

## Research article

# Anatomical variability of kidney arterial vasculature based on zonal and segmental topography

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## ABSTRACT

**Introduction:** To date, there is no unified approach to the lobar, zonal, and segmental structure of the kidney vasculature. There is no recognizable approach to define basic characteristics in regard to the lobes and segments identifying of the kidney. The branching of the renal artery has often been the subject of scientific research. This study aimed to analyze the arterial anatomy on the basis of zonal and segmental topography.

**Materials and methods:** This study is a prospective cadaver study on autopsy material using corrosion casting and CT imaging techniques. The arterial vasculature was visualized using corrosive casting. In this study, 116 vascular casts were included. We identified the number of arteries in the kidney hilum, their topography, branching variations of the renal artery, and local blood supply zones of renal masses considering *second-* and *third-order* renal artery branches. We used a micro-CT BRUKER SkyScan 1178, digital camera, Mimics-8.1, and R.

**Results:** This study has shown that RA divides into two or three zonal arteries, forming a two- or three-zonal vascular supply system. In the case of the two-zonal system, 54.3% of cases accounted for RA branching into ventral and dorsal arteries, whereas 15.5% of cases referred to superior polar and inferior polar zonal arteries. The three-zonal system implies 4 types of RA branching: 1) superior polar, ventral, and dorsal zonal branches (12.9%); 2) ventral, dorsal, and inferior polar zonal branches (9.5%); 3) two ventral and one dorsal zonal branches (5.2%), and 4) superior polar, central, and inferior polar zonal branches (2.5%).

**Conclusions:** The results of this research make us reconsider Grave's classification theory.

## 1. Introduction

The last decades have seen an increased grow rate of renal disease [1]. To date, several problems have emerged: an objective diagnostic problem [2]; the development of minimally invasive surgical interventions [3]; and a pedagogical challenge related to online anatomy education [4]. However, few studies have investigated renal anatomy and pathology, and these problems remain unsolved. For instance, renal cell carcinoma is the sixth most frequent cancer in men and the tenth most frequent cancer in women worldwide [5]. Recent developments in laparoscopic interventions and mainly partial nephrectomy suggest a promising treatment

**Abbreviations:** RA, renal artery (*arteria renalis*); ZS, zonal arterial segment.

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option for renal tumors [3]. To reduce intraoperative hemorrhage, mobilizing the vascular pedicle and clamping the renal artery (RA) are crucial. However, it may cause warm ischemia with the potential risk of kidney damage [6]. Clamping the renal artery branches, considering the kidney's segmental structure, could provide a bloodless surgical field and reduce the risk of ischemic damage to the greater portion of the organ [7,8]. To date, scientists have not come to a unified conclusion regarding the lobar, zonal and segmental structure of the kidney vasculature. However, there has been a debate on the renal artery (RA) branching. Meanwhile, kidney transplantation is growing in role and frequency [9,10]. Conversely, the increasing use of digital anatomy and the poor quality and reliability of the models available hinder their effective use, resulting in distorted mental representations among students and future physicians [11,12]. These factors determine the importance of kidney segmentation studies [13–16].

To date, the concept of kidney division into five segments has been recognized worldwide [17–19]. There are superior, superior anterior, inferior anterior, inferior, and posterior segments. *Terminologica Anatomica* lacks the term segmental artery of the kidney [20]. Usually, the *segmental artery* is considered to be a *second- or third-order* RA branch. Most of the RA divides into ventral and dorsal branches. Some other studies point out 3 branches of RA. Meanwhile, other variations of renal artery branching are possible [21,22]. The ventral branch splits into arteries that supply blood to kidney segments. Despite the branching pattern (magistral or distributed), RA is subdivided into 4 *second-order* arteries, i.e., *segmental*, leading to four kidney segments. The dorsal branch supplies blood to the posterior segment; therefore, it is considered to be a *segmental artery*. Then, similar to the ventral branch, it splits into several *second-order* arteries. These should be called *interlobular or segmental* arteries due to the principle of dichotomy and trichotomy. However, this division is confusing.

**This study aimed** to analyze the arterial anatomy of the kidney referring to the zonal and segmental topography.

## 2. Materials and methods

### 2.1. Study design

This research is a prospective cadaver study based on corrosion casting and CT imaging techniques using autopsy material.

**Inclusion Criteria:** The criteria for selecting the subjects included donated kidneys of both sexes, aged from 28 to 74 years, whose death did not relate to cardiovascular or urinary system injury, and weight of 120–200 g.

**Exclusion Criteria:** Participants (aged <28 or >74) with major congenital anomalies, vascular abnormalities, anamnesis of cardiovascular disease, or damaged kidneys due to improper handling were *excluded* from this study.

### 2.2. Ethical statement

This research is performed in accordance with the ethical standards of the institutional and national research committees, 1964 Helsinki Declaration and its later amendments. Ethical clearance was obtained from the Local Ethics Committee of Penza State University (protocol code 418).

### 2.3. Vascular casts

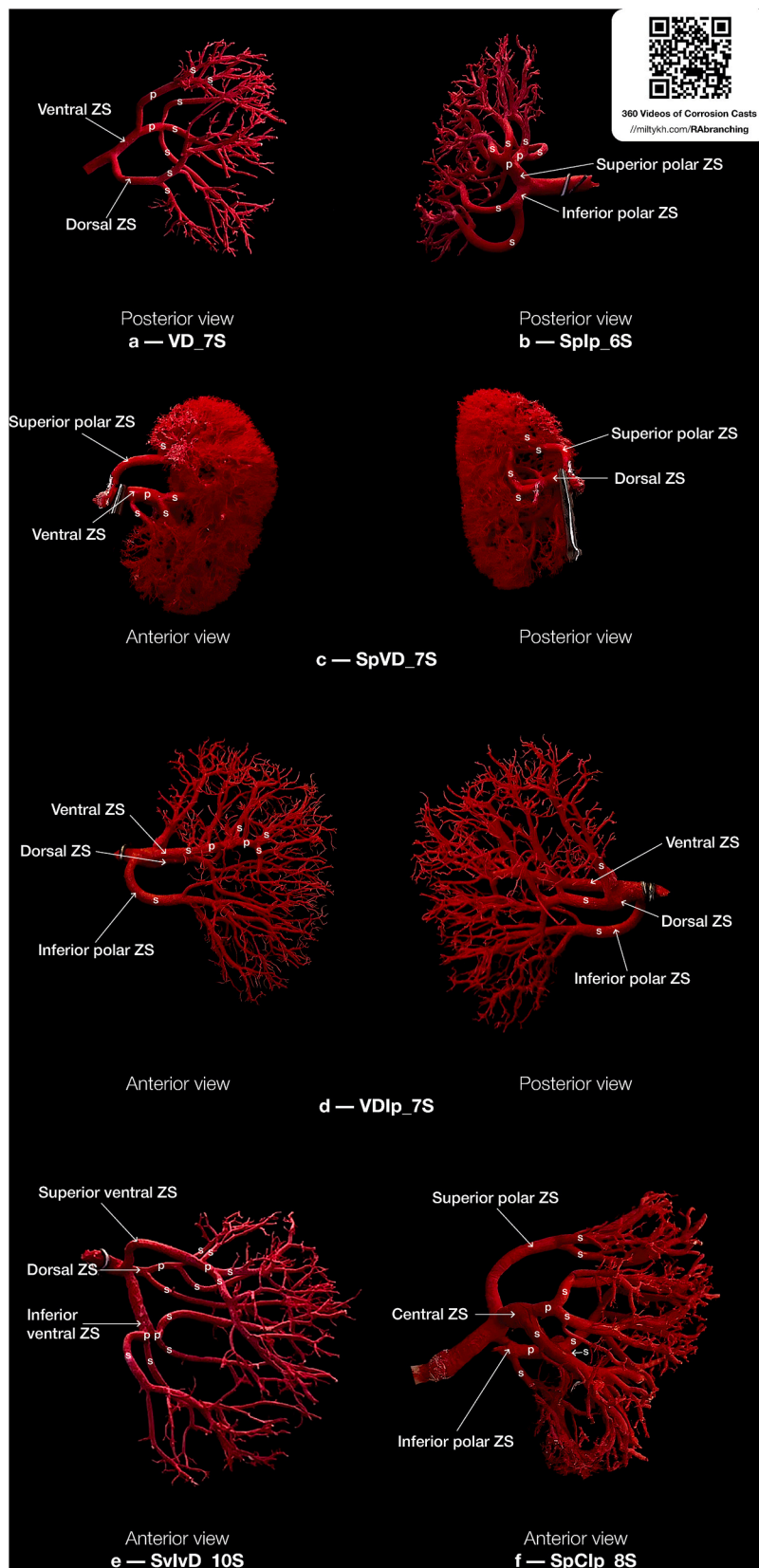
The arterial vasculature was visualized using corrosive casting. After the autopsy, the arterial vasculature of the kidney was washed through the renal artery with saline for 40–45 min at a pressure of 80–90 mm Hg and then placed in a vessel filled with saline to prevent deformation of the organ due to gravity. A radiopaque mixture was injected into the arterial vasculature. The mixture contains a polymer, "Protacryl M" (Stoma; Ukraine), which consists of dry and liquid components, a radiopaque agent, barium sulfate, and a universal color component [23]. The ratio of the mixture in mass %: "Protacryl M" powder – 50%; "Protacryl M" liquid – 20%; barium sulfate – 20%; dye – 10%. The container with the kidney was incubated at 36 °C for 24 h. Then, the kidney was dipped into a solution of full-strength alkali for 3–4 days in a thermal chamber. Tap water was used to rinse the corrosive cast. The minimum diameter of the cast vascular segments accounted for 0.05 mm.

### 2.4. Analysis of the vascular casts

In this study, 116 vascular casts were included. Vascular casts were scanned with a micro-CT BRUKER SkyScan 1178 (Bruker; Billerica, USA) and photographed with a Sony Cyber-shot DSC-RX10 M 4 (Sony; Tokyo, Japan). The first aspect was dedicated to identifying the number of arteries in the kidney hilum, their topography, and branching variations in three-dimensional space. Projection of kidney vasculature was analyzed in frontal, horizontal, and sagittal planes using Mimics-8.1 software (Materialise Co., Leuven, Belgium). In regard to dichotomous or trichotomous branching of RA (0), a local blood supply zone of renal masses was defined. A *renal zone* is termed a part of the renal mass that is vascularized by a *first-order* branch, i.e., the zonal branch (I), which splits up from RA (0). The term *kidney segment* refers to an area of the kidney containing the *second-order* branch, i.e., the interlobular artery (II).

### 2.5. Statistical analysis

The analysis was performed using R statistics software (version 4.1). The results are given as the frequency (percentage) of categorical variables. Median (ME) was calculated for arterial segments. The variance in incidence proportions was also determined [24].



(caption on next page)

**Fig. 1.** Corrosion Casts of Renal Arterial Vasculature. **a.** Two-zonal branching (male, 58 years); **b.** two-zonal branching (male, 53 years); **c.** three-zonal branching (female, 59 years); **d.** three-zonal branching (male, 72 years); **e.** three-zonal branching (female, 73 years); **f.** three-zonal branching (male, 76 years): ZS, zonal arterial segment; p, presegmental arterial segment; s, segmental arterial segment. 360° videos of corrosion casts are available at <https://miltykh.com/RAbranching/>.

The *metafor* R package was used to compute combined estimates [25]. Given the expectation of heterogeneity between studies, random-effect models were used for all analyses. The  $I^2$  and  $\tau^2$  statistics were utilized to measure the heterogeneity between studies.  $I^2$  measures the heterogeneity by expressing the percentage of total variance caused by the variation between studies, while  $\tau^2$  represents the variance between studies in a random-effects meta-analysis.

### 3. Results and discussion

Our study revealed that in 69.8% of cases, the renal artery (RA, *arteria renalis*) [20] branches into two *first-order* segments (I division level), which can be termed *zonal*. Thus, RA division occurs in the frontal plane into ventral (anterior) and dorsal (posterior) zonal arterial segments in 63 (54.3%) casts (Fig. 1 a). In 15.5% of cases (18 casts), the RA branches into the superior polar and inferior polar zonal arterial segments (Fig. 1 b) in the horizontal plane. RA division into three zonal arterial segments accounts for 35 casts out of 116. In 12.9% of cases (15 casts), the RA divides into superior polar, ventral, and dorsal zonal arterial segments (Fig. 1 c) relative to the frontal and horizontal planes. In 11 of casts (9.5% cases), the RA divides into ventral, dorsal, and inferior polar zonal arterial segments (Fig. 1 d). In 6 casts (5.2%), RA division into two ventral (superior and inferior) and dorsal zonal arterial segments (Fig. 1 e) occurred in the frontal plane. The least common division of the RA into superior polar, central, and inferior polar zonal arterial segments occurred in 3 casts (2.5%) (Fig. 1 f).

The *second-order* arterial segments (II division level), i.e., the segments branching of the zonal arterial segments, constitute a heterogeneous group (Table 1). In group 1 (58.3%), *first-order* arterial segments (zonal) divide into smaller branches with diameters 2.5–3 times fewer than their parental segments. The term *segmental* is used to refer to arterial segments of this group. The *presegmental* arterial segments did not give smaller branches with diameters 2.5–3 times fewer than their parental segments but divided into approximately equal *second-order* branches, accounting for 41.7%. Presegmental arterial segments are found in all 116 corrosion casts. In 81.9% of cases (95 casts), two presegmental arterial segments were observed. One and four presegmental arterial segments were found in fifteen (12.9%) and six (5.2%) casts, respectively.

Segmental arterial segments were also present in 100% of the corrosion casts studied. However, this group of segments is also heterogeneous. In 37.4% of cases, segmental arterial segments were derived from *first-order* segments, i.e., zonal. Meanwhile, 62.6% of segmental arterial segments branched out *second-order* segments and constituted a group of *third-order* segments (III division level).

The most abundant group of casts with seven segmental arterial segments amounted to 76.7%. In 18 casts (15.5%) six segmental arterial segments were found. Ten segmental arterial segments were identified in 5.2% of cases. In three casts (2.6%), eight segmental branches were observed.

The following groups were determined according to the division of the RA in the kidney hilum into *first-order* vessels, i.e., zonal arterial segments. In group 1, RA divides dichotomously into ventral and dorsal (Fig. 1 a) or superior and inferior zonal arterial segments (Fig. 1 b), creating a two-zonal vascular supply system. In group 2, the RA divides trichotomously into superior polar, ventral, dorsal zonal arterial segments (Fig. 1 c; Fig. 2 c); ventral, dorsal and inferior polar zonal arterial segments (Fig. 1 d; Fig. 2 d); superior and inferior ventral and dorsal zonal arterial segments (Fig. 1 e; Fig. 2 e); or superior polar, central and inferior polar zonal arterial segments (Fig. 1 f; Fig. 2 f), forming a three-zonal vascular supply system.

**Table 1**  
Rate of zonal, presegmental and segmental branches.

| Number of Branches (ME)                                                        | Casts (N)  | %           |
|--------------------------------------------------------------------------------|------------|-------------|
| <b>Zonal Arterial Segments (First-order Arterial Segments)</b>                 |            |             |
| 2                                                                              | 81         | 69.8%       |
| 3                                                                              | 35         | 30.2%       |
| <b>Presegmental Arterial Segments (Second-order Arterial Segments)</b>         |            |             |
| 1                                                                              | 15         | 12.9%       |
| 2                                                                              | 95         | 81.9%       |
| 4                                                                              | 6          | 5.2%        |
| <b>Segmental Arterial Segments (Second- and Third-order Arterial Segments)</b> |            |             |
| 6                                                                              | 18         | 15.5%       |
| 7                                                                              | 89         | 76.7%       |
| 8                                                                              | 3          | 2.6%        |
| 10                                                                             | 6          | 5.2%        |
| <b>Total</b>                                                                   | <b>116</b> | <b>100%</b> |

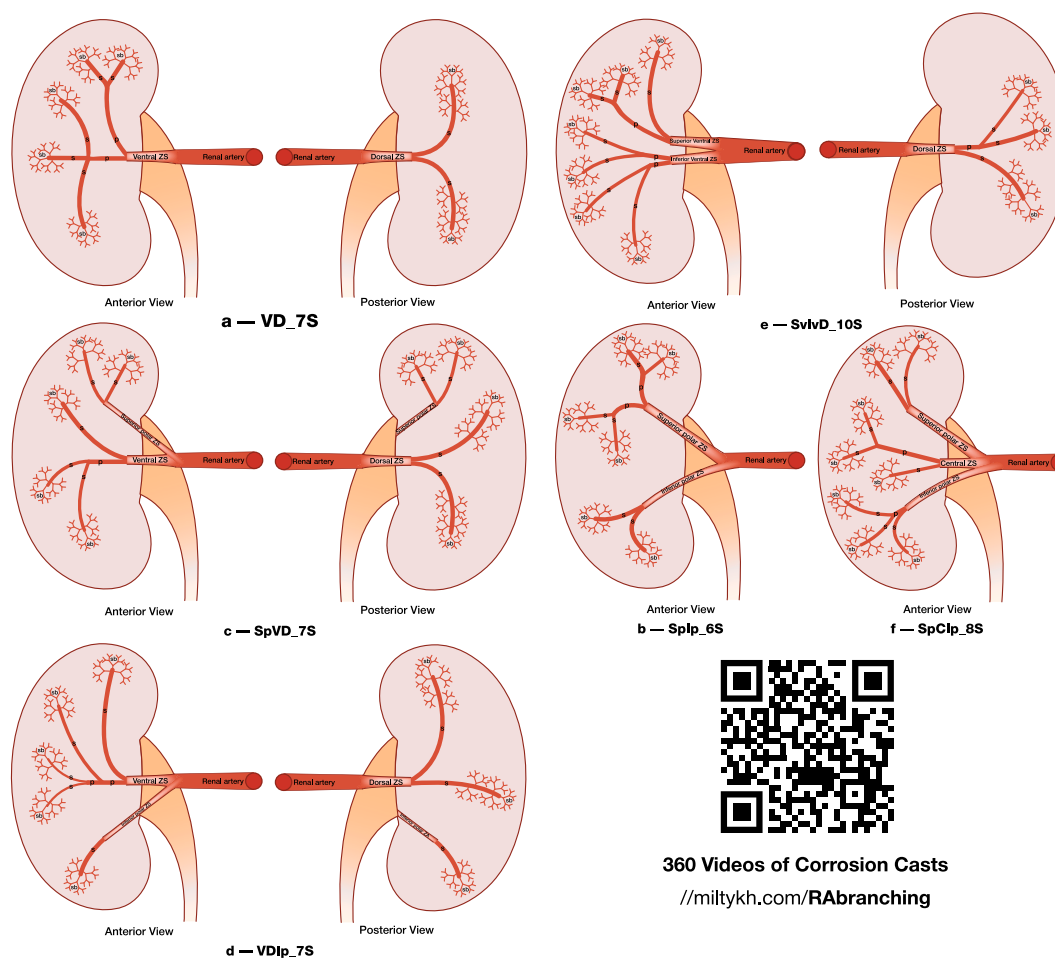


**Fig. 2.** Schemes of Branching Patterns. **a.** VD\_7S branching type (two-zonal system); **b.** SpIp\_6S branching type (two-zonal system); **c.** SpVD\_7S branching type (three-zonal system); **d.** VDIp\_7S branching type (three-zonal system); **e.** SvIvD\_10S branching type (three-zonal system); **f.** SpClp\_8S branching type (three-zonal system): ZS, zonal arterial segment; p, presegmental arterial segment; s, segmental arterial segment; sb, small branches. 360° videos of corrosion casts are available at <https://miltykh.com/RAbranching/>.

### 3.1. Two-zonal branching system

#### 3.1.1. VD\_7S (Ventral&Dorsal ZS – 7 segmental arterial segments) branching type

In 54.2% of cases, RA (0) divides into ventral and dorsal zonal arterial segments in the frontal plane (Fig. 1 a; Fig. 2 a). The ventral zonal branch (I) divides into two presegmental arterial segments (II), one of which originates two (III) and the other three segmental arterial segments (III). The dorsal zonal branch (I) branches into two segmental arterial segments (II).

#### 3.1.2. SpIp\_6S (Superior polar&Inferior polar ZS– 6 segmental arterial segments) branching type

In 15.5% of cases, RA (0) divides into superior polar and inferior polar zonal arterial segments in the horizontal plane (Fig. 1 b; Fig. 2 b). The superior polar zonal branch (I) gives off two presegmental arterial segments (II), all of which divide into two segmental arterial segments (III). Two segmental arterial segments (II) branches off the inferior polar zonal branch (I).

### 3.2. Three-zonal branching system

#### 3.2.1. SpVD\_7S (Superior polar, Ventral and Dorsal ZS – 7 segmental arterial segments) branching type

In 12.9% of cases, RA (0) divides relatively to the frontal and horizontal planes into superior polar, ventral, and dorsal zonal arterial segments (Fig. 1 c; Fig. 2 c). The ventral zonal arterial segment (I) branches into a segmental (II) and a presegmental (II) arterial segment, which gives off two segmental arterial segments (III). The superior polar (I) and dorsal zonal (I) branches divide into two segmental arterial segments (II) each.

### 3.2.2. VD<sub>Ip</sub>\_7S (Ventral, Dorsal and Inferior polar ZS – 7 segments) branching type

In 9.5% of cases, RA (0) divides relatively to the frontal and horizontal planes into ventral, dorsal and inferior polar zonal arterial segments (Fig. 1 d; Fig. 2 d). The ventral zonal branch (I) divides into a segmental (II) and a presegmental arterial segment (II), which branches into a segmental (III) and another presegmental arterial segment (III), which splits into two segmental arterial segments (IV). The dorsal zonal branch (I) divides into two segmental arterial segments (II). The inferior polar zonal branch is the origin of one segmental arterial segment (II). However, the place where the zonal branch switches to the segmental arterial segment cannot be determined.

### 3.2.3. Sv<sub>IV</sub>D\_10S (Superior ventral, Inferior ventral and Dorsal ZS – 10 segmental arterial segments) branching type

In 5.2% of cases, RA (0) splits into two ventral (superior and inferior) and dorsal zonal arterial segments in the frontal plane (Fig. 1 e; Fig. 2 e). The superior ventral zonal branch (I) divides into a segmental and presegmental arterial segment, which branches into two segmental arterial segments. The inferior ventral zonal branch (I) divides into two presegmental arterial segments (II), each of which splits into two segmental arterial segments (III). The dorsal zonal branch (I) divides into a segmental arterial segment (II) and a presegmental arterial segment (II), from which two segmental arterial segments (III) branch off.

### 3.2.4. SpC<sub>IP</sub>\_8S (Superior polar, Central and Inferior polar ZS – 8 segmental arterial segments) branching type

In 2.5% of cases, RA (0) branches relative to the frontal plane into superior polar, central, and inferior polar zonal arterial segments (Fig. 1 f; Fig. 2 f). The superior polar zonal branch (I) divides into two segmental arterial segments (II). The central (I) and inferior polar zonal branches (I) split into one segmental arterial segment (II) and one presegmental arterial segment (II), from which two segmental arterial segments (III) branch off.

Taken together, these results suggest several groups of arterial segments (Table 2). The term *arterial segment* refers to a part of the vasculature between the two nearest branching points [26–28]:

1. Zonal arterial segments are *first-order* arterial segments (I division level) that are located at the border of the kidney, i.e., part of the segment is outside the kidney (extraorganic part) and part is inside of it (intraorganic part);
2. Presegmental arterial segments are *second-to third-order* arterial segments (II-III division level), originating from zonal or prior division level presegmental arterial segments, from which segmental or presegmental arterial segments branch off;

**Table 2**  
Analysis of renal artery branching.

| Branching Type               | Zonal Arterial Segments (I) | Second-order Arterial Segments (II) (ME) | Third-order Arterial Segments (III) (ME) | Number of Segmental Arteries (ME) | Casts | %     |
|------------------------------|-----------------------------|------------------------------------------|------------------------------------------|-----------------------------------|-------|-------|
| Bifurcation of renal artery  |                             |                                          |                                          |                                   | 81    | 69.8% |
| Two-zonal branching          |                             |                                          |                                          |                                   |       |       |
| VD_7S                        | Ventral                     | P                                        | 3 S                                      | 7                                 | 63    | 54.3% |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
|                              | Dorsal                      | 2 S                                      |                                          |                                   |       |       |
| Splp_6S                      | Superior polar              | P                                        | 2 S                                      | 6                                 | 18    | 15.5% |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
|                              | Inferior polar              | 2 S                                      |                                          |                                   |       |       |
| Trifurcation of renal artery |                             |                                          |                                          |                                   | 35    | 30.2% |
| Three-zonal branching        |                             |                                          |                                          |                                   |       |       |
| SpVD_7S                      | Superior polar              | 2 S                                      |                                          | 7                                 | 15    | 12.9% |
|                              | Ventral                     | S                                        |                                          |                                   |       |       |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
| VDIp_7S                      | Dorsal                      | 2 S                                      |                                          | 7                                 | 11    | 9.5%  |
|                              | Ventral                     | S                                        |                                          |                                   |       |       |
|                              |                             | P                                        | S<br>P (→ 2 S)                           |                                   |       |       |
| SvIvD_10S                    | Dorsal                      | 2 S                                      |                                          | 10                                | 6     | 5.2%  |
|                              | Inferior polar              | → S                                      |                                          |                                   |       |       |
|                              | Superior Ventral            | S                                        |                                          |                                   |       |       |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
|                              | Inferior Ventral            | P                                        | 2 S                                      |                                   |       |       |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
| SpCIp_8S                     | Dorsal                      | S                                        |                                          | 8                                 | 3     | 2.5%  |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
|                              | Superior polar              | 2 S                                      |                                          |                                   |       |       |
|                              | Central                     | S                                        |                                          |                                   |       |       |
|                              |                             | P                                        | 2 S                                      |                                   |       |       |
|                              | Inferior polar              | S                                        |                                          |                                   |       |       |
|                              | P                           | 2S                                       |                                          |                                   |       |       |

3. Segmental arterial segments are *second- or third-order* arterial segments (II-III division level), from which smaller branches with diameters 2.5–3 times less than their parental segments are derived. Segmental arterial segments can originate from either zonal (I) or presegmental (II) arterial segments.

Graves' first discussions and analyses of renal artery branching emerged in 1954 [29]. He defines the renal segment as an area of renal parenchyma supplied by its segmental artery without intersegmental anastomoses. However, Graves' Classification overlooks the extraorgan arteries [30] and fails to describe the orders of arterial segments preceding the proper segmental arterial segments.

Merklin and Michels introduced the terms *main renal*, *aortic superior/inferior polar* and *renal inferior polar* arteries [31]. As defined above, the main renal artery (according to Merklin and Michels) should be considered the RA [20], and the aortic superior/inferior polar and renal inferior polar arteries should be considered zonal arterial segments. In 1962, Geyer and Poutasse [32] identified additional kidney vessels as *supernumerary*, *accessory* or *aberrant* and showed size-differences between these vessels. However, these vessels were not considered in our study. Poisel and Spängler in 1969 divided additional renal arteries based on the point of entry into the kidney: *supernumerary* and *accessory* enter through the renal hilum, whereas *aberrant* arteries pass via an area other than the hilum [33]. However, Stephens argued that the using the terms *supernumerary*, *accessory* and *aberrant* is not appropriate to describe these arteries, since all of the are necessary for an adequate blood supply to the kidney. According to Stephens, all these vessels are segmental renal artery branches and do not have anastomoses inside the renal parenchyma [34]. Sampaio and Passos adopted the terms *hilar* for abdominal aorta branches that enter the parenchyma in the kidney, *extrahilar* for branches of the renal artery that enter the renal parenchyma via areas other than the hilum, *superior polar* for branches of the aorta penetrating the upper pole of the kidney, and *inferior polar* for branches of the kidney in the area of the lower pole [35]. In our study, the hilar artery corresponds to RA (0) [20], whereas the zonal branches include the superior and inferior polar arteries. Satyapal et al. described an *additional* renal artery as a renal artery, other than the main renal artery, that arises from the aorta and terminates in the kidney [36]. Vilhova et al. classified renal arteries originating from the aorta or its main branches supplying the upper or lower kidney pole based on their entry into the renal parenchyma: *accessory* enters through the hilum and *perforated* enters outside the hilum [37]. According to the proposed classification, the branches that supply blood to the upper or lower renal pole based on their entry into the renal parenchyma are zonal branches (I). In our study, perforating arteries were not revealed, possibly due to the limitation of the corrosion casting technique where casting solution is injected directly into RA. Bordei et al. described kidney blood supply using the terms *superior/inferior polar arteries*, which supply renal poles; *main renal artery*, which is the largest artery in the renal hilum; and *additional hilar artery* with a smaller caliber [38]. We consider the superior and inferior polar arteries as zonal branches (I), whereas the main renal artery is RA (0). Holden et al. defined *accessory* renal arteries as vessels entering the renal parenchyma in the hilum along with the main renal artery, while *aberrant* arteries enter the kidney directly through the capsule outside the hilum [39]. In 2010, Daescu et al. suggested a new classification where renal arteries could be *hilar* and *polar* (superior/inferior) [40]. The polar arteries are divided into 4 groups: 1) solitary, 2) pedicular if the second is accompanied by a pole vein and nerve plexus, 3) false accessory if it replaces a segmental artery, and 4) true accessory if the renal artery extends into the corresponding segmental artery. According to our definitions, hilar and polar arteries (superior/inferior) are considered zonal arterial segments (I). Radiological findings suggest the presence of so-called presegmental arteries situated between the RA and segmental branches [41,42]. Weld et al. defined presegmental arteries as “a branch of the main renal artery that divided into two or more segmental arteries” and the segmental artery was defined as “a branch that enters the renal parenchyma” [41].

However, based on these study results, a certain number of presegmental branches may split into segmental branches and next-order presegmental arterial segments. Weld et al. did not analyze intraorgan branching of the RA, which causes this oversight.

A comparative analysis of most authors' data (Table 3), focused on renal arterial vasculature, shares several key results in most cases (Fig. 3 a, b). Certain differences may be caused by the sample size, individual anatomical features in various ethical groups, and study methodology.

A comparative analysis of the presegmental and segmental artery rates is outlined in Tables 4 and 5. The differences, in this case, are due to the difference in classification: Weld et al. [41] and Kang et al. [42] do not consider the intraorgan division of arteries.

In the analysis of 71 corrosion kidney casts, Sykes et al. [49] showed that 83% of cases accounted for five segmental branches and five kidney segments. The study of 100 corrosion casts by Ajmani and Ajmani [50] reached different conclusions, observing a significant variability in RA branching and in compliance with Graves' classification. Longia et al. [51] reached similar conclusions. Recent data have shown an imbalance in Graves' classification. Only 2 cases (total 15) reported a five-segment pattern [15]. However,

**Table 3**  
Comparison of zonal renal vasculature.

| Study                | Year | Population | Type of Study                      | Number of Specimens | Two zonal system | Three zonal system |
|----------------------|------|------------|------------------------------------|---------------------|------------------|--------------------|
| Rocco et al. [43]    | 1982 | Caucasian  | Cadaveric                          | 97                  | 85 (88%)         | 12 (12%)           |
| Shoja et al. [44]    | 2008 | Iranian    | Radiological                       | 81                  | 65 (80%)         | 10 (12%)           |
| Daescu E et al. [45] | 2012 | Romanian   | Cadaveric                          | 60                  | 42 (70%)         | 14 (23%)           |
| Rocco et al. [46]    | 2014 | Caucasian  | Contrast-enhanced MDCT             | 306                 | 265 (87%)        | 41 (13%)           |
| Macchi et al. [15]   | 2017 | Caucasian  | Corrosion casting                  | 15                  | 15 (100%)        | 0 (0%)             |
| Hung et al. [47]     | 2020 | Vietnamese | Cadaveric                          | 40                  | 21 (53%)         | 19 (47%)           |
| Pradhay et al. [48]  | 2021 | Indian     | MDCT                               | 82                  | 76 (93%)         | 6 (7%)             |
| Present Study        | 2023 | Caucasian  | Cadaveric (CT & Corrosion casting) | 116                 | 81 (70%)         | 35 (30%)           |

Note: MDCT – multidetector computer tomography.

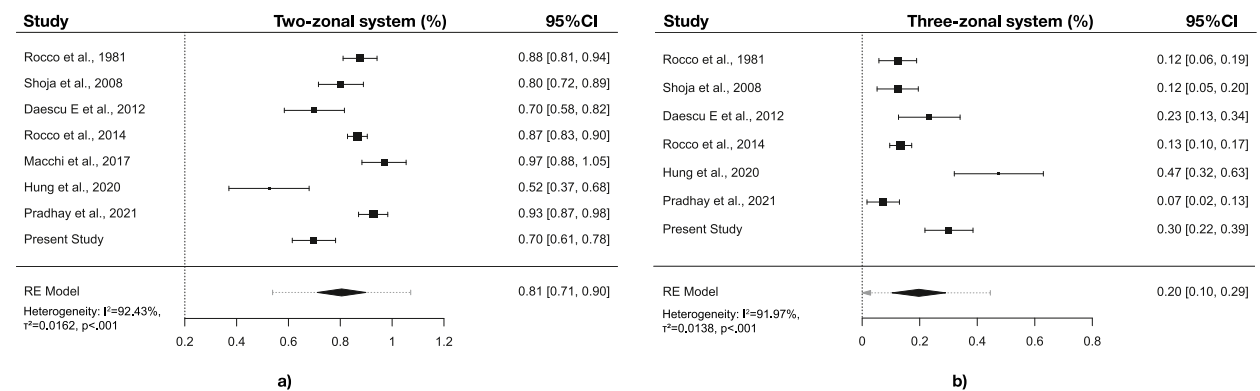


**Fig. 3.** Pooled proportions (%) with 95% confidence intervals (CIs) of two (a) and three-zonal (b) renal artery branching. RE Model – Random Effects model.

**Table 4**

Comparison of number of presegmental arteries.

| Study            | Year | Population | Type of Study                      | Number of Specimens   | Number of Presegmental Arteries |          |          |        |
|------------------|------|------------|------------------------------------|-----------------------|---------------------------------|----------|----------|--------|
|                  |      |            |                                    |                       | 0                               | 1        | 2        | 4      |
| Weld et al. [41] | 2005 | Caucasian  | Cadaveric                          | 73                    | 36 (49%)                        | 23 (32%) | 14 (19%) | –      |
| Kang et al. [42] | 2014 | Korean     | Contrast-enhanced MDCT             | 128 (116 – single RA) | 22 (19%)                        | 70 (60%) | 24 (21%) | –      |
| Present Study    | 2023 | Caucasian  | Cadaveric (CT & Corrosion casting) | 116                   | –                               | 15 (13%) | 95 (82%) | 6 (5%) |

**Table 5**

Comparison of number of segmental arteries.

| Study               | Year | Population | Type of Study                      | Number of Specimens   | Number of Segmental Arteries |             |             |             |             |           |           |
|---------------------|------|------------|------------------------------------|-----------------------|------------------------------|-------------|-------------|-------------|-------------|-----------|-----------|
|                     |      |            |                                    |                       | 3                            | 4           | 5           | 6           | 7           | 8         | 10        |
| Weld et al.<br>[41] | 2005 | Caucasian  | Cadaveric                          | 73                    | 16<br>(22%)                  | 25<br>(34%) | 23<br>(32%) |             |             |           |           |
| Kang et al.<br>[42] | 2014 | Korean     | Contrast-enhanced MDCT             | 128 (116 – single RA) | 7 (6%)                       | 34<br>(29%) | 75<br>(65%) |             |             |           |           |
| Present Study       | 2023 | Caucasian  | Cadaveric (CT & Corrosion casting) | 116                   |                              |             |             | 18<br>(16%) | 89<br>(77%) | 3<br>(3%) | 6<br>(5%) |

the study is limited to a small sample size. Unfortunately, due to the heterogeneity of the data, pooled proportions could not be determined.

These results confirm two main types of RA branching, i.e., two- and three-zonal vascular supply systems. These findings, detailed descriptions of renal arterial vasculature, suggested terminology denoting arterial segments, and classification of branching types can serve as a foundation for scientific discussion. In our opinion, applying this classification in daily practice will prove its necessity and worth more than any scientific discussion.

#### 4. Conclusion

In regard to the two-zonal system, RA branches into ventral and dorsal branches in 54.3% (VD\_7S) or superior polar and inferior polar zonal branches in 15.5% (SpIp\_6S).

Considering the three-zonal system, there are 4 types of RA branching:

SpVD\_7S – RA branches into superior polar, ventral, and dorsal zonal branches (12.9%).

VDIp\_7S – RA branches into ventral, dorsal, and inferior polar zonal branches (9.5%).

SvIvD\_10S – RA branches into two ventral and one dorsal zonal branches (5.2%).

SpCip\_8S – RA branches into superior polar, central, and inferior polar zonal branches (2.5%).

This research strongly requires reconsidering the 5-segment kidney statement.

#### Author contribution statement

Edgar S. Kafarov: conceived and designed the experiments; wrote the paper.

Ilia Mitykh: conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; wrote the

paper.

Andrey V. Dmitriev: conceived and designed the experiments; contributed reagents, materials, analysis tools or data.

Oleg K. Zenin: conceived and designed the experiments; analyzed and interpreted the data; wrote the paper.

## Data availability statement

Data will be made available on request.

## Declaration of interest's statement

The authors declare no conflict of interest.

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