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ZOOLOGY

Morphometric study of ostrich kidneys *Struthio camelus* Linnaeus, 1758

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ABSTRACT. In recent years, avian medicine has advanced in the recognition of kidney diseases, but little is known about the morphology and renal morphometry of the common ostrich *Struthio camelus* Linnaeus, 1758. This study aimed to describe the morphometry and location of kidneys in the common ostrich. Twenty-six cadavers, aged one to seven days, which died of natural causes on a farm in the municipality of Magé, state of Rio de Janeiro, Brazil, were donated to the Department of Animal and Human Anatomy at the *Universidade Federal Rural do Rio de Janeiro* (UFRRJ). The specimens were identified, sexed, and fixed in a 10% aqueous solution of formaldehyde. The kidneys and renal divisions were measured using a precision digital caliper. The kidneys of *S. camelus* are elongated, and lobular, and have three renal divisions (cranial, middle, and caudal). The average length of the right kidney was 6.69 ± 0.83 cm, and the left kidney was 6.87 ± 0.81 cm. The body length correlated positively and significantly with the lengths of the right kidney ($r = 0.8273$, $p = 0.0017$) and left kidney ($r = 0.8534$, $p = 0.0008$) in females. The renal cranial limit was observed at the eighth lumbar vertebra (L8) in 22 kidneys (42.3%), and the caudal limit, at the eighth sacrocaudal vertebra (Sc8) in 11 kidneys (21.2%), and the second caudal vertebra (C2) in 11 kidneys (21.2%). The morphometric dimensions and skeletopy of the ostrich kidney contribute to the field of comparative avian anatomy and assist in the interpretation of imaging techniques.

Keywords: avian; nephrology; wild animals; anatomy; urinary system; ratite birds.

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Introduction

The common ostrich *Struthio camelus* Linnaeus, 1758 is a ratite bird native to the African continent and is considered the largest living bird, measuring up to 2.75m in height and weighing up to 50kg (Deeming, 1999). The common ostrich is primarily raised for meat and egg production (Pittaway & Niekerk, 2015). Producers have faced numerous challenges, ranging from infrastructure to the morphophysiological knowledge of the animals.

Birds are uricotelic, meaning they excrete uric acid, a low-toxicity, and water-insoluble substance, making it the most adaptable form for terrestrial life. Like those of other vertebrates, the role of bird kidneys includes filtration, excretion or secretion, and absorption. Kidneys also play a crucial role in water conservation and the reabsorption of necessary substances (Ritchison, 2008).

Kidneys represent approximately 1% of the bird's body weight and the avian renal system has anatomical and physiological specificities that influence disease processes, diagnoses, and treatment modalities (Burgos-Rodríguez, 2010). The biochemical and qualitative evaluation of ostrich urine supernatant was described by Mushi, Binta, and Isa (2001), with variations attributed to the hydration state of the animal influenced by climatic factors. However, the renal morphology of this species is based on domestic birds, especially poultry.

This study aimed to describe the morphometry and location of kidneys in the common ostrich. Variations in allometric relationships of the kidneys have been reported for Australian passerines that feed on nectar and insects (Richardson, Wooller, & Casotti, 1991), as well as in chickens (*Gallus domesticus*), marsh harriers (*Circus aeruginosus*), and mallards (*Anas platyrhynchos*) (Dhyaa, Ali, Azhar, & Ahmed, 2014). However, measurements such as length and width have not yet been reported in *S. camelus*.

Material and methods

This study was approved by the Research Ethics Committee of the *Universidade Federal Rural do Rio de Janeiro* (018/2017).

A total of 26 cadavers, 15 males and 11 females, totaling 52 kidneys, from ostrich chicks aged one to seven days, who died of natural causes on a farm in the municipality of Magé, state of Rio de Janeiro, Brazil, were used. The specimens were donated to the Department of Animal and Human Anatomy at the *Universidade Federal Rural do Rio de Janeiro* (UFRRJ), where they were sexed, and numbered. The body length was measured from the mandibular bone to the tip of the pygostyle bone, using a flexible metal tape measure.

The specimens were placed in dorsal recumbency, and an incision was made in the skin and muscles caudal to the last rib to access the descending portion of the aorta. A plastic cannula was introduced into this vessel to fix the cadaver with a 10% aqueous solution of formaldehyde. Subsequently, an aqueous solution (1:1 dilution) of Petrolatex S-65 [Duque de Caxias Refinery (Reduc) of Petrobras, Duque de Caxias, Rio de Janeiro State], mixed with the dye (Suvinil xadrez®), was injected through the cannula. Animals were then immersed in a 500L low-density polyethylene box containing a 10% aqueous formaldehyde solution for 15 days to complete the fixation and polymerization of the latex. After this period, the ventrocaudal portion of the body cavity was opened, and the intestinal viscera were removed to expose the kidneys and their respective vessels and skeleton. The renal portions of each bird were dissected on both sides, and measurements (length and width) were taken individually and for each renal division using a precision digital caliper (ZAAS Precision, Amatools®).

The mean and standard deviation of kidney and renal portion measurements were calculated and compared between sexes using the unpaired Student's t-test. The Pearson correlation coefficient ($-1 < r < 1$) estimated the relationship between renal measurements and body length. Differences were considered statistically significant at $p < 0.05$. Data were analyzed using GraphPad Prism 5 software.

Results

The kidneys of *S. camelus* specimens presented as elongated and lobular. The kidneys are deeply embedded in the renal fossae, the ventral depression of the synsacrum. The medial faces of the kidneys border the aorta, which lies in the dorsal midline plane. The morphological analysis revealed the kidneys are divided into three distinct and incomplete parts: cranial renal division, with a rounded shape; middle renal division, elongated and narrower; and a caudal renal division, well-developed and elongated (Figure 1). The boundary between the cranial and middle renal divisions is marked by iliac arteries, while the boundary between the middle and caudal renal divisions is demarcated by ischiatic arteries. The ureters leave the caudal divisions of the kidneys caudomedially.

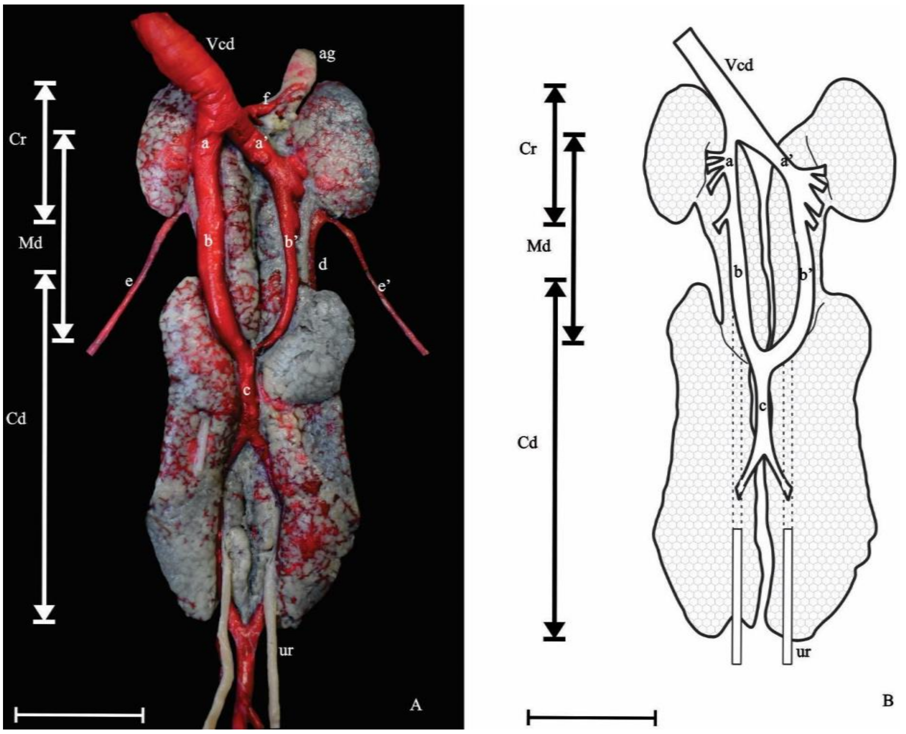

Figure 1. Digital photomacrograph (A) and schematic representation (B) of the ventral view of the kidneys from a male specimen of *Struthio camelus*. Cr: cranial renal division; Md: middle renal division; Cd: caudal renal division; ur: ureter; ag: adrenal gland; a, a': right and left common iliac veins; b, b': right and left caudal renal veins; c: anastomosis between the caudal renal veins; d: left caudal renal portal vein; e, e': right and left pubic veins; f: adrenal veins. Scale bar: 10 mm.

The average body length was 31.47 ± 3.53 cm (n = 26); 31.53 ± 3.40 cm in males (n = 15) and 31.38 ± 3.87 cm in females (n = 11), showing no statistically significant differences (p = 0.92). The average length of the right kidney was 6.69 ± 0.83 cm; 6.76 ± 0.84 cm in males and 6.59 ± 0.84 cm in females; the average length of the left kidney was 6.87 ± 0.81 cm; 6.82 ± 0.74 cm in males and 6.95 ± 0.93 in females. No significant differences were detected between the sexes for the right (p = 0.62) and left (p = 0.69) renal lengths; and between antimeres in males (p = 0.84) and females (p = 0.35). Body length in females was positively and significantly correlated with the right (r = 0.8273 and p = 0.0017) and left (r = 0.8534 and p = 0.0008) renal lengths.

The analysis of renal divisions for the whole sample showed that the cranial division had an average length of 1.96 ± 0.34 cm and width of 1.26 ± 0.28 cm, the middle division had an average length of 1.57 ± 0.30 cm and width of 0.60 ± 0.11 cm, and the caudal division had an average length of 2.66 ± 0.37 cm and width of 1.20 ± 0.22 cm. This study indicated that the caudal renal division was statistically larger than the middle division (p < 0.0001) and the cranial renal division was statistically larger than the middle division (p < 0.0001). However, lengths and widths of renal divisions were not significantly significant differences between sexes and antimeres, except for the length of the cranial division in males, which showed a statistical difference between antimeres (p = 0.03), with the right cranial division having a smaller width (Table 1).

The average total lengths of the kidneys and the lengths and widths of the renal divisions are listed in Table 2.

Table 1. Mean and standard deviation of the length (cm) and width (cm) of the kidney divisions of *Struthio camelus* (n = 26). The p-value refers to the unpaired Student's t-test for comparing means between antimeres.

	Right	Left	p-value
	Kidney length of males (n = 15)		
Cranial Division	1.96 ± 0.40	1.97 ± 0.23	0.94
Middle Division	1.53 ± 0.23	1.75 ± 0.43	0.09
Caudal Division	2.60 ± 0.35	2.86 ± 0.43	0.08
	Kidney length of females (n = 11)		
Cranial Division	1.97 ± 0.44	1.92 ± 0.32	0.77
Middle Division	1.46 ± 0.16	1.49 ± 0.19	0.71
Caudal Division	2.53 ± 0.28	2.58 ± 0.33	0.70
	Kidney width of males (n = 15)		
Cranial Division	1.13 ± 0.25	1.33 ± 0.21	0.03*
Middle Division	0.59 ± 0.09	0.59 ± 0.10	0.94
Caudal Division	1.17 ± 0.18	1.17 ± 0.21	0.93
	Kidney width of females (n = 11)		
Cranial Division	1.25 ± 0.33	1.35 ± 0.29	0.49
Middle Division	0.61 ± 0.12	0.64 ± 0.13	0.56
Caudal Division	1.21 ± 0.24	1.27 ± 0.27	0.56

*Significant difference (p < 0.05).

Table 2. Mean and standard deviation of total kidney length (cm) and the length (cm) and width (cm) of renal divisions in *Struthio camelus* (n = 26). The p-value refers to the unpaired Student's t-test for comparing means between sexes.

	Males (n = 15)	Females (n = 11)	p-value
Length of the right kidney	6.76 ± 0.84	6.59 ± 0.84	0.622
Cranial Division	1.96 ± 0.40	1.97 ± 0.44	0.967
Middle Division	1.53 ±0.23	1.46 ± 0.16	0.416
Caudal Division	2.6 ± 0.35	2.53 ± 0.28	0.592
Length of the left kidney	6.82 ± 0.74	6.95 ± 0.93	0.685
Cranial Division	1.97 ± 0.23	1.92 ± 0.32	0.648
Middle Division	1.75 ± 0.43	1.49 ± 0.19	0.077
Caudal Division	2.86 ± 0.43	2.58 ± 0.33	0.082
Width of the right kidney			
Cranial Division	1.13 ± 0.25	1.25 ± 0.33	0.287
Middle Division	0.58 ± 0.09	0.60 ± 0.12	0.617
Caudal Division	1.17 ± 0.18	1.21 ± 0.24	0.594
Width of the left kidney			
Cranial Division	1.33 ± 0.21	1.35 ± 0.29	0.853
Middle Division	0.59 ± 0.10	0.64 ± 0.13	0.294
Caudal Division	1.17 ± 0.21	1.27 ± 0.27	0.288

The cranial renal limit was observed at the eighth lumbar vertebra (L8) in 22 kidneys (42.3%), the seventh lumbar vertebra (L7) in 11 kidneys (21.2%), between L7 and L8 in nine kidneys (17.3%), between L8 and the first sacral vertebra (S1) in six kidneys (11.5%), at S1 in three kidneys (5.8%), and the second sacral vertebra (S2) in one kidney (1.9%), with no significant difference between antimeres in the specimens. The caudal renal limit varied among specimens, occurring at the eighth sacrocaudal vertebra (Sc8) in 11 kidneys (21.2%), the second caudal vertebra (C2) in 11 kidneys (21.2%), the seventh sacrocaudal vertebra (Sc7) in eight kidneys (15.4%), the first caudal vertebra (C1) in six kidneys (11.5%), the fifth sacrocaudal vertebra (Sc5) in four kidneys (7.7%), the sixth sacrocaudal vertebra (Sc6) in three kidneys (5.8%), between Sc5 and Sc6 in two kidneys (3.8%), between Sc8 and C1 in two kidneys (3.8%), between C1 and the second sacrocaudal vertebra (C2) in two kidneys (3.8%), at the third caudal vertebra (C3) in two kidneys (3.8%), and between Sc7 and Sc8 in one kidney (1.9%) (Table 3).

Table 3. Absolute frequency (AF) and simple percentage (SP) of the cranial and caudal limits of *Struthio camelus* kidneys (n = 26).

		Males				Females			
		Right Kidney		Left Kidney		Right Kidney		Left Kidney	
		AF	SP	AF	SP	AF	SP	AF	SP
Cranial Limit	L7	-	-	-	-	5	45.5	6	54.5
	L7-L8	3	20.0	3	20.0	2	18.2	1	9.1
	L8	8	53.3	8	53.3	3	27.3	3	27.3
	L8-S1	3	20.0	3	20.0	-	-	-	-
	S1	1	6.7	1	6.7	-	-	1	9.1
	S2	-	-	-	-	1	9.1	-	-
Caudal Limit	Sc5	1	6.7	1	6.7	1	9.1	1	9.1
	Sc5-Sc6	1	6.7	1	6.7	-	-	-	-
	Sc6	2	13.3	1	6.7	-	-	-	-
	Sc7	4	26.7	3	20.0	1	9.1	-	-
	Sc7-Sc8	1	6.7	-	-	-	-	-	-
	Sc8	3	20.0	4	26.7	2	18.2	2	18.2
	Sc8-C1	-	-	-	-	1	9.1	1	9.1
	C1	2	13.3	-	-	2	18.2	2	18.2
	C1-C2	-	-	-	-	1	9.1	1	9.1
	C2	1	6.7	5	33.3	3	27.3	2	18.2
	C3	-	-	-	-	-	-	2	18.2

Discussion

The arrangement of kidneys in the synsacral region and the three renal divisions in *S. camelus* is similar to those observed in domestic birds (Islam et al., 2004; Dhyaa et al., 2014; Carretero, König, Liebich, & Korbel, 2016; Singh, 2017), wild birds (Nabipour, Alishahi, & Asadian, 2009; Batah, 2012; AL-Ajeely & Mohammed, 2012), and correspond to existing descriptions for the species under study (Bezuidenhout, 1986; Fowler, 1991; Bezuidenhout, 1999).

In this study, the presence of lobules was observed throughout the renal surface of *S. camelus*. In chickens, King (1975) described a renal lobule as the area of tissue bounded by terminal branches of the renal portal veins, and some lobules protrude on the kidney surface as small, rounded projections with afferent veins at their edges.

In *S. camelus*, the boundary between the cranial and middle renal divisions was demarcated by the external iliac arteries, and between the middle and caudal renal divisions, it was delimited by the ischiatic arteries. These boundaries between renal divisions are common in birds, as described by King (1975) for chickens, Al-Ajeely and Mohammed (2012) for pigeons (*Columba livia domestica*), and Wideman Jr., Braun, and Anderson (1981) for domestic fowl.

The caudal renal division was statistically larger with a high level of significance, followed by the cranial and middle divisions. This result is similar to that described for ostriches (Macalister, 1864), chickens (Braun & Dantzler, 1972; Braun, 1993; Islam et al., 2004), sparrows (*Passer domesticus*; *Melospiza melodia*; *Passerculus sandwichensis*) (Casotti & Braum, 2000), pigeons (Al-Ajeely & Mohammed, 2012), and mallard duck (*Anas platyrhynchos*) (Dhyaa et al., 2014). When compared to the coot bird (*Fulica atra*) (Batah, 2012) and harrier (*Circus aeruginosus*) (Dhyaa et al., 2014), the result is contradictory, as these species showed a well-developed cranial renal division followed by the middle and caudal divisions. King (1975) described in chickens that each kidney is divided into a rounded cranial division, a thinner middle division, and a more expanded and irregularly shaped caudal division.

In this study, the kidneys of ostrich chicks aged one to seven days had a length of 6.78 cm. Macalister (1864) described the kidneys of adult ostriches with a length of 33.02 cm, and Bezuidenhout (1999) with 30.0 cm. Due to the differences in age and body size of the specimens studied, it is not possible to compare the studies between adult specimens of *S. camelus* and other bird species.

The average length of the left kidney (6.87 ± 0.81cm) was higher than that of the right kidney (6.69 ± 0.83cm), although this difference was non-significant. Richardson et al. (1991) reported that the left kidneys were longer than the right in Australian passerines, with this difference being significant in nectarivorous and insectivorous species. However, symmetric kidneys were observed in chickens (King, 1975; Islam et al., 2004). Al-Ajeely & Mohammed (2012) reported that pigeon kidneys showed a positive and significant correlation between the lengths of the left and right kidneys with body weight.

The renal divisions showed no differences in width, except in males, for which the right cranial renal division had a smaller width. This difference may be related to the presence of loops of the jejunum and ileum occupying the right caudal quadrant of the body cavity. Zhang, Ren, and Tang (2011) observed that the right testicle has a smaller length and greater width in ostrich chicks between one to five days of age, which seems to be related to the smaller width of the right cranial renal division.

Variations in the length and width of renal divisions are relevant in avian clinical practice because the nerves of the sacral and lumbar plexuses pass through the kidneys. Due to the close association with the kidney, any case of renal enlargement can impact nerves, leading to paresis or paralysis (Burgos-Rodríguez, 2010).

Conclusion

Our results fill a gap in the literature regarding ostrich chicks, illustrating that their kidneys have three divisions, with the caudal renal division being the most elongated, followed by the cranial and middle divisions. The morphometric dimensions and their skeletal descriptions do not differ between sexes and aid in the interpretation of imaging techniques. This is clinically relevant as the region of the renal fossae, where the kidneys are inserted, is crucial in cases of trauma. Additionally, the findings contribute to the field of comparative avian anatomy.

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