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Proposal for a new classification of the renal artery in the bovine kidney

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ABSTRACT: Proper vascularisation is necessary for the correct functioning of all organs. The kidneys of various mammalian species have been examined in order to understand the functioning of this organ. This article presents the first classification of the renal artery division in the kidneys of adult cattle. We collected and analysed specimens of arteries from bovine kidneys with the aim of improving our understanding of their morphology and functioning. The study was conducted on 50 kidneys, 25 right ones and 25 left ones, taken from cattle of both sexes. The examined kidneys were dissected and corrosion casts were made. Division of the renal artery into between two and four primary segmental arteries takes place just before entering the renal hilum. Cranial primary segmental arteries number from one to two (most frequently one), whereas the hilar and caudal ones always occur singly. The mentioned vessels are then divided into between one and four secondary segmental arteries running within the renal sinus. The hilar region (mid-zone) of the kidney exhibits the most variation in terms of vascularisation. The vascularisation of the caudal pole exhibits the lowest degree of variation. Taking into consideration the range of vascularisation of the organ by the particular divisions of the renal artery, three renal branching pattern types were distinguished: type I (84.1% of cases; this type consists of Ia, Ib, Ic and Ic subtypes) – two branches – the renal artery is divided into cranial and caudal primary segmental arteries; type II (11.36% of cases; with IIa and IIb subtypes) – three branches – the renal artery is divided into the cranial, hilar and caudal primary segmental arteries; type III (4.54% of cases) – four branches – the renal artery is divided into two cranial, one hilar and one caudal primary segmental artery. The division of the renal artery takes place along the long axis of the organ. Bovine kidneys are characterised by asymmetry, which may influence the length and diameter of the main arteries. The caudal primary segmental artery has the biggest mean length and mean diameter. The division of the renal artery occurs just before it enters the renal hilum or in the renal sinus.

Keywords: cattle; cow; adult; artery division; branching pattern; corrosion casts; blood supply

Proper vascularisation is necessary for the correct functioning of all organs. The occlusion of renal vessels can be caused by obstructive uropathy, renal vascular obstruction, renal parenchymal disorders, embolism or thrombosis. Reduction of blood flow through kidneys is the most frequent cause of acute renal failure (Flye et al. 1982; Kansal et al. 2008; Koivuviita et al. 2014). The kidneys of various mammalian species (i.e., rat, dog, sheep, pig) have been examined in order to better understand the functioning of this organ in health and disease. Moreover, an understanding of the course of arterial vessels in the kidney is useful when performing surgical procedures such as nephrectomy (Bagetti Filho 2008) or renal biopsy (Naoi et al. 1985). Laparoscopic procedures in the case of large animals are increasingly performed for diagnostic or therapeutic purposes (King et al. 1998; Steiner

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and Zulauf 1999; Marien et al. 2001). The most frequent indications for nephrectomy in large animals are nephrolithiasis, pyelonephritis, hydronephrosis and renal neoplasm (Fubini 2004). In bovine cases of unilateral nephrectomy, a biopsy of the remaining kidney should also be performed to establish the presence of bacteria or drug residues (Fubini 2004). According to Fischer (2002), the most frequent complications concerning renal biopsies are connected with haemorrhaging. Importantly, animal organs can be used in research, as well as to facilitate the introduction of new technologies and surgical techniques both in human and veterinary medicine. Bovine kidneys are useful *inter alia* for research on the development of surgical techniques to correct partial nephrectomy (Moinzadeh et al. 2005a; Moinzadeh et al. 2005b; Bagetti Filho 2008).

All of the above issues highlight the need to learn more details about the anatomy of kidneys in bovines, as only a small number of publications have described the course and dimensions of kidney arteries in this species. However, these studies have not been detailed and contain very little data on the subject. Therefore, the aim of this study was to collect and analyse specimens of renal arteries that could help in understanding the morphology and functioning of these anatomical structures. This article presents the first classification of the division of renal arteries in the kidneys of adult cattle, information which might be helpful in work connected with this organ.

MATERIAL AND METHODS

The study was conducted on fifty kidneys, twenty-five right ones and twenty-five left ones, taken from cattle (*Bos primigenius*, f. *taurus* – Polish black and white Holstein-Friesian breed) of both sexes. Forty-four organs, after removing the layer of small vessels of the renal cortex, were used for the analysis of the types of renal vascularisation. In six organs, the primary segmental arteries were injected with Plastogen G stained with various colours (red, blue or yellow). In those specimens, the cortical layer was not removed to show the course of boundaries between particular areas of the organ and the distribution of vascularisation. The kidneys along with their adjacent structures were obtained directly after the animals had been slaughtered. The weights of the cattle from which the organs were taken ranged from 483 kg to 670 kg, and their ages ranged from 15 to 70 months. The examined cattle kidneys were injected with Plastogen G and corrosion casts were made. The usefulness and suitability of this method were confirmed in previous studies (Polguj et al. 2009; Polguj et al. 2011; Polguj et al. 2015). The research project and the procedures employed herein were approved by the Bioethics Commission of the Medical University of Lodz (Protocol No. 23/LB 710-DTN/2014).

After the dissection of the renal artery and ureter, a cannula was inserted into the lumen of each. The mentioned intrarenal structures were then rinsed with distilled water through the cannula. After draining the water, a chemohardenable material called Plastogen G (Alfons Schmidt, Germany) was injected with a syringe through the cannula into the ligated artery or ureter. Plastogen G was diluted with methacrylate diluent to obtain a consistency which would penetrate all the vessel structures. It was injected under a pressure of 100 mm Hg in order to fill the lumen of the structures thoroughly. In order to better visualise the particular parts of arterial vascularisation of the kidney, Plastogen G was stained red, yellow and blue with pigments for acrylic paints. After filling the preparation with the material, the stumps of the renal artery and ureter were ligated and the whole preparation was then immersed in 0.9% sodium chloride at 40 °C for 24 hours, to allow Plastogen to harden. The preparations thus obtained were corroded in 10% potassium hydroxide in a laboratory incubator (at a temperature of 40 °C) for 24 hours to obtain corrosion casts that were next rinsed with running water. The preparations were measured using a digital slide calliper. Photographs were taken with a digital camera.

Kidneys have ventral and dorsal surfaces (Nomina Anatomica Veterinaria, ICVGAN 2012). In the right kidney, these are easy to identify, whereas the left kidney is pushed to the right side by the rumen and turned around its own long axis by 90 degrees in such a way that its hilum is situated dorsally. In order to facilitate a description of the course of arteries, the surfaces of the left kidney were determined during the autopsy of the animal when its abdominal cavity and urinary organs were in dorsal recumbency, with the stomach and intestines removed (according to Budras et al. 2003). In this position, the surfaces that can be determined on the left kidney are the same as for the right kidney.

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Segmental arteries are branches of the renal artery which can be accessed outside the renal sinus. Primary (direct branches of the renal artery) or secondary segmental arteries (branching off from the primary ones) can be differentiated (Pereira-Sampaio et al. 2007). In this paper, the following abbreviations of the mentioned vessels are used: primary segmental artery (PSA) and secondary segmental artery (SSA).

In bovine kidneys, three regions – cranial pole, hilar region, caudal pole – have been distinguished. The boundary between these areas was determined by imaginary lines perpendicular to the long axis of the organ, drawn through the most cranial and the most caudal margins of the renal hilum. For easier determination of the above-mentioned areas and the vessels vascularising them, the organs were wrapped in a thin tape at the boundary lines.

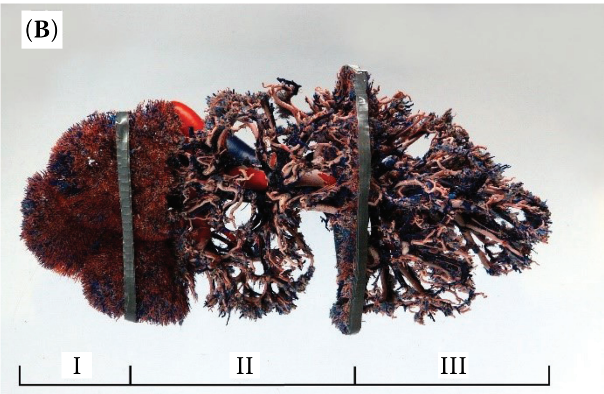

Figure 1. (**A**) Regions of bovine kidney and the arrangement of structures in the renal hilum. (**B**) Specimen with the layer of small vessels of the renal cortex partly removed. The tapes at the level of the anterior and posterior margin of the renal hilum. Corrosion cast, Plastogen G, × 3 reduction

I = cranial pole, II = hilar region, III = caudal pole, 1 = renal artery, 2 = renal vein, 3 = ureter

Then, on both sides of the tape, a shallow incision with a hot precision knife was made. The layer of small vessels of the renal cortex was removed on both sides of the boundaries defined in this way (Figure 1). The type and origin of arteries was then determined in the three kidney areas thus obtained.

RESULTS

The hilum (on average 77.4 mm long) was located more anteriorly; thus, the caudal pole (on average 69.6 mm long) was longer than the cranial pole (on average 53.6 mm long) (Figure 1). Division of the renal artery into two to four branches took place just before it entered the renal hilum. Depending on the region towards which the mentioned branches were heading, they are referred to as cranial, hilar or caudal primary segmental arteries. Cranial PSAs were either one or two in number (most frequently one), whereas the hilar and caudal PSAs always occured singly. The mentioned vessels were then divided into between one and four secondary segmental arteries running within the renal sinus (Figure 2). The dimensions of the vessels are given in Table 1. Clear boundaries could be observed between the specimens injected with stained Plastogen G (Figure 3). No arterial anastomoses were visible between the particular divisions of the renal artery and their branches (the segmental arteries).

In 39 kidneys (88.64%), the cranial pole was supplied by the cranial primary segmental artery that

Figure 2. Division of arteries in the bovine kidney. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = caudal primary segmental artery, 4 = secondary segmental arteries

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Table 1. Dimensions of segmental arteries (mm)

Vessel	Measurement	PSA	SSA
Cranial	average length	14.3	15.2
	average diameter	5.1	3.8
Hilar	average length	17.2	20.6
	average diameter	4.1	4.3
Caudal	average length	27.7	23.6
	average diameter	6.1	4.6

PSA = primary segmental artery, SSA = secondary segmental artery

ends by spliting into two (68.18%) or three (20.46%) secondary segmental arteries (Figure 2), while in three kidneys (6.82%), the cranial PSA extended directly to the cranial pole and divided into interlobar arteries. Only in two kidneys (4.54%) did two cranial PSAs branch off directly from the renal artery (Figure 4). These extended directly into the ventral and dorsal surfaces of the cranial pole.

The hilar region (mid-zone) of the kidney exhibited the most variation area in terms of vascularisation. It was most frequently supplied by branches coming off from the caudal primary segmental artery as a result of the size of the above-mentioned vessel and the site at which it branches off from the main trunk of the renal artery. The beginning of this artery was located more cranially than the site at which the renal pelvis comes into the ureter (Figure 5). In its course to the caudal region, this vessel gave secondary segmental arteries to the ventral, dorsal or both surfaces of the hilar region. In the clear majority of cases, that is, in 26 organs (59.09%), the ventral surface was supplied by two SSAs, branches of the cranial and caudal PSAs, whereas the dorsal surface of the hilar region was supplied by an SSA from the caudal PSA (Figure 5). In a lower number of cases (six organs, 13.64%) a

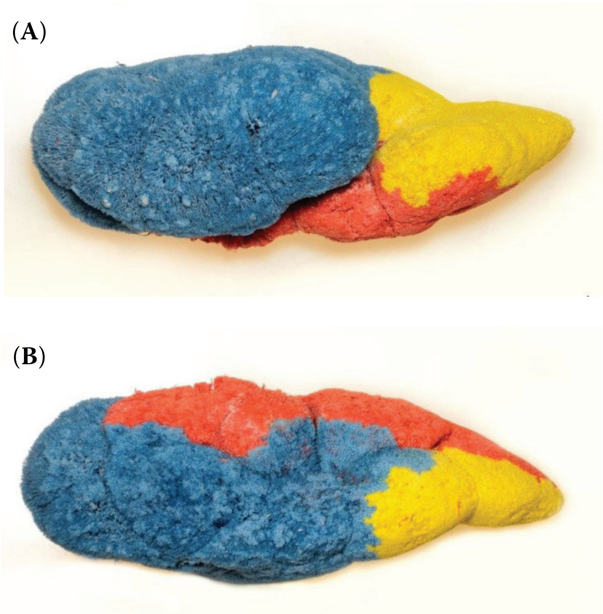

Figure 3. Regions of the kidney supplied by three divisions of the renal artery. (**A**) Medial margin, (**B**) lateral margin. Corrosion cast, Plastogen G, × 6 reduction

Yellow area = dorsal surface of the cranial pole, red area = ventral surfaces of the cranial pole and mid-zone, blue area = the caudal pole and dorsal surface of the mid-zone

Figure 4. Type III renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental arteries, 3 = hilar primary segmental artery, 4 = caudal primary segmental artery, 5 = secondary segmental arteries, 6 = renal pelvis, 7 = ureter. Segmental arteries to the hilar region (arrows)

Figure 5. Type Ia renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = caudal primary segmental artery, 4 = secondary segmental arteries, 5 = renal pelvis, 6 = ureter. Segmental arteries to the hilar region (arrows)

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Figure 6. Type Ib renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = caudal primary segmental artery, 4 = secondary segmental arteries, 5 = renal pelvis, 6 = ureter. Segmental arteries to the hilar region (arrows)

Figure 8. Type Id renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = caudal primary segmental artery, 4 = secondary segmental arteries. Segmental artery to the hilar region (arrow)

somewhat different vascularisation of the mid-zone was observed. The ventral surface of the mid-zone was supplied by the SSA that came from the cranial PSA, whereas the dorsal surface was supplied by two SSAs, one from the cranial and another from the caudal PSA (Figure 6). In two kidneys (4.54%), the whole mid-zone was supplied by the cranial PSA (which gave off one SSA) (Figure 7), and in further three organs (6.82%), by the caudal PSA (between one and two SSAs) (Figure 8). In five cases (11.36%), the dorsal surface of the hilar region was supplied both by the direct extension of the hilar PSA and by the branch of the caudal PSA, while the ventral surface was supplied by the SSA from the cranial PSA (Figure 9). In two kidneys (4.54%), the vascularisation came from the cranial, hilar and caudal PSAs (ventral surface) and also from hilar and caudal PSAs (dorsal surface) (Figure 10).

The vascularisation of the caudal pole exhibited the lowest degree of variation. In all of the organs, the ventral and dorsal parts of this area were supplied by the caudal PSA (and its SSAs, which were between two and three in number) (Figure 6).

Taking into consideration the range of vascularisation of the organ by the particular divisions of the renal artery, the following renal branching pattern types were distinguished (Figure 11).

Type I. Two divisions (branches) – the renal artery is divided into the cranial primary segmen-

Fig. 7. Type Ic renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = caudal primary segmental artery, 4 = secondary segmental arteries, 5 = renal pelvis, 6 = ureter. Segmental artery to the hilar region (arrows)

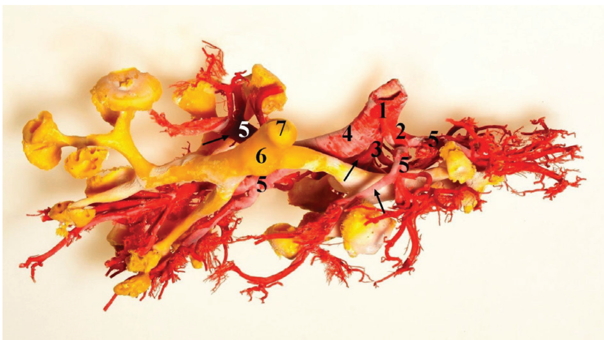

Figure 9. Type IIa renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = hilar primary segmental artery, 4 = caudal primary segmental artery, 5 = secondary segmental arteries, 6 = renal pelvis, 7 = ureter. Segmental arteries to the hilar region (arrows)

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Figure 10. Type IIb renal branching pattern. Corrosion cast, Plastogen G, × 3 reduction

1 = renal artery, 2 = cranial primary segmental artery, 3 = hilar primary segmental artery, 4 = caudal primary segmental artery, 5 = secondary segmental arteries, 6 = renal pelvis, 7 = ureter. Segmental arteries to the hilar region (arrows)

tal artery and caudal primary segmental artery. Subtype Ia (59.1% of cases; Figure 5): the cranial PSA vascularises the whole cranial pole, as well as anterior part of the ventral surface of the hilar region; the caudal branch vascularises the whole caudal pole, the posterior part of the ventral surface and the dorsal surface of the hilar region (the boundary between regions vascularised by these two branches is presented in Figure 12). Subtype Ib (13.64% of cases; Figure 6): the cranial PSA vascularises the whole cranial pole, the ventral surface and anterior part of the dorsal surface of the hilar region; the caudal PSA vascularises the posterior part of the dorsal surface of the hilar region and the whole caudal pole. Subtype Ic (4.54% of cases;

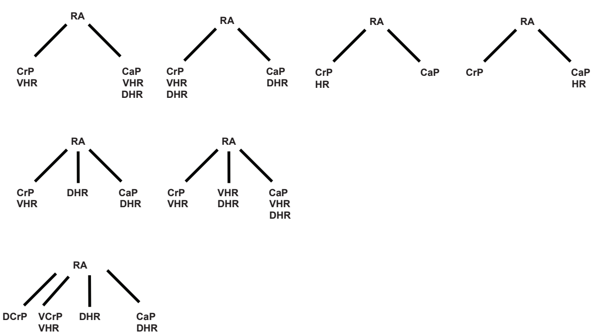

Figure 11. Schematic representations of the different renal branching pattern types

RA = renal artery, CrP = cranial pole, VCrP = ventral surface of the cranial pole, DCrP = dorsal surface of the cranial pole, HR = hilar region, VHR = ventral surface of the hilar region, DHR = dorsal surface of the hilar region, CaP = caudal pole

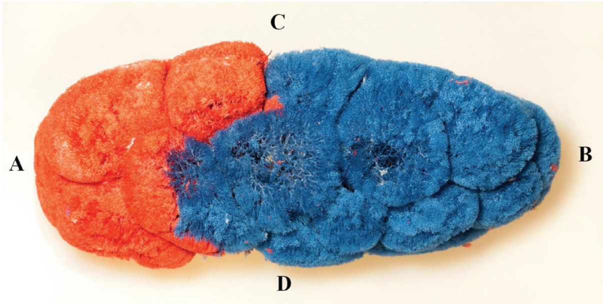

Figure 12. Most common type of blood supply to bovine kidneys - border between two regions of vascularisation. Corrosion cast, Plastogen G, × 3 reduction

A = cranial pole, B = caudal pole, C = ventral surface, D = dorsal surface

Figure 7): the cranial PSA vascularises the whole cranial pole and the whole hilar region; the caudal PSA vascularises the whole caudal pole. Subtype Id (6.82% of cases; Figure 8): the cranial PSA vascularises the whole cranial pole; the caudal PSA vascularises the whole caudal pole and the whole hilar region.

Type II (11.36% of cases). Three divisions (branches) – the renal artery is divided into the cranial, hilar and caudal primary segmental arteries. Subtype IIa (6.82% of cases; Figure 9): the cranial PSA vascularises the whole cranial pole, as well as the ventral surface of the hilar region; the hilar PSA vascularises the anterior part of the dorsal surface of the hilar region, whereas the caudal PSA vascularises the posterior part of the dorsal surface of the hilar region and the whole caudal pole. Subtype IIb (4.54% of cases; Figure 10): the cranial PSA vascularises the whole cranial pole, as well as the anterior part of the ventral surface of the hilar region; the hilar PSA vascularises the middle part of the ventral surface of the hilar region and the anterior part of the dorsal surface of the hilar region, whereas the caudal PSA vascularises the posterior parts of the ventral and dorsal surfaces of the hilar region, and the whole caudal pole.

Type III (4.54% of cases; Figure 4). Four divisions (branches) – the renal artery is divided into two cranial PSAs, the hilar PSA and the caudal PSA. One of the cranial branches vascularises the dorsal surface of the cranial pole and the other cranial branch vascularises the ventral surface of the cranial pole and the ventral surface of the hilar region; the hilar PSA vascularises the anterior part of the dorsal surface of the hilar region, whereas the caudal PSA

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vascularises the posterior part of the dorsal surface of the hilar region and the whole caudal pole.

DISCUSSION

A characteristic feature of the bovine kidney is that the division of the renal artery takes place either just before it enters the renal hilum or in the renal sinus. In many animals, this division is visible earlier – outside of the organ, e.g., in sheep (Aksoy et al. 2004) more than 1 cm, and in the goat (Aslan et al. 2001) more than 2 cm before entering the renal hilum. Pereira-Sampaio et al. (2007) reported that the division of the renal artery occurred deeper in the renal hilum in only 6.55% of swine kidneys, in which cases its direct branches cannot be seen. Another significant feature of the bovine kidney is the direction of the renal artery division. The renal artery is most frequently divided along the organ into cranial and caudal primary segmental arteries. In swine (Evan et al. 1996; Pereira-Sampaio et al. 2007), the renal artery is also divided in the same way. Moreover, some authors (Arnautovic 1962; Arnautovic and Bevandic 1964; Shahrasbi and Radmehr 1975) describe a similar course of the main branches of the renal artery in the kidneys of ruminants, and Liumsirichaoren et al. (1997) observed the occurrence of cranial and caudal branches in a swamp buffalo. However, in many other animals, e.g., sheep (Aksoy et al. 2004), goat (Aslan et al. 2001), rat (Fuller and Huelke 1973), cat, dog (Fuller and Huelke 1973; Marques-Sampaio et al. 2007), macaque (Horacek et al. 1987) and in humans (Sampaio and Aragao 1990; Urban et al. 2001; Hazirolan et al. 2011), the renal artery is divided into ventral (anterior) and dorsal (posterior) branches. Moreover, in the mentioned animals, as well as in humans, the number of segmental arteries is larger, e.g., in sheep, from three to six vessels; in the cat (Fuller and Huelke 1973; Aksoy and Ozudogru 2003), generally from four to five segmental arteries; in humans (Sampaio and Aragao 1990), from four to five vessels. In cattle, meanwhile, primary segmental arteries range from two to four in number. In their scheme of the vascularisation of the three main regions (cranial, middle, caudal) in a swamp buffalo kidney, Liumsirichaoren et al. (1997) noted that the renal artery in this species was divided into cranial and caudal branches, while the hilar region (middle) was most often vascularised by arteries (between one and two vessels) that were branches of the caudal branch. In cattle, the situation is somewhat different. A similar scheme of vascularisation as in the swamp buffalo occurs only in 6.82% of cattle kidneys. In a clear majority (59.1%) of organs the cranial primary segmental artery vascularises the whole cranial pole and the ventral surface of the hilar region, whereas the caudal primary segmental artery vascularises the caudal pole, the dorsal surface of the hilar region as well as part of its ventral surface. This example shows that differences in the course of arteries also occur among species within the Bovidae family. The biggest similarity between the two species is that the caudal branch of the renal artery is a bigger and longer vessel than the cranial one.

The division of the renal artery into the ventral and dorsal branches or into the cranial and caudal branches has an influence on the scope of vascularisation of the organ, which can be observed in the examples of the macaca, swine and cattle. In macaques (Horacek et al. 1987), the anterior division vascularises the anterior surface of the kidney, while the posterior division heads towards the posterior surface of the kidney, and the boundary between these areas most frequently runs along the convex edge of the organ. However, according to Horacek et al. (1987), the anterior or posterior branch may also vascularise a larger part of the organ. Evan et al. (1996) reported that in a swine kidney the upper or lower polar arteries vascularise the cranial or caudal part of the organ. As a result, the line of division between the vascularisation areas in a swine kidney most often runs symmetrically across the organ. In a bovine kidney the cranial and caudal branches of the renal artery mostly vascularise the anterior and posterior parts (poles) of the kidney. The boundary between the mentioned areas of vascularisation more often than not runs across the organ, but not as symmetrically as in a swine. In bovine kidney this division exhibits more variation, because usually the cranial or caudal branches, heading towards their poles, can also vascularise the whole hilar region or only its ventral or dorsal surface. In cattle, it can be observed that the division line between the different ranges of vascularisation on the ventral surface is most often shifted towards the caudal pole; in the middle part it runs along the organ on its convex edge, whereas on the dorsal surface it goes closer to the cranial pole.

Both in bovine and swine kidneys (Pereira-Sampaio et al. 2004), a single renal artery can be

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identified, an observation which was confirmed by Erdogan and Kilinc (2011). They also confirmed that in the kidneys of bovine foetuses the renal artery occurs as a single artery in 90% of cases. In human kidneys, in 4–61.5% of organs additional (accessory or supernumerary) renal arteries can be observed (Satyapal et al. 2001; Gulas et al. 2016). In swine, in most of the cases (Evan et al. 1996) (93.4%) the renal artery splits into two branches. In a minority (6.6%) of organs the main trunk of the renal artery is divided into three large branches. Two of those branches head towards the whole upper pole and a minor part of the lower pole, and the third branch heads towards the remaining part of the lower pole. In a clear majority of the cases studied here (84.1%), the renal artery was also divided into two branches, but also three (11.36%) or even four (4.54%) main divisions could be distinguished. Erdogan and Kilinc (2011), who were the first to examine the kidneys of bovine foetuses, stated that in cattle, the renal artery most frequently (90% of cases) gave three segmental arteries and they supplied both poles and the middle part of the kidney. According to the authors, the most infrequent case is when four segmental arteries occur (10%), out of which two segmental arteries vascularise both poles of the organ and the other two vascularise its middle part. Differences in these two structures with respect to bovine kidneys might result from the fact that in foetal life the vessels are short and the branch to the hilar region is close to the main trunk of the renal artery. Over the course of the development and growth of the kidney, when the length of arteries increases, the branch that reaches the hilar region grows further from the renal artery, and most frequently comes from the cranial or caudal primary segmental artery.

In human kidneys, not only the direct branches of the renal artery, but also segmental arteries are visible before they enter the renal hilum (Weld et al. 2005). In swine (Pereira-Sampaio et al. 2007) and bovine kidneys, the renal artery is divided into the cranial and caudal primary segmental arteries right before or just on the level of the renal hilum, or (in the cattle) even deeper in the renal sinus. In swine (Pereira-Sampaio et al. 2007), these branches are commonly divided into the segmental arteries after entering the renal sinus. In bovine kidneys, the main branches (primary segmental arteries) also divide on the level of the renal hilum or deeper in the renal sinus. Therefore, the secondary segmental arteries in these animal organs are barely visible or completely hidden in the renal sinus.

Similarities between swine (Evan et al. 1996; Pereira-Sampaio et al. 2004) and bovine kidneys can be observed in the vascularisation of the cranial pole. In both species, two or three segmental arteries are always present and most often come from the cranial branch of the renal artery. In 32.97% of swine kidneys (Pereira-Sampaio et al. 2004), a third vessel named the apical segmental artery was found, whereas in the material examined here, the presence of three vessels in the cranial pole was observed in 20.46% of cases. According to Sampaio and Aragao (1990), the superior pole of a human kidney is also supplied by two or three segmental arteries.

The mid-zone exhibits the most variation in swine (Evan et al. 1996; Pereira-Sampaio et al. 2004) and bovine kidneys. In (Pereira-Sampaio et al. 2004) 47.25% of cases, the dorsal part of this region in a swine kidney was supplied by an artery that originated from the cranial division, whereas in 31.87% of cases, there was a single branch from the caudal division. In 20.88% of cases, both vessels were found on the dorsal side of the organ. The ventral side of this region was in the majority of cases, i.e., in 60.44% of cases, supplied by only one vessel from the caudal or cranial divisions. In 20.88% of cases, two vessels were observed. In cattle, the situation is different. In 59.1% of cases, the branches of the cranial and caudal primary segmental arteries came to the ventral surface of the hilar region, while the other branch from the caudal division supplied the dorsal surface of this region. In 18.64% of cases, on the contrary, the dorsal surface of the hilar region was supplied by branches of the ventral and dorsal primary segmental arteries, while the ventral surface was supplied by a branch of the cranial primary segmental artery. The mid-zone was supplied only by the cranial branch (4.54% of cases) or only by the caudal branch (6.82%) of the renal artery. If the hilar primary segmental artery was present, it vascularised mainly the dorsal surface of the mid-zone, and the ventral surface was supplied most often by the cranial primary segmental artery. The anterior surface of the middle part of the human kidney was supplied by the arteries formed only out of the anterior branch of the renal artery, while the dorsal surface of this organ was supplied by the posterior segmental artery (Sampaio and Aragao 1990).

Similar as in bovine kidneys (100%), the ventral and dorsal parts of the caudal pole of swine kidneys

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(Pereira-Sampaio et al. 2004; Pereira-Sampaio et al. 2007) (84.62% of cases) were supplied by the branches from the caudal division. In 15.38% of swine kidneys (Pereira-Sampaio et al. 2004), the caudal division supplied only the ventral surface, while the dorsal surface was supplied by an artery coming from the cranial division. Comparing swine (Evan et al. 1996; Pereira-Sampaio et al. 2004) and bovine kidneys, it can be noticed that neither the cranial pole nor the caudal pole vary in terms of vascularisation as much as the hilar region does. In 62.2% of human kidneys (Sampaio and Aragao 1990), blood was supplied to the inferior pole with the inferior segmental artery from the anterior branch of the renal artery. In 37.8% of cases, the inferior pole was supplied both by the arteries formed out of the anterior and the posterior branches of the renal artery. The distinctive feature of the bovine kidney is the fact that the hilum of the kidney is located closer to the cranial pole resulting in the majority of vessels accumulating in the anterior and middle parts of the kidney. Furthermore, among the direct branches of the renal artery, the caudal ones were always longer. The caudal pole in bovine kidneys exhibited the lowest degree of variation in terms of vascularisation, because it took up a large area, and only one caudal primary segmental artery reached the posterior pole.

We observed clear boundaries between different areas injected with Plastogen G of various colours (Figures 3 and 12). There were no visible arterial anastomoses between the branches of the renal artery and each division of the renal artery vascularised its respective region of the organ. A similar situation can also be observed in other mammals (Fuller and Huelke 1973; Horacek et al. 1987; Evan et al. 1996; Pereira-Sampaio et al. 2004; Marques-Sampaio et al. 2007) and in humans (Sampaio and Aragao 1990).

In conclusion, the classification of the renal artery division in bovine kidneys was established and compared with the literature available for other mammalian species and for humans. Three main renal branching pattern types could be distinguished. Compared to the kidneys of other mammals, bovine kidneys are characterised by an asymmetrical structure, which influences the length and diameter of the main arteries. The caudal branches of the renal artery are always longer and thicker than the cranial and hilar ones, respectively. The fact that the hilum of the kidney is located closer to the cranial pole results in the majority of vessels accumulating in the anterior and middle parts of the kidney. The division of the renal artery in a cattle kidney occurs in the longitudinal plane of the organ, which is similar to swine but different than in other mammals, for example sheep, goat, dog, cat, rat and humans. The bovine kidney is characterised by the division of the renal artery at the level of the renal hilum or in the renal sinus. In many animals, this division is observed outside of the organ.

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