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Structure and arterial vascularization of the kidney in the European fallow deer (Dama dama) and red deer (Cervus elaphus)

Patrycja Jankowska[1], Agata Skalska[1], Hieronim Frąckowiak[1], Marek Bogdaszewski[2], Maciej Zdun[1]

Abstract

The red deer (*Cervus elaphus)* and the European fallow deer (*Dama dama)* belong to the deer family and are found in Eurasia, North America and South America. In Poland, just after the European roe deer, they are the most common cervids.

The present study aimed to describe the morphological structure and vascularization of kidneys in red and fallow deer. For this purpose, 96 kidneys were obtained from 48 individuals, which were measured and weighed. Preparations were made using two methods. The first allowed the renal arteries to be injected with stained latex and the soft tissues fixed in a formalin solution. The second is to obtain a corrosive preparation by injecting a self-curing polymer and leaving it in an enzymatic bath. The kidneys of the red deer are larger and heavier than those of the European fallow deer. The relation of the cortex to the medulla is similar between the two species, with a marked difference between wild and farmed specimens, indicating a correlation between kidney morphology and environmental factors. The renal artery is a strongly marked vessel that bifurcates into the cranial renal artery and the caudal renal artery, with subsequent triple segmentation of each, resulting in efficient vascularisation of a vital organ for survival. The information gathered may prove crucial to the future veterinary care of farmed cervids.

Running title: Renal anatomy and vascularization in some cervids

Keywords: artery, cervids, kidney, ruminants

[1]Department of Basic and Preclinical Sciences, Institute of Veterinary Medicine, Nicolaus Copernicus University in Toruń, Toruń, Poland
[2]Witold Stefański Institute of Parasitology of the Polish Academy of Sciences, Research Station in Kosewo Górne, Kosewo Górne, Poland
***Correspondence:** maciejzdun@umk.pl
Full list of author information is available at the end of article

Introduction

The deer family (Cervidae) comprises four subfamilies: the Cervinae, Hydropotinae, Megamuntiacus and Odocoileinae. In the past, the classification also included the *Moschinae*, of which the musk deer (*Moschus moschiferus*) is a representative but now belongs to the family Moschidae. The Cervidae species occur in North America, South America and Eurasia, on most continental islands and North Africa [1]. In Poland, five species of cervids occur in the wild: the European roe deer (*Capreolus capreolus)*, red deer (*Cervus elaphus),* European fallow deer (*Dama dama)*, European elk (*Alces alces)* and eastern red deer (*Cervus nippon*). The first four species are common in Poland, and as of 2022, their numbers were: 33213 European elk, 35540 European fallow deer, 291700 red deer and 918500 European roe deer [2]. Deer breeding is also popular in the country, and one of the first farms to be established is the Professor Andrzej Malczewski Research Station of the Institute of Parasitology of the Polish Academy of Sciences in Kosewo Górne, established in 1984. The Station maintains three species of cervids: European fallow deer, eastern red deer and red deer.

The kidney, in ruminants, is a paired organ located in the lumbar region. The kidney of the cervids is of the unipapillary type. The two most important functions of the kidney are the excretion of metabolic products and the regulation of extracellular fluid composition and volume [3]. They use approximately 20% of the blood from the abdominal aorta via the renal arteries [4]. Concentrating urine depends directly on certain anatomical features, especially the long loops of Henle [5] that occupy the medullary layer of the kidney.

The limited number of studies on kidney morphology and vascularisation in red and European fallow deer prompted this study. The aim of this study was to describe the macroscopic structure of the kidney, including vascularisation in red deer and European fallow deer under different livestock conditions and to compare the results obtained between wild and farm animals.

Material and methods

The study was conducted on 96 kidneys of animals of two species of the deer family, 52 kidneys of red deer (*Cervus elaphus*), of which 20 organs were obtained from wild animals and 32 from farm animals, and 44 kidneys of European fallow deer (*Dama dama)*, which included 20 kidneys of wild European fallow deer and 24 of farm European fallow deer. The study consisted of measuring, preserving and preparing the organs. The kidneys were from adult animals obtained from both hunting (in October and November) and slaughterhouses.

The fresh material was weighed and then measured in three planes. The length of the kidney at the



FIGURE 1 Specimen of the left kidney of a European fallow deer. Cross-section in the sagittal plane with latex-injected arteries

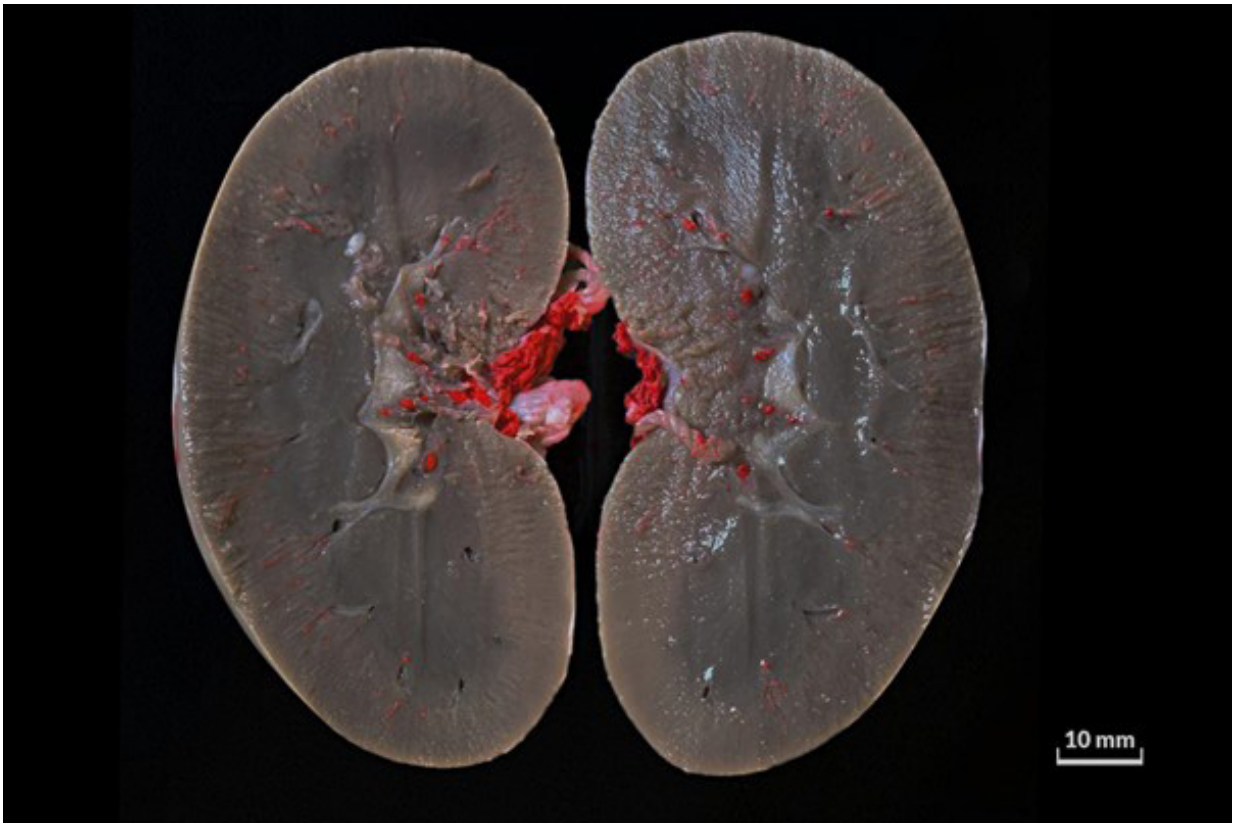


FIGURE 2 Preparation of the right kidney of a red deer. Cross-section lateral to the sagittal plane latex-injected arteries; pseudo-papillae and renal pelvic recessuses visible

TABLE 1 Parameters of external measurements of left and right kidneys of the red deer and European fallow deer (height, width, thickness and weight)

	SPECIES	ORIGINS	LEFT KIDNEY				RIGHT KIDNEY			
			height $\underline{x}$ [mm] and S	width $\underline{x}$ [mm] and S	thickness $\underline{x}$ [mm] and S	weight $\underline{x}$ [mm] and S	height $\underline{x}$ [mm] and S	width $\underline{x}$ [mm] and S	thickness $\underline{x}$ [mm] and S	weight $\underline{x}$ [mm] and S
1	red deer	environment	109,01 ± 7,58	44,68 ± 7,09	37,60 ± 3,88	126,80 ± 35,42	106,60 ± 8,90	47,96 ± 5,40	35,76 ± 6,85	130,30 ± 36,34
2	European fallow deer	environment	77,84 ± 8,29	35,70 ± 4,58	29,72 ± 3,86	64,00 ± 11,72	75,60 ± 6,58	35,20 ± 3,33	31,35 ± 4,81	65,27 ± 12,90
3	red deer	breeding	102,09 ± 10,23	39,59 ± 3,96	28,42 ± 3,20	108,88 ± 20,24	100,95 ± 10,75	43,30 ± 3,35	27,33 ± 3,64	114,75 ± 21,87
4	European fallow deer	breeding	73,15 ± 4,21	34,40 ± 4,24	22,25 ± 2,59	50,00 ± 4,95	72,96 ± 4,40	34,92 ± 3,29	21,68 ± 3,09	50,09 ± 5,28

TABLE 2 Measurements of cortical and medullary height of left and right kidneys and the relationship between these parameters in the red deer and European fallow deer

	SPECIES	ORIGINS	LEFT KIDNEY			RIGHT KIDNEY		
			cortex $\underline{x}$ [mm] and S	core $\underline{x}$ [mm] and S	cortex-to-core	cortex $\underline{x}$ [mm] and S	core $\underline{x}$ [mm] and S	cortex-to-core
1	red deer	environment	8,75 ± 1,45	15,13 ± 2,70	1:1,7474 ± 0,2630	9,86 ± 1,61	16,18 ± 2,16	1:1,6790 ± 0,2996
2	European fallow deer	environment	8,95 ± 0,89	11,85 ± 2,64	1:1,3498 ± 0,3660	8,40 ± 0,56	10,36 ± 3,03	1:1,2380 ± 0,3713
3	red deer	breeding	9,49 ± 1,46	15,18 ± 2,51	1:1,6117 ± 0,2218	9,36 ± 1,16	15,00 ± 1,60	1:1,6173 ± 0,1855
4	European fallow deer	breeding	7,13 ± 0,18	11,35 ± 0,05	1:1,5938 ± 0,0321	7,04 ± 0,60	10,73 ± 0,78	1:1,4504 ± 0,0129

highest points of the cranial and caudal poles, the width at the widest point of the medial and lateral margins and the thickness between the visceral and wall surfaces. A calliper with a precision of 0.05 millimetres was used for measurement. To observe the morphology of the renal arteries, they were injected with stained LBS 3060 latex (Synthos, Poland) and then preserved in a 10 % formalin solution for three weeks in cold storage (temp. 3°C). The vasculature of 38 right and 38 left kidneys (46 of red deer and 34 of European fallow deer) was assessed after prior preparation with surgical instruments. To measure the height of the cortex and medulla of the kidneys, they were measured in a longitudinal section in the median plane at the level of the renal pelvis. Their mutual proportions were determined based on the results of the cortex and medulla height measurements and their combined value. Some of the specimens (N=20; 5 from each group) were made using the corrosion method, which consisted of injecting Duracryl® Plus polymer (SpofaDental, Czech Republic) stained with COLOREX® concentrate (Śnieżka, Poland) into the renal arteries and leaving the kidneys in Persil® enzyme bath (Henkel, Germany) for three weeks at 42°C. All preparations were documented in an Excel chart and photographed with a camera (Nikon D3200), saving the files in JPG format. PhotoScape X 4.2.1 (Mooii Tech) and GIMP 2.10.22 were used for image processing.

Results

A fibrous capsule covered the organs. The renal vein, renal artery and ureter were identified in the hilar region. In the sagittal section, the macroscopic organization of the kidney showed a division into two clearly demarcated parts, i.e. an external light cortex and an internal dark medulla (**Fig. 1, 2**). The renal pyramids can be distinguished. The apex of these pyramids faces the renal sinus and forms the renal papilla. The renal sinus contained the renal pelvis, whose area of the vasculature and ureter could be distinguished. The renal artery is a branch of the abdominal aorta, and the renal vein enters the caudal vena cava.

Weight and external measurements are shown in **table 1**. The right kidney was proving heavier. The left kidneys of wild red deer were characterized by the highest values of external measurements, with the following results: 109.01 ± 7.58 mm height, 44.68 ± 7.09 mm width and 37.60 ± 3.88 mm thickness. In contrast, the right kidneys of the ranch fallow deer stood out as the smallest, with a height of 72.96 ± 4.40 mm, a width of 34.92 ± 3.29 mm and a thickness of 21.68 ± 3.09 mm. The organs of ranch fallow deer distinguished the smallest size.

The results of cortex-to-core kidney height measurements and their ratio are shown in **table 2**. Similar values of cortex-to-core ratio were observed in both groups of breeding animals. However, in in-

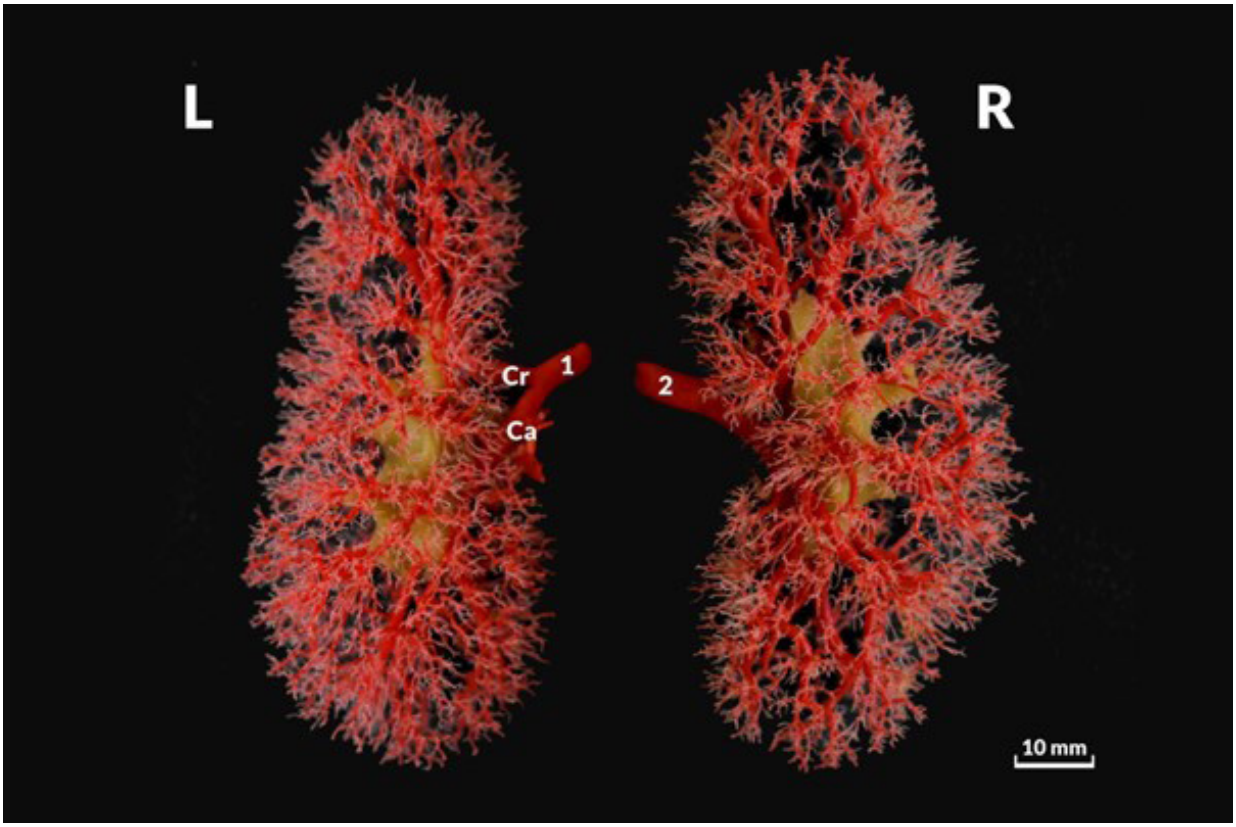


FIGURE 3 Right (R) and left (L) kidney of red deer, corrosive preparation. 1 – left renal artery, 2 – right renal artery, Cr – cranial renal artery, Ca – caudal renal artery



FIGURE 4 Left kidney of red deer, corrosive preparation. Cr – cranial renal artery. Ca – caudal renal artery. 1, 2, 3 – segments of the cranial renal artery, consecutively: cranial, middle and caudal. 4, 5, 6 – segments of the caudal renal artery, consecutively: intracranial, middle and caudal

dividuals obtained from the wild, we had extreme values. Namely, the highest cortex-to-core ratio was observed in the left kidney of red deer at 1:1.7474 ± 0.2630 and the lowest at 1:1.2380 ± 0.3713 in the left kidney of European fallow deer.

Through access from the renal hilum, the preparation visualized a division of the renal artery, which occurred in front of the renal hilum in 82% of the dissected kidneys of wild red deer and 69% of wild European fallow deer. In farmed specimens, these results differed, with the renal artery dividing in front of the renal hilum in 63% of dissected kidneys of red deer and 73% in farmed European fallow deer. Further vascularisation branches to the organ's corresponding parts were visualized on cross-section. The renal artery was segmented into two main vessels – the cranial and caudal renal artery (**Fig. 3, 4**). The preparation results indicated that the cranial and caudal renal artery usually divides into the corresponding three branches each, giving a total of 6 – these segments are signed and marked in **figure 4**. In the analyzed specimens, these results ranged from 4 to 7 branches in total. Further secondary divisions were characterized by high individual variability, usually dividing into two further segments. Located at the cortex and medulla border, the arcuate arteries give rise to numerous interlobular arteries.

Discussion

The kidneys of red deer differed from those of European fallow deer in weight and dimensions, being proportionally larger and heavier. Macroscopic division between dark medulla and lighter cortex is a characteristic feature of many representatives of cervids and, among others, goats. In the musk deer (*Moschus moschiferus*), a darker cortex and a lighter medulla have been observed [6]. Striations of the medulla result from the anatomical arrangement of the main parts – the loop of Henle, the long nephrons and the medullary part of the collecting tubules [3,7]. When comparing the cortex-to-core ratio, the results showed the similarity of these parameters in red deer and European fallow deer. Differences could be observed between breeding animals and those obtained from hunting. Especially the results of the last group's kidney measurements were similar to those of a study conducted on another representative of the deer family, the Axis axis species, in which the average thickness of the cortex was found to be about 1:1.3272, which was comparable to the values measured in cattle [8]. Physiological processes in cattle are highly dependent on water; hence the urine of this species, compared to the composition of sheep urine, has a much lower concentration of components [9]. Wild European fallow deer were characterized by a reduced cortex-to-core ra-

tio and red deer by an enlarged ratio – indicating a possible correlation between kidney morphology and environmental factors of those species. Kidney morphology may be influenced by various environmental factors such as unrestricted access to water or diet composition. Experimentally, it has been shown that the environment at the beginning of the postnatal developmental period and even in the prenatal period influences the formation of the corticomedullary ratio, a phenomenon described as phenotypic or developmental plasticity [10].

The arterial vascularisation of the kidneys in both cervid species studied is comparable to that in other representatives of the Cervidae family and farmed animals like cattle, excluding the goats in which a double renal artery has been found. Segmentation of renal artery to a cranial and caudal segment was observed in another cervid representative, the grey brocket (Mazama gouazoubira) [11]. It is worth mentioning that the renal artery in the gray brocket is divided in the transverse plane [11], similar to that in domestic cattle [12]. In sheep, on the other hand, this division occurs in the dorsal plane, dividing the renal artery into dorsal and ventral [13]. In both researched species, European fallow deer and red deer, the segmentation occurred in the transverse plane. Located at the cortex and medulla border, the arcuate arteries give rise to numerous interlobular arteries. Their density confirms the physiology of the kidney as an organ of the excretory system, as >99% of the filtrate is reabsorbed in the medulla into which the interlobar arteries penetrate [14].

Conclusions

Our study showed differences in the morphological structure of the kidneys between wild and farmed individuals of indicating the importance of environmental factors in kidney development. Comparing the results on the structure as well as vascularization of the kidneys confirmed the similarity with other representatives of the Cervidae family and with farm animals such as cattle. The morphology of renal vascularization should be an important aspect when performing imaging studies and surgical procedures of both farmed and wild species.

Ethical approval
The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals. As the research material was collected posthumously, no Ethical Committee approval is needed for this study.

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Not applicable.

Corresponding author
Maciej Zdun DVM, PhD, Department of Basic and Preclinical Sciences, Institute of Veterinary Medicine, Nicolaus Copernicus University in Toruń, Toruń, tel: +48 56 611 22 31, e-mail: maciejzdun@umk.pl.

Conflict of interest
The authors declare they have no conflict of interest.

References

1. Howerth EW, Nemeth NM, Ryser-Degiorgis MP. Cervidae. In: Terio KA, McAloose D, St Leger J, editors. Pathology of wildlife and zoo animal [Internet]. Elsevier: London; 2018 [cited 2023 Apr 17]. Chapter 6. Available from: https://doi.org/10.1016/B978-0-12-805306-5.00006-7/.
2. Charyło E, Gesich J, Jagłowska A. Statistical yearbook of forestry. Statistical Office in Białystok: Białystok, Poland; 2022. 356 p.
3. Reece WE. Dukes' physiology of domestic animals. 13th ed. Wiley-Blackwell: Ames (Iowa), USA; 2015. 763 p.
4. Abidu-Figueiredo M, Roza MS, Passos NC, Silva BX, Scherer PO. Renal artéria com dupla origem na porção abdominal da aorta em caprino. Acta Vet Bras. 2009;3(1):38-42; DOI:10.21708/avb.2009.3.1.970.
5. Schmidt-Nielsen B, O'Dell R. Structure and concentrating mechanism in the mammalian kidney. Am J Physiol. 1961;200:1119-24; DOI:10.1152/ajplegacy.1961.200.6.1119.
6. Sudahan N A, Suri S, Sarma K, Azmi S, Kumar P. Anatomical study on the kidney of musk deer (Moschus moschiefrus). Indian J Anim Sc. 2008;78(7):725-6.
7. Dyce KM, Sack WO, Wensing CJG. Textbook of Veterinary Anatomy. 4th ed. Saunder: St.Louis; 2010. 834 p.
8. Hari Prakash B, Lalitha P S, Rathinam T, Baskar V R, Vasaviah V. Morphology of kidney of spotted deer, Axis axis, with relation to its environment. J Vet Anim Sci. 2000;31:86-9.
9. Hafez ESE. Adaptation of domestic attifrtals. Lea and Febiger: Philadelphia; 1968. 415 p.
10. Stone G, Johnston I, Willmer P. Environmental physiology of animals 2nd ed. Blackwell Publishing: Hoboken; 2005. 784 p.
11. Martins TMM, Martins TRM, Fontana CAP, Lima FC, Pereira DKS, Pereira KF, Malysz T. Renal morphological description of brown brocket deer, Mazama gouazoubira, Fisher 1814 (Artiodactyla; cervidae). Res Soc Devel. 2020;9(10): e4929108868; DOI:10.33448/rsd-v9i10.8868.
12. Szymanski J, Olewnik L, Wysiadecki G, Przygocka A, Polguj M, Topol M. Proposal for a new classification of the renal artery in the bovine kidney. Vet Med. 2018;63(2):63-72; DOI:10.17221/130/2017-VETMED.
13. Carvalho MAM de, Miglino MA, Machado GV, Machado-Júnior AAN, Vale EF, Azevedo LM. Segmentação anatomo-cirúrgica arterial do rim de javali (Sus scrofa) adulto. Biotemas. 2006;19(4):85-90.
14. Johns EJ, Ahmeda AF. Renal Circulation. Reference Module in Biomedical Sciences [Internet]. Elsevier: London; 2014 [cited 2023 Apr 28]. Available from: https://doi.org/10.1016/B978-0-12-801238-3.00200-2/.