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The analysis of renal artery cross-section area and kidney volume in CT-angiography

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ABSTRACT

Background: The purpose of this study was to assess the relationship between renal artery cross-section area and kidney volume with consideration of anatomical variants of renal arteries, sexual dimorphism and lateralisation.

Material and methods: Two hundred and two patients, 104 women and 98 men, aged 57.3 ± 16 years were examined using CT-angiography of abdominal aorta for various reasons. The cross-section areas of renal arteries were measured automatically with a vessel tracking program and summed up on each side in case of the presence of additional renal arteries. The kidneys were measured manually.

Results: Additional renal arteries (ARA) were found in 68 patients (33.7%). Fifty three (77.9%) of them had one, 11 (16.2%) two and 4 (5.9%) three ARAs. Bilateral ARAs occurred in 10 cases (14.7% patients with ARA). Proximal branching of renal artery occurred in 36 (8.4%) renal arteries. The cross-section area of the largest renal artery depended on the number of ipsilateral renal arteries. Mean cross-section area of the main left renal artery was larger than on the right side (28.52 mm^2 vs. 25.36 mm^2 , $p < 0.01$) in the whole analysed group. Strong sexual dimorphism in renal artery cross-section area was

observed ($p < 0.01$) in favour of men (31.3mm^2 in men and 22.9mm^2 in women). Mean total renal artery cross-section area has positively correlated with kidney volume ($p < 10^{-13}$) in both sexes with Pearson correlation value of 0.5.

Conclusions: The cross-section area of renal arteries correlated positively with kidney volume in both sexes. Presence of ARAs do not influence the sum of cross-section areas of renal arteries. In case of a difference between left and right renal artery cross-section area with symmetrical kidneys, it is necessary to look for ARA.

Key words: renal dimensions, renal vasculature, accessory renal arteries

Introduction

The proper size of kidney depends on many congenital and acquired factors, e.g. Body Mass Index [17], height, weight, total body area[7], age, sex, kidney's position, presence of stenosis of the renal artery [9]. It might be supposed that the renal artery cross-section area may belong to the group of factors influencing the kidney size. Due to common occurrence of renal vasculature variants the determination of the relations between parameters of the kidney and the renal arteries with consideration of renal artery variants examined in CTA as well as the sexual dimorphism may contribute to more effective procedures performed in the renal area and thus to improve outcomes in patients with atypical renal arteries anatomy.

Renal arteries (RA) vary in number and morphology. Additional renal artery (ARA) is a common incidental finding while performing imaging diagnostic for a variety of reasons. CTA has over 98% sensitivity and specificity in the detection of accessory renal arteries [19]. According to the literature as much as one in three of examined patients have minimum one additional renal artery[13], which is asymptomatic and recognized as an anatomical variant. However, renal arteries take part in significant constitutional processes including arterial blood pressure regulation. These vessels are also exceptionally important during planning surgery e.g. kidney donation and transplantation, as well as percutaneous intraluminal procedures on renal arteries e.g. denervation due to persistent hypertension.

The aim of this study was to assess the relationship between renal artery cross section area and kidney volume with consideration of variants of renal arteries, sexual dimorphism and lateralisation.

Material and methods

Two hundred and two patients, 104 women (51,5%) and 98 men (48,5%), aged 18-88 years were examined using CTA of abdominal aorta for various reasons. Average patient's age was 57.3 ± 16 years, mean age of women and men counted 57 ± 15.7 and 57.6 ± 16.4 years respectively.

Iodine contrast medium was administered intravenously with the rate of 3,5-4,5 mL/s using an automatic syringe. Bolus tracking method was used. CTA examinations were performed with 64-detector CT scanner LightSpeed VCT (GE Healthcare). The thickness of the scan was 0.625 mm.

From consecutive 260 patients 58 were excluded from the study due to anomalies or diseases that hampered the kidney or artery measurements including 35 studies with inadequate contrast enhancement (below 200 Hounsfield units measured in the abdominal aorta), 12 patients with severe atherosclerosis, 5 with aortic aneurysm and 5 individuals with only one functioning kidney (either after nephrectomy or due to unilateral nephrosclerosis) as well as one renal graft recipient.

Images were analyzed on dedicated workstation AW4.4. Renal arteries were visualized using vessel tracking program on transverse reconstructions. The cross-section area of renal arteries was measured automatically 10 mm from the origin. In case of additional renal artery the cross-section areas of all renal arteries were measured 10mm from the origin of each renal artery and were summed up on the left and on the right side. The cross-section area of single renal artery or the sum of cross-section areas in case of ARA were named *total renal artery cross-section area*. Polar arteries - small additional arteries supplying kidney poles - were taken into account. The kidneys were measured manually in their maximum length along the longitudinal axis of the kidney. The maximum width was measured perpendicularly to the longitudinal axis in the widest part of the kidney (Fig. 1). Kidney volume was calculated using cylinder volume formula:

$$\text{Kidney volume} = \pi \times (\frac{1}{2} \times \text{width})^2 \times \text{length}$$

The level of renal arteries branching off from the aorta was related to the proper vertebra. Proximal separation of the first branch of renal artery was defined by branching within first 15 mm from the origin, while distal branching over 15 mm. Aorta cross-section area was measured just above the level of renal arteries branching off from the aorta.

The obtained parameter values were subsequently analysed using statistic tests. Descriptive statistics and tests p-values were calculated using R programming language [15]. Group comparisons, e.g. for difference in sex, were made using t-tests. Whenever normal distribution assumption was violated, two-sample Wilcoxon test was used. Comparisons of groups with several factor levels were made using the one-way analysis of variance (one-way ANOVA). When inferencing about relationship between two continuous variables, linear models were used and appropriate significance test was performed. For the analysis of contingency tables Chi-square test was used. Throughout paper p-value 0.05 was considered statistically significant.

Results

One hundred thirty four patients had one renal artery on each side (“1+1”). Additional renal arteries (ARAs) were found in 68 individuals (33.7%). Fifty three of them (77.9%) had one additional renal artery: 32 on the left (“1+2”) and 21 on the right (“2+1”) side, 11 (16.2%) had two (6 x “2+2”, 3 x “1+3”, 2 x “3+1”) and 4 (5.9%) had three ARA. Bilateral additional renal arteries occurred in 10 cases (4.9% of the whole examined group and 14.7% of patients with accessory renal arteries). Males tend to have additional renal arteries more frequently than women, however the correlation was not significant (p-value~0.1). No lateralisation of additional renal arteries was observed, neither in males nor in females. (Fig. 2)

Mean total cross-section area of the left (L) renal arteries was significantly larger than on the right side (R) (L – 28.52 mm² R – 25.36 mm², p<0.01) in both sexes (L/male – 33.18, R/male – 29.14 mm² p<0.01; L/female – 24.1 mm² R/female – 21.87 mm² p<0.05). Very strong difference between sexes in total renal artery cross-section area was observed (p-value <10⁻¹⁰) in favour of men (mean 31.3mm² in men and 22.9mm² in women).

In cases of ARA the cross-section area of the largest renal artery on each side depended on the number of ipsilateral renal arteries. The more additional renal arteries were found, the smaller was the cross-section area of the largest ipsilateral renal artery ($p < 0.05$). There was no statistical difference in total cross-section area of renal arteries between the groups with and without ARA.

Mean total renal artery cross-section area were strongly positively correlated with kidney volume ($p < 10^{-13}$) in both sexes with Pearson correlation value of 0.5 (Fig. 3).

Total renal artery cross-section area decreased with age ($p < 0.01$) and differed between sexes. Over 25% of variability of cross-section area of renal artery can be explained with age and sex.

Proximal separation of the first branch of the renal artery occurred in 36 renal arteries (8.4% of renal arteries), neither lateralization nor sex dimorphism in proximal branch separation was observed.

Calculated volume of the kidney was in significant relation to sex ($p < 10^{-7}$) with smaller volume in women. There was no relation between kidney size and side of the body.

In women renal arteries branched off earlier from the aorta. Mean female renal arteries branching off was at the level of the first lumbar vertebra (L1) while in males - at the level of the second lumbar vertebra (L2) ($p < 0.05$)

Discussion

The proper size of kidney depends on many congenital and acquired factors, e.g. Body Mass Index [17], height, weight, total body area [7], age, sex, kidneys position, presence of stenosis [9]. Glodny et al. presented in a study performed on a large group of patients that one of the factors positively correlated with the kidney size is the number of additional renal arteries [9]. In our study the kidney volume decreased with age and was smaller in women which remains in accordance with the literature. Presence of additional arteries did not influence the kidney volume in our study.

We have not found any study of the relationship between renal artery cross-section area and kidney volume in the literature. This relationship seems to be intuitive and in fact

strong statistical significance was revealed between the two factors mentioned above. Measurement of renal artery diameter has usually been performed in research studies. In this study automatic cross-section area measurement was chosen due to the fact that vessels cross-section may not always occur as a perfect circle, taking more elliptic shape.

The more additional renal arteries were found, the smaller was the cross-section area of the largest ipsilateral renal artery. This observation should induce a radiologist to look for an additional renal artery in case of a difference between left and right renal artery cross-section area with symmetrical kidneys. Moreover, any disproportion of the renal artery cross-section area (or sum of the areas, in case of the presence of an additional renal artery) and the kidney volume should raise suspicions of pathology. The above correlation corresponds with a study performed by Ramadan et al. [16] who demonstrated that renal artery diameter as well as a formula including renal artery diameter and kidney length can accurately predict the presence of additional renal artery. Aytac et al. [2] who proved the observation can be transferred to ultrasound examination of renal arteries.

There was no statistical difference in total cross-section area of renal arteries between the groups with and without ARA. Therefore we can infer that blood flow is not multiplied in the presence of ARA.

The presence of additional renal arteries is a common feature occurring in 20-32.3% of patients [3, 8, 13]. In our study patients with additional renal arteries constituted 33.7% of the examined group, which corresponds with other studies performed with the use of CTA. Budhiraja et al. observed as much as 62.2% occurrence of supernumerary renal arteries in a study performed on 37 cadavers [4]. (Tab.1) In vast majority of cases this anomaly does not cause any symptoms or difficulties. There are however certain clinical settings in which knowledge of ARA existence is valuable.

Accessory renal artery provides blood supply to a part of the kidney. This fact may become an obstacle during stent-graft implantation in the treatment of aortic aneurysm. Special iliorenal vessel grafts can then be used to maintain the flow in the additional artery [5]. There are also reports claiming the renal function remains stable after covering additional renal artery with stent graft during similar procedures [1].

In case of the necessity of renal artery denervation due to persistent hypertension presence of an additional renal artery may result in worse effect of the procedure [11].

Accessory renal arteries are suspected to be one of the causes of the development of hydronephrosis. Glodny et al. [8] proved on a large group of patients that presence of additional arteries was not related to either the width of renal pelvis or hydronephrosis.

Presence of additional renal arteries is an important finding in the course of living kidney donation and renal transplantation as it may influence the operative method as well as choice of the kidney to be donated [14, 19]. Additional renal artery may influence the course of post-transplantation period [6]. Preoperative visualization of the vasculature may allow to perform the proper anastomoses and therefore prevent long-term vascular complications [10] .

Proximal branching in renal arteries included in this study was a rather rare phenomenon comparing to scarce literature, even though less strict criteria of proximal separation of the first renal artery branch were set. Tarznamni et al. described proximal branching in 35.89% [18], but they did not observe any lateralization which remains in line with the results of our study.

Our study has several limitations. Kidney volume was measured with approximation, more precise CT-based renal cortex volume measurement was not performed. However, this method can be used in living donors to predict future renal graft function [12] and seems to be more accurate in certain cases – e.g. predicting graft function - than total kidney volume. On the other hand, manual measuring of kidney length and width seems to be somewhat a more convenient and quicker method of the assessment of the kidney size in everyday practice than more time-consuming assessment of renal cortex volume and may be easily applied in ultrasound examination as well.

The 64-detector CT scanner enables to obtain images with the high resolution with slice thickness of as low as 0,625 mm. In a case of additional renal artery narrower than 1 mm the computer program may not have visualized the vessel.

Conclusions

Total cross-section area of the renal arteries correlated positively with kidney volume in both sexes.

One in three people has ARA, however it does not influence the total cross-section area of renal arteries. In case of a difference between left and right renal artery cross-section area with symmetrical kidneys, it is necessary to look for ARA.

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Table 1. Occurrence of additional renal arteries

Authors	Occurrence of ARA	Material	Method	Year
Bordei et al. [3]	20%	272 kidneys	dissection	2004

Glodny et al. [8]	24.4%	1072 patients	CT	2011
Staškiewicz et al. ^A	27%	996 patients	CT	2015
Satyapal et al. ^B	27.7%	130 patients	angiography	2001
Kornafel et al. [13]	32.3%	201 patients	CT	2010
Budhiraja et al. [4]	62.2%	37 cadavers	dissection	2013

^A Staskiewicz G, Jajko K, Torres K, Czekajska-Chehab E, Maciejewski R, Drop A. Supernumerary renal vessels: analysis of frequency and configuration in 996 computed tomography studies. *Folia Morphol*, 2015, Sep 18 ; ^B Satyapal KS, Haffejee AA, Singh B, Ramsaroop L, Robbs J V, Kalideen JM. Additional renal arteries: incidence and morphometry. *Surg Radiol Anat*. 2001;23(1):33–8.

Figure 1. 3D reconstruction of kidneys and abdominal aorta with renal arteries. A simplified method of kidney volume measurement. The maximum kidney length and width are measured.

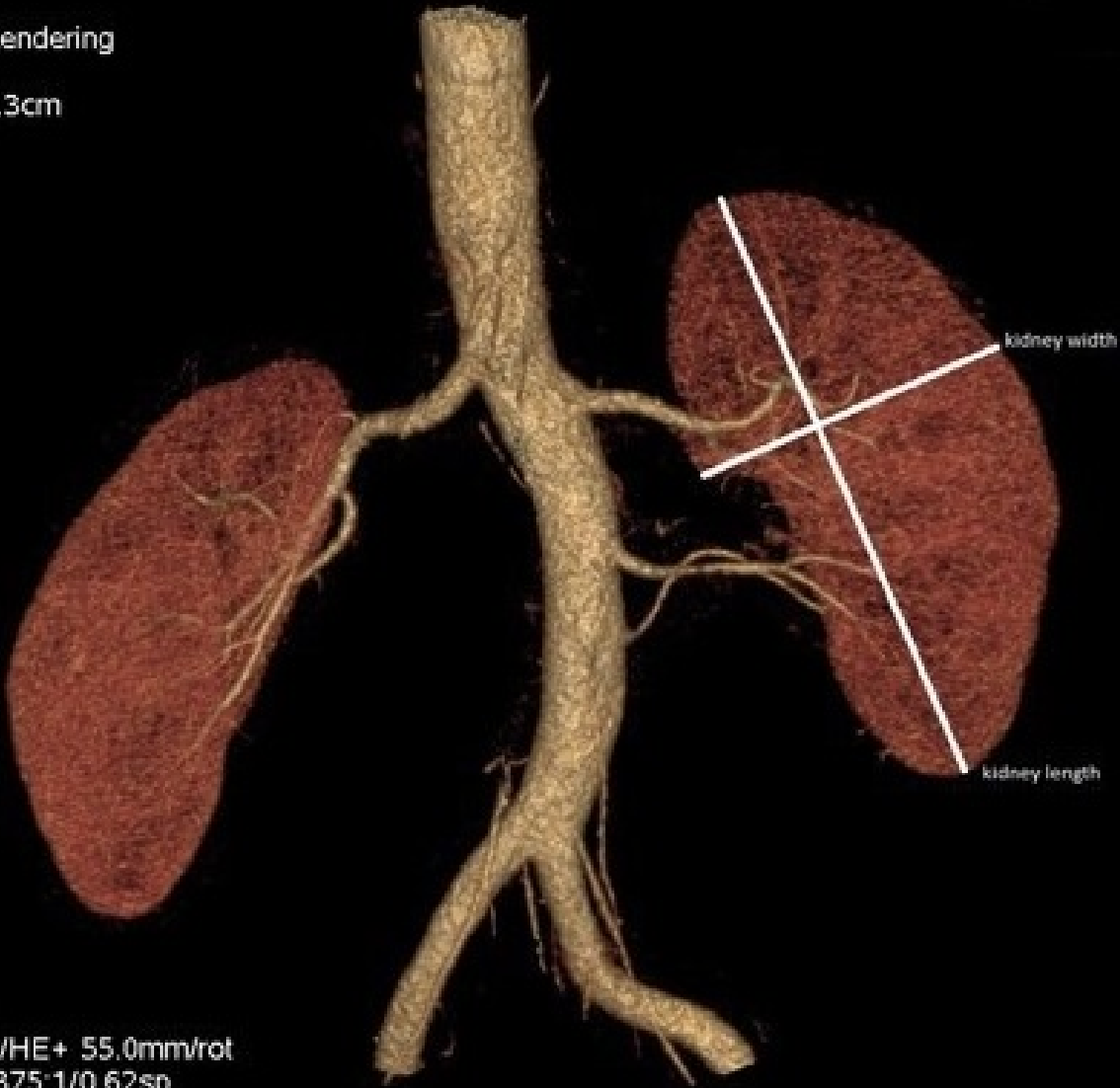
Figure 2. Number of particular variants of renal arteries bilateral distribution in men and women. 1+1 – one renal artery on each side, 1+2 – one accessory renal artery on the left side, 2+1 – one accessory renal artery on the right side, 1+3 and 3+1 analogically, 2+2 – one accessory artery bilaterally, 2+3 – one accessory artery on the right and two on the left side, 3+2 – one accessory artery on the left and two on the right

Figure 3. The correlation between total renal artery cross-section area and kidney volume.

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Volume Rendering

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