

# Venous supply of horseshoe kidneys and normal kidneys: an angio-multislice computed tomography-based study

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**Background:** Horseshoe kidney (HSK) is a common developmental anomaly which can be associated with many atypical anatomical variants of blood supply. The aim of this study was to identify the anatomical variants of renal veins supplying HSK, with particular emphasis on their relationship with the arterial system.

**Materials and methods:** The analysis included 94 patients with HSK and 248 persons with normal kidneys (NK). Based on computed tomography-angiography, the number of renal arteries and veins was determined, along with the levels the arteries branched off the aorta and the veins communicated to their parental vessels.

**Results:** Four hundred and twenty-three renal arteries (4.5 per person) and 364 renal veins (3.78 per persons) were found in HSK group ( $p = 0.004$ ), as compared with 598 arteries (2.41 per person) and 567 veins (2.29 per person) in the NK group ( $p = 0.025$ ). Mean number of renal veins in women with HSK was higher than in men (4.11 vs. 3.72 per patient,  $p = 0.03$ ). In the HSK group, the number of renal arteries correlated significantly with the number of renal veins only among men ( $k_s = 0.35$ ,  $p = 0.009$ ). In patients with NK, significant correlations between the number of renal arteries and renal veins were found both in the whole group and among men and women.

**Conclusions:** Horseshoe kidneys are drained by a higher number of renal veins than NK, especially in women; this also refers to accessory renal veins. The number of renal veins for HSK is less dependent on the number of corresponding arteries than these for NK. (Folia Morphol 2023; 82, 2: 368–374)

**Key words:** horseshoe kidney, vascular variations, renal vein

## INTRODUCTION

Horseshoe kidney (HSK) is a common developmental anomaly which can be associated with many atypical anatomical variants of blood supply [2, 4]. Knowledge of these variants is clinically relevant whenever pathological changes are present in the

kidney or adjacent organs. Blood supply of HSK requires a careful and comprehensive assessment before a planned surgical procedure, such as nephrectomy, transplantation or management of aortic aneurysms [3, 12, 26]. Furthermore, the presence of the atypical anatomical variants of blood supply can be associated

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with nephrolithiasis and compression syndromes, such as nutcracker syndrome [8, 17].

The vascular system of kidneys and as well as HSK itself was considerably studied but most of the literature was concerned with arterial blood supply system omitting venous one. Never-the-less, patients with HSK usually do not present any clinical symptoms, the untypical development of the organ provoke preserving vascular system existing for fetal period which can cause complications during either invasive treatment or morbid processes. Up to now the authors have noticed the relation between HSK and anatomical variants of both kidney veins as well as inferior vena cava but the studies were limited in number and usually based on modest sum of participants [9–11, 16]. We found it profitable to deepen the knowledge of this field and decided to plan a study to identify anatomical variants of renal veins supplying HSK, with particular emphasis on their relationship with the arterial system.

## MATERIALS AND METHODS

The protocol of the study was approved by the Local Bioethics Committee at the Medical University of Lodz, Poland (decision no. RNN/132/17/KE of 11 April 2017).

The study material consisted of images from all consecutive patients in whom computed tomography (CT)-angiography of the abdominal aorta and minor pelvis demonstrated the presence of HSK (images taken between January 2006 and February 2019) or normal kidneys (NK) (images taken between March 2016 and January 2017). The images were extracted from the PACS archiving system at the Department of Radiology, University Clinical Hospital No. 1 in Lodz, Poland.

The only inclusion criterion for the HSK group was the presence of a single HSK, whereas the control group included only the images from patients who presented with two typically located and NK. The patients were excluded from the study if they underwent partial or complete resection of the kidney, received kidney transplant, their CT angiographic images were incomplete or had inadequate technical quality (lack of all kidney components on the image, insufficient contrast enhancement, motor artifacts or other artifacts hindering full evaluation of renal vessels, e.g. metallic hardware in the spine or barium contrast in the intestines).

Eventually, the HSK group included 94 patients (37 women and 57 men) aged between 15 and 96

years (mean  $66.4 \pm 15.93$  years). The median age of the HSK group was 65.5 years and lower and upper quartile corresponded to 58 and 81 years, respectively. Control group was comprised of 248 patients (122 men and 126 women) with two typically located and NK. Mean age of the controls was  $66.4 \pm 15.01$  years, with the range between 24 and 94 years, a median of 68 years, and lower and upper quartile of 58 and 78 years, respectively.

Computed tomography-angiography was performed with GE Light Speed 64 VCT scanner (GE Healthcare, Milwaukee, WI, US; 120 kV, 10 mA, mAs — dynamic), with 0.625-mm layer width and 0.6-mm pitch, after intravenous administration of 80–100 mL of Ultravist 370 contrast agent (BAYER Schering Pharma AG, Germany) with an automatic syringe at a flow rate of 4.5–4.2 mL/s. The data were acquired for 6 s after achieving a 150 jH contrast enhancement at the level of the aortic bifurcation. Transverse, sagittal and frontal CT angiographic images were evaluated at a doctor's console with the aid of AW 4.0 GE software. The number of renal arteries and veins was determined, along with the level at which the arteries branched off the aorta and the level at which the veins connected to their parental vessels. The number of arteries and veins was calculated as a sum of all vessels supplying the HSK or two NK. This approach was chosen to prevent problems with distinguishing between the vessels supplying the right lateral and the left lateral part of the HSK.

Both groups of patients, with HSK and NK, were divided into subgroups depending on the level at which the renal arteries and veins connected to their parental vessels:

- level I — patients with veins draining to the inferior vena cava and arteries branching off the aorta;
- level II — patients with veins draining to the common iliac vein and arteries branching off the common iliac arteries;
- level III — patients with veins draining to the internal and external iliac veins and arteries branching off the internal and external iliac arteries.

Patients with HSK or NK who did not satisfy any of the criteria mentioned above were not included in this part of the analysis.

Moreover, the number of patients who represented various anatomical variants of renal venous drainage included in the classification proposed by Koc et al. [13], i.e. single renal vein (variant I + II) and accessory renal veins (variant III), was determined.

**Table 1.** Frequency of additional renal veins in relation to its anatomical variant

	Horseshoe kidneys			Normal kidneys		
	Whole group	Women	Men	Whole group	Women	Men
Variant I + II	10 (10.64%)	1 (2.70%)	9 (16.67%)	189 (76.21%)	95 (77.87%)	94 (74.60%)
Variant III	84 (89.36%)	36 (97.30%)	48 (83.33%)	59 (23.79%)	27 (22.13%)	32 (25.40%)

Furthermore, the topography of the left renal vein was analysed

### Statistical analysis

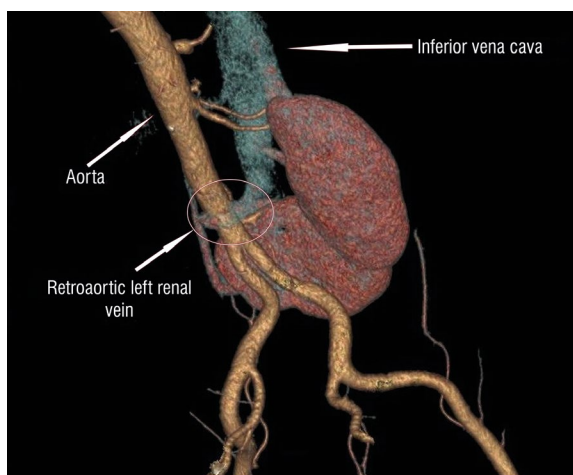
Statistical characteristics of quantitative variables were presented as means, standard deviations (SD), medians, minimum and maximum values, and quartiles. Before the between-group comparison of values of a given quantitative variable, normality of its distribution within the groups was verified with the Shapiro-Wilk test. As the distributions of analysed variables in the study groups were not normal, the significance of between-group differences was verified with a non-parametric Mann-Whitney U-test, and relationships between pairs of selected variables were determined based on the Spearman's coefficients of rank correlation.

The figures were created with syngo.via (Siemens Healthineers, Erlangen, Germany) and Microsoft Paint 3D (Microsoft, Albuquerque, New Mexico, United States of America).

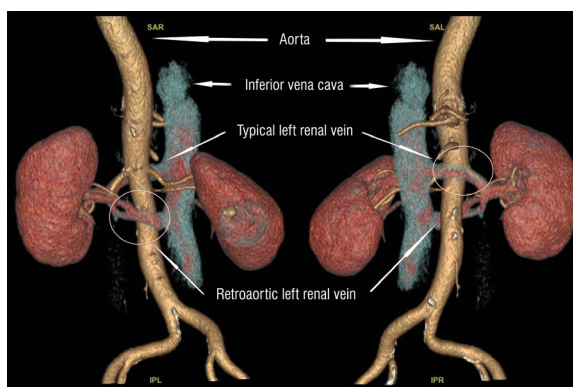
## RESULTS

A total of 423 renal arteries and 364 renal veins were found in the group of patients with HSK, as compared with 598 renal arteries and 567 renal veins in patients with NK. The between-group differences in the number of renal arteries and renal veins were statistically significant ( $p < 0.001$ ). Detailed data, including classification of the patients into the anatomical variants proposed by Koc et al. [13] are presented in Table 1.

The identified anatomical variants of the left renal vein included circumaortic renal vein and retroaortic renal vein. In patients with HSK, circumaortic renal vein was found in 2 (2.20%) cases and retroaortic renal vein in 12 (6.59%) (Fig. 1). Circumaortic (Fig. 2) and retroaortic left renal veins were also identified in 7 (2.82%) and 12 (4.8%) patients with NK, respectively. The between-group differences in the occurrence of the circumaortic and retroaortic variants were statistically significant ( $p < 0.001$  and  $p = 0.008$ , respectively).



**Figure 1.** Horseshoe kidney. Left renal vein presents retroaortic variant.



**Figure 2.** Two normal kidneys. Left kidney is drained by two renal veins creating circumaortic variant.

### Relationship between the number of renal veins and patient sex

The mean number of renal veins was stratified according to patient sex. In the HSK group, women presented with a significantly higher number of renal veins than men, 4.11 vs. 3.72 per patient, respectively ( $p = 0.03$ ). In contrast, no significant relationship between patient sex and the mean number of renal veins was found in the group with NK (Table 2).

**Table 2.** Mean numbers of renal arteries and veins in patients with horseshoe kidneys (HSK) and in patients with normal kidneys (NK)

	Whole group		Group of women		Group of men	
	Veins	Arteries	Veins	Arteries	Veins	Arteries
HSK group	3.87	4.5	4.11	4.24	3.72	4.67
NK group	2.29	2.41	2.24	2.34	2.29	2.50

Mean number of renal veins in women with HSK was 4.11 as compared with 2.24 in women with NK; the between-group difference was statistically significant ( $p < 0.001$ ).

Also, among men, patients with HSK presented with a significantly higher mean number of renal veins than those with NK (3.72 vs. 2.29,  $p < 0.001$ ) (Table 2).

#### Relationship between the number of renal veins and renal arteries

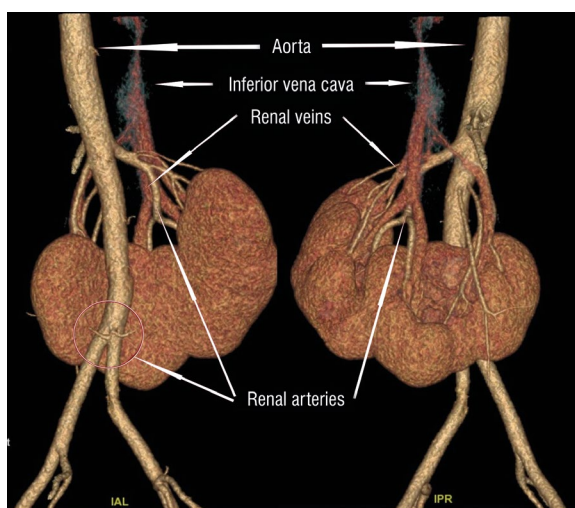
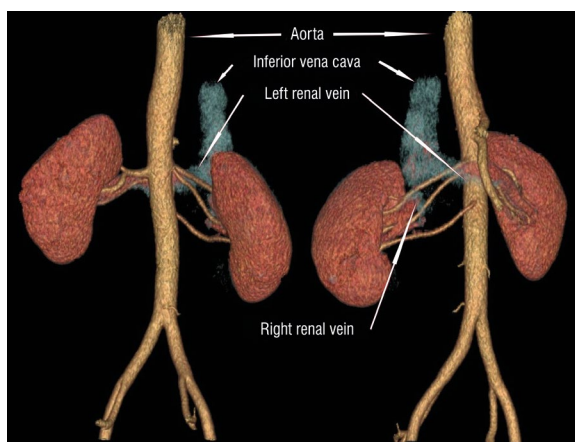
Mean numbers of renal veins and renal arteries in the HSK group were 3.78 and 4.50 per patient, respectively; the difference was statistically significant ( $p = 0.004$ ) (Fig. 3). When the results were stratified according to patient sex, men with HSK presented with 3.72 renal veins and 4.67 renal arteries on average ( $p < 0.001$ ), whereas the mean number of renal veins and renal arteries in women with HSK was 4.11 and 4.24 per patient, respectively ( $p = 0.77$ )

In patients with NK, the difference between the number of renal veins and renal arteries was statistically significant in the whole group (2.29 vs. 2.41,  $p = 0.025$ ) and among men (2.29 vs. 2.50,  $p = 0.016$ ) (Fig. 4). However, no statistically significant difference was found between the number of renal veins and renal arteries in women with normal kidneys ( $p = 0.52$ ) (Table 2).

#### Correlations between the number of renal veins and the number of renal arteries

No statistically significant correlations between the number of renal veins and renal arteries were observed in the whole HSK group and among women with this developmental anomaly. However, a moderately strong correlation between the number of renal veins and renal arteries was found in male patients with HSK ( $k_s = 0.35$ ,  $p = 0.009$ ).

The patients with HSK were also stratified according to the level at which the renal veins and renal arteries communicated to their parental vessels. After stratifying the patients according to this criterion, statistically significant correlations between the number

**Figure 3.** Horseshoe kidney supplied by 5 renal artery and drained by 3 renal veins.**Figure 4.** Two normal kidneys supplied by 5 renal arteries and 2 renal veins.

of renal veins and renal arteries were found at level II in the whole study group ( $k_s = 0.28$ ,  $p = 0.006$ ) and at the level I among men ( $k_s = 0.27$ ,  $p = 0.04$ ) (Table 3).

In patients with NK, significant correlations between the number of renal veins and renal arteries were found both in the whole group and among women and men (Table 4). We did not analyse correlations between the number of renal veins and renal arteries communicating to their parental vessels at

**Table 3.** Correlation between number of renal veins and arteries in a group of patients with horseshoe kidneys depending on vessel level

	Whole group		Group of women		Group of men	
	$k_s$	$p$	$k_s$	$p$	$k_s$	$p$
Level I	0.13	0.203	-0.04	0.834	<b>0.27</b>	<b>0.040</b>
Level II	<b>0.28</b>	<b>0.006</b>	0.44	0.086	0.12	0.673

**Table 4.** Correlations in between number of renal arteries and veins depending on anatomical variant of a kidney

	Normal kidneys group		Horseshoe kidneys group	
	$k_s$	$p$	$k_s$	$p$
Whole group	<b>0.25</b>	<b>&lt; 0.001</b>	0.16	0.150
Group of women	<b>0.22</b>	<b>0.014</b>	-0.08	0.634
Group of men	<b>0.26</b>	<b>0.003</b>	<b>0.35</b>	<b>0.009</b>

various levels due to a too small number of vessels representing levels II and III in the group with NK.

## DISCUSSION

Arterial supply of the kidneys can be quite heterogeneous. Renal arteries may differ in terms of their number, division patterns and origins [7, 14, 15, 23]. As this problem is clinically recognised, especially with regards to the accessory arteries, it has been frequently analysed in postmortem studies, as well as antemortem, using various imaging techniques, such as ultrasonography, magnetic resonance, but most of all, multislice computed tomography [1, 6, 19, 25]. However, the knowledge of renal venous supply is also important from a clinical perspective, as the atypical venous pattern may pose a threat during surgical procedures involving the kidneys and adjacent organs. The awareness of various anatomical variants of venous supply and careful preoperative assessment thereof may prevent inadvertent damage of blood vessels during the procedure [5, 9, 20]. This is particularly important considering that venous bleeding is markedly more difficult to control than the arterial bleeding.

Blood supply of HSK is particularly important from both research and clinical perspective. Horseshoe kidney is the most common congenital anomaly occurring with a frequency of 1 per 400–800 live births [21, 23]. Only a few published studies analysed the arterial supply of HSK and the reports on venous supply of this structure are even rarer. This justifies comprehensive research on the anatomy of venous supply in this type of kidney.

A total number of renal veins supplying HSK in our material was 353, which corresponded to 3.88 veins per patient; in turn, the overall number of veins for NK was 567, which corresponded to 2.29 veins per person. The difference turned out to be statistically significant. Moreover, a significant difference was found in the overall number of renal arteries and veins supplying HSK and NK ( $p < 0.001$  and  $p < 0.001$ ).

The number of veins supplying HSK in women turned out to be significantly higher than in men. In contrast, no significant sex-related difference was found in the number of renal veins for NK.

We also verified whether HSK were supplied with the accessory renal veins more often than the NK. To the best of our knowledge, the occurrence of accessory veins for HSK has not been studied thus far. The proportion of accessory renal veins supplying NK in our control group was similar as in previous studies in which it has been estimated at 8.0–18.8%.

In the case of both HSK and NK, the number of renal arteries was significantly higher than the number of renal veins ( $p = 0.004$  and  $p = 0.025$ ). This observation is consistent with the results of a postmortem study of American patients conducted by Pollak et al. [18] and an angio-CT-based study of NK carried out by Staśkiewicz et al. [22]. In both these studies, the number of renal arteries was higher than the number of renal veins, but none of the authors specified whether the difference was statistically significant.

Interestingly, when the results were stratified according to patient sex, the number of renal arteries was significantly higher than the number of renal veins among men, but not in women. A significant difference in the number of renal arteries and renal veins was found neither in female patients with HSK nor in women with NK.

Moreover, we observed a weak, albeit significant correlation between the number of renal arteries and renal veins supplying the NK ( $p < 0.001$ ). The significant correlation was found both in the whole group of patients with NK and after stratifying the results according to sex. While also Staśkiewicz et

al. [22] reported a similar association between the number of renal arteries and renal veins for the NK, they found a significant correlation only for the right kidneys. We did not observe a significant correlation between the number of renal arteries and renal veins supplying HSK in the whole group and among female patients. However, a significant correlation between the number of renal arteries and renal veins was found in men with this developmental anomaly ( $p = 0.003$ ).

During the next stage of the study, we analysed a relationship between the origins of renal arteries and renal veins for HSK. As only three veins represented variant III of renal venous drainage according to the classification proposed by Koc et al. [13], no statistical analysis was carried out for level III, which included this variant. We found a weak correlation between the origins of renal arteries and renal veins at level II in the whole HSK group ( $p = 0.006$ ) and at the level I in men ( $p = 0.04$ ). The relationships between the origins of renal arteries and renal veins were not analysed in patients with NK as none of the renal arteries in this group branched off the aorta below its bifurcation and none of the renal veins connected to other vessels than the inferior vena cava.

From a clinical perspective, particularly important are the circumaaortic and retroaortic variants of the left renal vein [3, 24]. Our observation that the retroaortic variant was more common than the circumaaortic variant is consistent with the results published by several other authors, but it needs to be stressed that their studies included patients with NK. Surprisingly, comparative analysis of patients with HSK and NK demonstrated that these were the latter who significantly more often presented with the circumaaortic variant.

Our study had few limitations: the group of patients with HSK was relatively smaller than in typical anatomical analyses, and we did not compare the CT findings with the results of other imaging studies or postoperative protocols. Moreover, men outnumbered women in the HSK group.

## CONCLUSIONS

Venous supply of HSK differs substantially from the supply of NK and does not follow any pattern included in the commonly used classification systems. Horseshoe kidneys are drained by a higher number of renal veins than NK, especially in women; this also

refers to accessory renal veins. The number of renal veins for HSK is less dependent on the number of corresponding arteries. The venous system of HSK is characterised by the lack of correlation or only a weak association between the levels at which the renal veins and renal arteries connect to their parental vessels, as well as by atypical frequency of various anatomical variants of the left renal vein.

These findings justify a comprehensive individualised diagnostic evaluation of both arterial and venous supply in each patient with HSK qualified for a surgical procedure involving the area of this organ.

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**Conflict of interest:** None declared

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