomoses between the developing large veins. It may be generally suspected that the presence of more than one renal vein could be a remnant of a venous anastomosis from the period of embryonic development [28–30].

That is why the coexistence of renal vascular variations may be associated with prenatal development, even more so because arterial and venous development takes place simultaneously.

Conclusions

Based on the analysis of the arterial and venous vascularisation of the kidneys in humans, it is concluded that, in the context of anatomic variation regarding the extrarenal arteriovenous system of the kidneys, there is a statistically significant relationship between the number of coexisting arteries and veins in the kidneys. The side of the body is of significance as far as renal arterial and venous multiplicity is concerned. The presence of multiple renal arteries is more common in left kidneys compared with right kidneys. Multiple renal veins, on the other hand, are usually found in the right kidneys. Knowledge of the anatomical diversity of renal vascularization is important for diagnosing kidney diseases and understanding some of the specific features of the clinical background, especially in the case of transplants, where accurate radiological assessment of donor kidney vascularisation is essential and of paramount importance in preoperative planning.

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Ethical approval

The research protocol was submitted for review and approved by the Bioethical Committee of the Collegium Medicum of Jan Kochanowski University in Kielce (resolution No. 1/2019).

Conflict of interest

The authors declare no conflict of interest.

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