







Original Articles

Dimensions and skeletopy of kidneys in two populations of *Cerdocyon thous* (Linnaeus, 1766)

Dimensões e esqueletopia dos rins em duas populações de *Cerdocyon thous* (Linnaeus, 1766)

Paulo de Souza Junior^{1,4} , Erick Candiota Souza¹ , Shirley Viana-Peçanha² , Fernanda Coelho Simas Bernardes³ , Marelise Moral Montana⁴ , Marcelo Abidu-Figueiredo² 

¹Laboratório de Anatomia Animal da Universidade Federal do Pampa (UNIPAMPA), Uruguaiana, RS, Brasil.

²Departamento de Anatomia Animal e Humana da Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica, RJ, Brasil.

³College of Veterinary Medicine, Veterinary Teaching Hospital, University of Illinois at Urbana-Champaign, USA.

⁴Programa de Pós-graduação em Ciência Animal da UNIPAMPA.

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ABSTRACT

Cerdocyon thous is the South American canid with great geographic distribution. To the south of Ecuador, two isolated populations have been identified, living in different average temperatures and food availability. The objective was to measure the length, width, thickness and volume of the kidneys, length of renal vessels, and verify the renal skeletopy in two populations of *C. thous*. Kidneys and renal vessels were measured from 34 cadavers collected on highways in the Brazilian territory. From the Atlantic Forest biome (latitude 22°), 14 specimens (seven males and seven female) were analyzed, and from the Pampa biome (latitude 29°), 20 specimens (eight males and twelve female). On average, in the right antimeres the kidneys measured 49.9 × 25.2 × 24.4 mm, had a volume of 16.5 cm³, the renal artery measured 21.3 mm and the renal vein 19.4 mm. In the left antimeres, the kidneys measured 49.3 × 24.4 × 22.8 mm, with a volume of 14.6 cm³ and the artery and vein measured 21.0 mm and 28.4 mm, respectively. The right kidney was always cranial and predominantly positioned ventrally to vertebrae L1–L3, while the left one was positioned ventrally to vertebrae L2–L4. There was no difference in the comparison between sexes or antimeres. Most renal dimensions were significantly higher in the specimens from the Pampa biome, possibly due to the body size and type of diet. This result warns of interpreting diagnoses that depend on the evaluation of the normal renal dimensions in this species.

RESUMO

Cerdocyon thous é o canídeo sul americano com maior distribuição geográfica. Ao sul do Equador, duas populações distintas são reconhecidas, submetidas a diferentes temperaturas médias e disponibilidade de alimento. Objetivou-se mensurar o comprimento, largura, espessura e volume dos rins, comprimento dos vasos renais e esclarecer a esqueletopia renal em duas populações isoladas de *C. thous*. Para tal, foram estudados rins e vasos renais de 34 cadáveres coletados mortos em rodovias brasileiras. Catorze espécimes (sete machos e sete fêmeas) são provenientes do bioma Mata Atlântica (latitude 22°) e 20 espécimes (oito machos e doze fêmeas) do bioma Pampa (latitude 29°). Na média, os rins direitos mediram 49,9x25,2x24,4 mm, tinham um volume de 16,5 cm³ e a artéria renal direita mediu 21,3 mm e a veia renal direita 19,4 mm. Os rins esquerdos mediram 49,3x24,4x22,8 mm tinham volume de 14,6 cm³ e as artérias e veias renais direitas mediram 21,0 mm e 28,4 mm, respectivamente. Os rins direitos foram sempre craniais e predominantemente posicionados ventralmente às vértebras L1 a L3, enquanto os rins esquerdos estavam posicionados majoritariamente ao nível de L2 a L4. Não houve diferença na comparação das medidas entre os sexos ou antímeros. Praticamente todas as medidas renais foram significativamente maiores nos espécimes do bioma Pampa, possivelmente devido ao

* Corresponding author: paulosouza@unipampa.edu.br

maior porte corporal e dieta com maior consumo proteico. Estes achados alertam para que sejam consideradas as diferentes procedências de animais de uma mesma espécie para avaliar parâmetros de normalidade das dimensões renais em procedimentos de medicina de animais selvagens.

INTRODUCTION

Cerdocyon thous, also known as “crab-eating fox,” is the wild canid with the largest distribution area in the South American continent. With great capacity to adapt to habitats in the Neotropics, *C. thous* inhabits areas of closed or open vegetation (COURTENAY; MAFFEI, 2004; HUNTER, 2011; KASPER et al., 2014). Two disjointed dispersion areas are recognized in South America: one to the north and the other to the south of Ecuador. To the north of Ecuador, the dispersion area is distributed in Colombia, Venezuela, Guyana and Suriname; to the south of Ecuador, it is found in Brazil, Paraguay, Argentina, Uruguay and Bolivia (COURTENAY; MAFFEI, 2004). *C. thous* has a body mass of 5–9 kg and can measure up to 1.2 m from the snout to tail (KASPER et al., 2014). An omnivore, it eats fruits, insects, crustaceans, small vertebrates and eggs (HUNTER, 2011). Although its conservation is not threatened, *C. thous* suffers pressure from hunting by rural producers to obtain the skin, is run over by cars, and is infected with diseases transmitted by domestic dogs (HUNTER, 2011; KASPER et al., 2014).

The kidneys are paired, sublumbar retroperitoneal organs located ventrally to the hipaxial musculature and laterally to the aorta artery and caudal vena cava. Each kidney has two surfaces (dorsal and ventral), two poles (cranial and caudal), and two margins (lateral and medial) (NICKEL; SCHUMMER; SEIFERLE, 1979). The medial surface contains the renal hilum that defines a space, the renal sinus, which contains the ureter, blood vessels, lymphatic vessels, and nerves (NICKEL; SCHUMMER; SEIFERLE, 1979). The renal artery has a dorsal position in relation to the renal vein. In dogs, renal vein duplicity is more common than the renal artery (EVANS; LAHUNTA, 2013).

The high occurrence of *C. thous* in nature and its high frequency in zoos and private collections reflects in the hundreds of annual veterinary services to individuals of this species (COURTENAY; MAFFEI, 2004; SILVA et al., 2014). Consequently, several studies report diagnoses of diseases (FREDO et al., 2015; RIBEIRO; VEROCAI; TAVARES, 2009), biochemical test values (MATTOSE et al., 2015; SILVA; NOGUEIRA; SANTANA, 1993), ultrasound evaluation (SILVA et al., 2014), and surgical procedures (PICCOLI et al., 2017) to the kidneys of *C. thous*.

Knowledge of the renal dimensions is fundamental for diagnosis in nephrology and urology (BARR; HOLT; GIBBS, 1990; KONDE et al., 1984). Although there are reports on kidney measurements in domestic (EVANS; LAHUNTA, 2013; NICKEL et al., 1979; STOCCO et al., 2016) and wild carnivores (EVANS; AN, 2014; SOUZA et

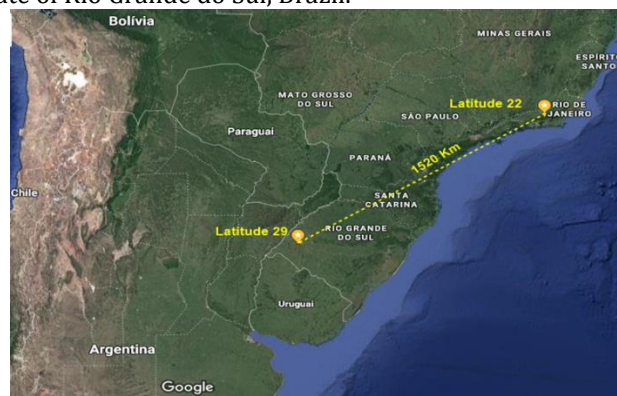
al., 2018), no studies report the normal dimensions of the kidneys of *C. thous*. In anatomical terms, one study describes the sectoral intrarenal arterial branching in one female specimen of *C. thous* (MENEZES et al., 2011) and another reports on one case of duplicity of the left renal artery (PEÇANHA et al., 2020). In addition, the *C. thous* size has significant intra-specific variation, tending to be larger in populations farther south of the South American continent (BUBADUÉ et al., 2016; MARTINEZ et al., 2013). Therefore, it seems plausible to assume that the normal average dimensions of the kidneys may differ in different populations of the same species.

The aim of this study was to establish kidney and renal vessel measurements and renal skeletopy in individuals from two isolated populations of *C. thous*, to subsidize procedures in wildlife medicine, and to clarify if the size of the kidneys varies depending on the population's habitat.

MATERIAL AND METHODS

Thirty-four adult specimens of *C. thous* were collected dead on highways of the Atlantic Forest biome (State of Rio de Janeiro, Brazil), under the authorization of the Ethics Committee on Animal experimentation (protocol 018/2017), and of the Pampa biome (State of Rio Grande do Sul, Brazil), under the authorization of IBAMA/SISBIO (number 33667). From the Atlantic Forest biome, 14 cadavers were collected (seven males and seven females) and from the Pampa biome, 20 cadavers (eight males and twelve females). The collection sites of the specimens of the Atlantic Forest biome were around latitude 22° and those of the Pampa biome, 29°, about 1.520 km in a straight line (Figure 1).

Figure 1 – Graphical representation of the approximate points of collection of the specimens of *Cerdocyon thous*: Atlantic Forest biome (latitude 22°), in the State of Rio de Janeiro, Brazil and Pampa biome (latitude 29°) in the State of Rio Grande do Sul, Brazil.



Source: adapted from Google Maps®

After collection, the specimens had their thoracic cavities opened, the thoracic aorta identified for cannula placement, and fixed by intravascular injection of a 50% formaldehyde solution. Next, the latex solution stained with red pigment was perfused in the vascular bed and the cadavers were immersed in polyethylene tanks with a 10% formaldehyde solution to finish the process of fixing and conserving the specimens.

After at least seven days of fixation, the cadavers were washed in running water and the peritoneal cavity was opened for dissection and for measuring the kidneys and renal vessels (Table 1). A digital caliper (0–150 mm, 0.01 mm resolution, accuracy ± 0.02 mm, Eda®) was used to

obtain measurements of craniocaudal length, latero-medial width, and dorsal-ventral thickness in both kidneys. Renal volume was calculated by applying the equation for the volume of an ellipsoid stipulated by Barr (1990), where Volume (V) = length (L) \times Width (W) \times Thickness (T) $\times 0.523$. The lengths of the renal artery and vein were also measured in both antimeres, taken between the abdominal aorta or caudal vena cava to the renal hilum. Only kidneys and renal vessels in perfect macroscopic conditions were included in the present study and, therefore, in some cadavers it was not possible to measure both kidneys and vessels bilaterally.

Table 1 – Morphometric measurements and respective abbreviations of the kidneys and renal vessels of *Cerdocyon thous*.

Variable	Abbreviation
Length of the left kidney	LLK
Width of the left kidney	WLK
Thickness of the left kidney	TLK
Ellipsoid volume of the left kidney	VLK
Length of the left renal artery	LLA
Length of the left renal vein	LLV
Length of the right kidney	L RK
Width of the right kidney	WRK
Thickness of the right kidney	TRK
Ellipsoid volume of the right kidney	VRK
Length of the right renal artery	LRA
Length of the right renal vein	LRV

To determine skeletopy accurately, the poles (cranial and caudal) of each kidney were marked with radiopaque pins before cadavers were radiographed. The radiographic images were obtained in a lateral projection with the Phillips® brand device, Aquilla Plus 300 model. Radiographs were taken in a Kodak® Direct View Computerized cassette system, exposure of 40 KV, 200 mA in 0.1 s and saved in DICOM® format. After viewing with Radiant Dicom Viewer® software version 1.6.8, the files were converted to JPEG format. The position of both poles projected to the vertebrae was noted.

The BioEstat 5.3® software was used to obtain descriptive statistics data (standard deviation and arithmetic mean) and unpaired Student's t-test to compare measurements between specimens of the two

biomes (Atlantic Forest \times Pampa), between sexes and antimeres, considered significant when $p < 0.05$.

RESULTS

Both right and left kidneys received an artery and a vein from the abdominal aorta and caudal vena cava, respectively (Figure 2). When considering all sampling in the present study ($n = 34$) and disregarding the habitats of the specimens, no measure differed significantly between males and females (Table 2). All renal measurements of the specimens of the Pampa biome had absolute averages higher than those of the Atlantic Forest biome, with the exception of the LLV (Table 3). The widths and volumes of both kidneys and the lengths of the left and right renal arteries were significantly higher in the Pampa specimens (Figure 3).

Figure 2 – Photomacrography with ventral view of the excised right kidney and adjacent structures of a male adult specimen of *Cerdocyon thous*. **AA**, cranial abdominal artery; **AbW**, abdominal wall; **Ao**, abdominal aorta; **CVC**, caudal vena cava; **Di**, diaphragm, **K**, right kidney; **PhA**, phrenic artery; **PhAB** phrenic- abdominal trunk; **RA**, right renal artery; **RV**, right renal vein. Bar: 20 mm.

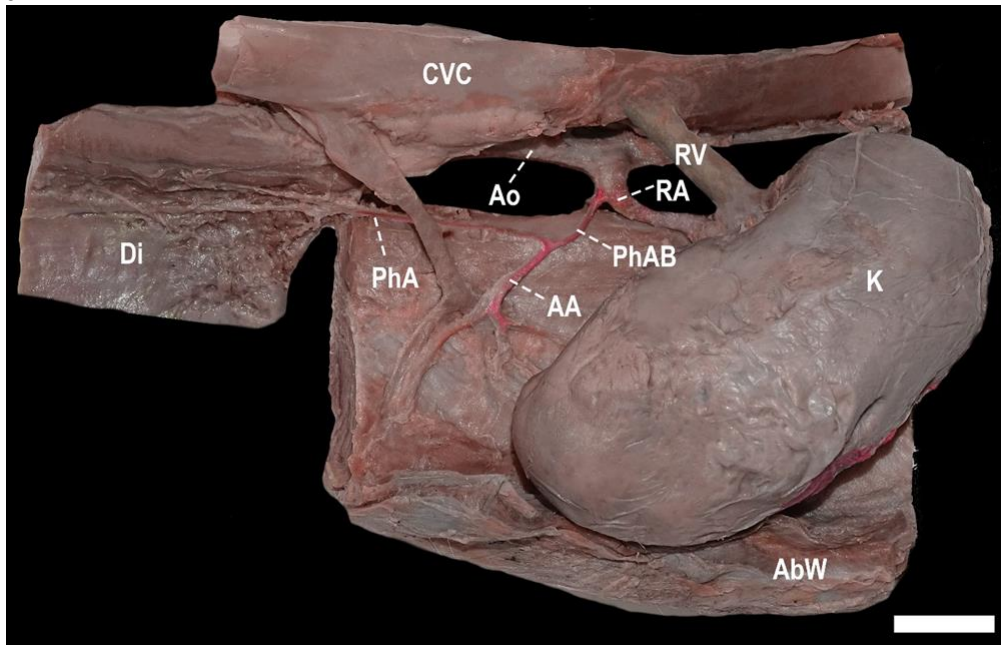


Table 2 – Arithmetic mean and standard deviation of renal measurements of all specimens of *Cerdocyon thous* analyzed and separated by sex. The *p*-value corresponds to the result of the unpaired Student's t-test to compare the averages between males and females.

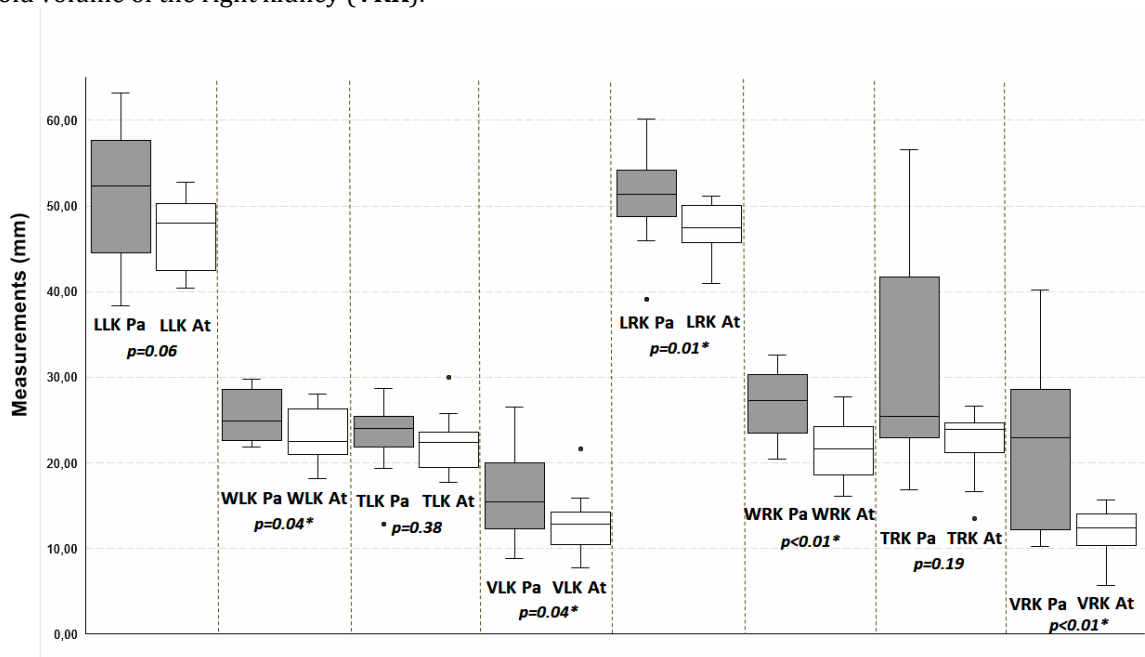
Variables	General	Male	Female	<i>p</i>
LLK(mm)	49.3±6.5(n = 30)	50.6±6.3(n = 14)	48.1±6.7(n = 16)	0.32
WLK(mm)	24.4±3.2(n = 30)	24.4±3.1(n = 14)	24.4±3.4(n = 16)	0.96
TLK(mm)	22.8±3.5(n = 30)	22.6±3.7(n = 14)	23.0±3.4(n = 16)	0.75
VLK(cm ³)	14.6±4.7(n = 30)	14.7±4.1(n = 14)	14.5±5.2(n = 16)	0.89
LLA(mm)	21.0±7.8(n = 27)	20.4±7.4(n = 13)	21.5±8.4(n = 14)	0.72
LLV(mm)	28.4±5.3(n = 25)	27.5±4.8(n = 11)	29.0±5.7(n = 14)	0.50
LRK(mm)	49.9±4.9(n = 31)	50.3±3.7(n = 13)	49.7±5.7(n = 18)	0.76
WRK(mm)	25.2±4.7(n = 31)	25.9±4.0(n = 13)	24.6±5.2(n = 18)	0.45
TRK(mm)	24.4±6.1(n = 31)	23.4±3.4(n = 13)	25.0±7.5(n = 18)	0.44
VRK(cm ³)	16.5±6.8(n = 31)	16.2±4.4(n = 13)	16.7±8.2(n = 18)	0.81
LRA(mm)	21.3±7.2(n = 29)	19.7±7.8(n = 13)	22.6±6.6(n = 18)	0.30
LRV(mm)	19.4±5.5(n = 25)	20.9±6.2(n = 11)	18.2±4.8(n = 14)	0.24

Table 3 – Arithmetic mean and standard deviation of the renal measurements of *Cerdocyon thous*, separated by biomes (Pampa and Atlantic Forest) and the *p*-value in the unpaired Student's t-test comparing the means of the two groups.

Variables	Pampa	Atlantic Forest	<i>p</i>
LLK(mm)	51.3±7.6(n = 16)	46.9±4.2(n = 14)	0.06
WLK(mm)	25.5±2.9(n = 16)	23.1±3.1(n = 14)	0.04*
TLK(mm)	23.3±3.7(n = 16)	22.2±3.3(n = 14)	0.38
VLK(cm ³)	16.2±5.0(n = 16)	12.7±3.5(n = 14)	0.04*
LLA(mm)	26.3±7.0(n = 14)	15.2±3.3(n = 13)	<0.01*
LLV(mm)	27.4±6.2(n = 12)	29.2±4.3(n = 13)	0.40
LRK(mm)	51.6±5.2(n = 19)	47.3±2.9(n = 12)	0.01*
WRK(mm)	27.4±3.9(n = 19)	21.7±3.6(n = 12)	<0.01*
TRK(mm)	25.5±7.1(n = 19)	22.6±3.9(n = 12)	0.19
VRK(cm ³)	19.2±7.2(n = 19)	12.1±2.8(n = 12)	<0.01*
LRA(mm)	24.0±7.6(n = 17)	17.4±4.4(n = 12)	0.01*
LRV(mm)	19.4±6.6(n = 14)	19.3±4.1(n = 11)	0.96

Means in the same line with different superscripts are significantly different ($p < 0.05$).

Figure 3 – Box-plot type chart demonstrating the comparison between each renal measurement among *Cerdocyon thous* specimens of different biomes. Gray boxes correspond to the Pampa biome (Pa) and white boxes to the Atlantic Forest Biome (At). The p-value corresponds to the unpaired Student's t-test for comparing means. *significant value, $p < 0.05$. Length of the left kidney (LLK), Width of the left kidney (WLK), Thickness of the left kidney (TLK), Ellipsoid volume of the left kidney (VLK), Length of the right kidney (LRK), Width of the right kidney (WRK), Thickness of the right kidney (TRK) and Ellipsoid volume of the right kidney (VRK).



The renal dimensions did not differ between males and females when specimens of the same biome were compared, except for the larger LLV measurements in

the females of Pampa and for LRA in the females of Atlantic Forest (Table 4).

Table 4 – Arithmetic mean and standard deviation of renal measurements of specimens of *Cerdocyon thous*, separated by biomes (Pampa and Atlantic Forest) and by sex. The p-values correspond to the result in the unpaired Student's t-test comparing the averages between sexes for each habitat.

Variables	Pampa		P	Atlantic Forest		p
	Male	Female		Male	Female	
LLK(mm)	54.9±4.9(n = 7)	48.4±8.3(n = 9)	0.09	46.2±3.9(n = 7)	47.8±4.6(n = 7)	0.49
WLK(mm)	25.5±2.8(n = 7)	25.6±3.3(n = 9)	0.95	23.4±3.2(n = 7)	22.8±3.1(n = 7)	0.75
TLK(mm)	22.4±4.9(n = 7)	24.1±2.3(n = 9)	0.39	22.7±2.4(n = 7)	21.6±4.1(n = 7)	0.54
VLK(cm ³)	16.5±4.7(n = 7)	16.0±5.5(n = 9)	0.85	12.9±2.7(n = 7)	12.6±4.4(n = 7)	0.85
LLA(mm)	26.7±5.1(n = 6)	26.1±8.5(n = 8)	0.88	15.1±3.9(n = 7)	15.4±2.6(n = 6)	0.84
LLV(mm)	23.3±2.4(n = 5)	30.3±6.5(n = 7)	0.03*	31.0±3.1(n = 6)	27.7±4.9(n = 7)	0.18
LRK(mm)	52.5±3.4(n = 7)	51.1±6.1(n = 12)	0.57	47.6±1.9(n = 6)	47.0±3.8(n = 6)	0.73
WRK(mm)	28.1±3.2(n = 7)	27.0±4.4(n = 12)	0.59	23.5±3.6(n = 6)	19.8±2.8(n = 6)	0.08
TRK(mm)	24.1±2.1(n = 7)	26.3±8.7(n = 12)	0.42	22.7±4.7(n = 6)	22.4±3.3(n = 6)	0.91
VRK(cm ³)	18.8±3.9(n = 7)	19.5±8.6(n = 12)	0.81	13.1±2.5(n = 6)	11.2±3.0(n = 6)	0.26
LRA(mm)	23.9±8.2(n = 7)	24.0±7.5(n = 10)	0.97	14.8±2.9(n = 6)	20.1±4.2(n = 6)	0.03*
LRV(mm)	23.2±8.0(n = 5)	17.3±4.9(n = 9)	0.10	18.9±3.9(n = 6)	19.8±4.7(n = 5)	0.74

*significantly different ($p < 0.05$).

The LLK, LLA, LLV, LRK, WRK, VRK and LRA measurements had a significantly higher mean in the male specimens of the Pampa biome than in the males of the Atlantic Forest (Table 5). Among females, the LLA,

WRK and VRK measurements were significantly higher in the Pampa specimens. In the comparison of measurements between antimeres (Table 6), only LLV was significantly higher ($p < 0.001$) than LRV.

Table 5 – Arithmetic mean and standard deviation of renal measurements of specimens of *Cerdocyon thous*, separated by biomes (Pampa and Atlantic Forest) and by sex. The *p*-values correspond to the result in the unpaired Student's t-test comparing the averages between the two habitats for each sex.

Variables	Males			Females		
	Pampas	Atlantic For.	<i>p</i>	Pampas	Atlantic For.	<i>p</i>
LLK(mm)	54.9±4.9(n = 7)	46.2±3.9(n = 7)	<0.01*	48.4±8.3(n = 9)	47.8±4.6(n = 7)	0.86
WLK(mm)	25.5±2.8(n = 7)	23.4±3.2(n = 7)	0.22	25.6±3.3(n = 9)	22.8±3.1(n = 7)	0.12
TLK(mm)	22.4±4.9(n = 7)	22.7±2.4(n = 7)	0.87	24.1±2.3(n = 9)	21.6±4.1(n = 7)	0.16
VLK(cm ³)	16.5±4.7(n = 7)	12.9±2.7(n = 7)	0.11	16.0±5.5(n = 9)	12.6±4.4(n = 7)	0.19
LLA(mm)	26.7±5.1(n = 6)	15.1±3.9(n = 7)	<0.01*	26.1±8.5(n = 8)	15.4±2.6(n = 6)	0.01*
LLV(mm)	23.3±2.4(n = 5)	31.0±3.1(n = 6)	<0.01*	30.3±6.5(n = 7)	27.7±4.9(n = 7)	0.18
LRK(mm)	52.5±3.4(n = 7)	47.6±1.9(n = 6)	0.01*	51.1±6.1(n = 12)	47.0±3.8(n = 6)	0.16
WRK(mm)	28.1±3.2(n = 7)	23.5±3.6(n = 6)	0.03*	27.0±4.4(n = 12)	19.8±2.8(n = 6)	<0.01*
TRK(mm)	24.1±2.1(n = 7)	22.7±4.7(n = 6)	0.48	26.3±8.7(n = 12)	22.4±3.3(n = 6)	0.19
VRK(cm ³)	18.8±3.9(n = 7)	13.1±2.5(n = 6)	0.01*	19.5±8.6(n = 12)	11.2±3.0(n = 6)	0.01*
LRA(mm)	23.9±8.2(n = 7)	14.8±2.9(n = 6)	0.03*	24.0±7.5(n = 10)	20.1±4.2(n = 6)	0.26
LRV(mm)	23.2±8.0(n = 5)	18.9±3.9(n = 6)	0.27	17.3±4.9(n = 9)	19.8±4.7(n = 5)	0.38

*significant difference ($p < 0.05$)

Table 6 – *P*-value corresponding to the unpaired Student's t-test for the comparison of means between antimeres, in specimens of *Cerdocyon thous*, without distinction of sex or habitat.

Left	Right	<i>p</i>
LLK(mm)	LRLK(mm)	0.66
WLK(mm)	WRK(mm)	0.48
TLK(mm)	TRK(mm)	0.22
VLK(cm ³)	VRK(cm ³)	0.21
LLA(mm)	LRA(mm)	0.88
LLV(mm)	LRV(mm)	<0.001*

*significant difference ($p < 0.05$)

The predominant skeletopy for the left kidney was a ventral positioning to the L2–L4vertebrae, corresponding to 40% of the specimens where it was

possible to make this determination (Table 7). For the right kidney, the most frequent skeletopy was between the L1 and L3 vertebrae in 58% of the specimens.

Table 7 – Distribution of skeletopy of the kidneys of *Cerdocyon thous*, divided by antimere and by sex.

Skeletopy	Left kidney			Right kidney		
	Total <i>n</i> = 30(%)	Male <i>n</i> = 14(%)	Female <i>n</i> = 16(%)	Total <i>n</i> = 31(%)	Males <i>n</i> = 13(%)	Females <i>n</i> = 18(%)
L2–L4	12 (40.0)	7 (50.0)	5 (31.3)	5 (16.1)	2 (15.4)	3 (16.6)
L2–L3	7 (23.3)	2 (14.3)	5 (31.3)	-	-	-
L1–L3	3 (10.0)	1 (7.1)	2 (12.5)	18 (58.1)	9 (69.2)	9 (50.0)
L3–L5	5 (16.7)	3 (21.5)	2 (12.5)	1 (3.2)	-	1 (5.6)
L3–L4	2 (6.7)	1 (7.1)	1 (6.2)	-	-	-
L2–L5	1 (3.3)	-	1 (6.2)	1 (3.2)	1 (7.7)	-
T13–L2	-	-	-	4 (13.0)	1 (7.7)	3 (16.6)
T13–L3	-	-	-	1 (3.2)	-	1 (5.6)
L1–L4	-	-	-	1 (3.2)	-	1 (5.6)

DISCUSSION

In absolute values, the kidneys of *C. thous* measured about 43–55×21–29×18–30 mm. Compared with other species of the order Carnivora, the kidneys have smaller dimensions than in medium-sized domestic dogs (60–90×40–50×30×40 mm) (EVANS; LAHUNTA, 2013), are longer than in domestic cats (38×24×23 mm) (STOCCO et al., 2016), (38–44 × 27–31 × 20–25 mm) (NICKEL; SCHUMMER; SEIFERLE, 1979), similar to the wild sympatric canid *Lycalopex gymnocercus* (45×24×21 mm) (SOUZA et al., 2018) and are two times bigger in all

dimensions than in the mustelid *Mustela putorius furo* (24–30 × 12–13.5 × 11 × 13.5 mm) (EVANS; AN, 2014).

The ellipsoid volume of the kidney of the *C. thous*, estimated between 14 cm³ in the left kidney and 16 cm³ in the right kidney, was bigger than of *L. gymnocercus* (12 cm³ in the left kidney and 11 cm³ in the right kidney) (SOUZA et al., 2018) and also bigger than in the domestic cat (9–12 cm³ in the left kidney and 9–11 cm³ in the right kidney) (STOCCO et al., 2016). Such comparisons seem pertinent to the size of the species: *C. thous* tends to be smaller than a medium-sized dog, but slightly bigger

than *L. gymnocercus* and a lot bigger than domestic cats and *M. p. furo*.

Among the data of the present study, probably what is most striking is the fact the kidneys of the specimens of *C. thous* from Pampa biome are significantly bigger in practically all the dimensions than those of individuals from the Atlantic Forest biome. Previous studies have shown that the skull size of *C. thous* specimens is inversely proportional to temperature-related variables; it means that in populations to the south of Ecuador, the greater the latitude the greater the size of individuals (MARTINEZ et al., 2013). This finding is consistent with the results of the present study, where specimens of *C. thous* collected near latitude 29° (Pampa) have kidneys significantly bigger than specimens collected near latitude 22° (Atlantic Forest). The collection areas are about 1.500 km away and differ in vegetation and annual average temperatures. The Pampa biome has more challenging periods of low rainfall than the Atlantic Forest, which is known to be humid (PENNEREIRO et al., 2018). Perhaps, this relationship between the selective pressure of the environment on kidney morphology can play a role in understanding the differences found in renal dimensions between the two populations.

Based on the geographic distribution previously proposed (CABRERA, 1931), it is possible the two populations analyzed in the present study constitute distinct subspecies: *C. t. entrerrianus* at Pampa biome and *C. t. azarae* at Atlantic Forest biome. In agreement with the comparison of skull dimensions performed in a previous study (MARTINEZ et al., 2013), the kidneys also did not differ between individuals of the same subspecies. It has been recognized three heterogeneous groups of *C. thous* when it comes to the morphometric patterns of the skull, and the specimens of the present study were also in distinct groups (MACHADO; HINGST-ZAHER, 2009).

When analyzing skulls of *C. thous*, one study added that the skull of the specimens to the south had a larger fixation area for the temporal muscle, and thinner and sharper extra molar or premolar teeth (BUBADUÉ et al., 2016). These characteristics indicate a greater bite force and greater drilling capacity of the prey, suggesting preference for carnivorous diet in individuals to the south. The authors speculate that the sympatry of *C. thous* with another canid of similar size, *L. gymnocercus*, creates a demand for competitive adaptations that would not occur in other regions.

Higher protein intake influences renal hemodynamics and increases the glomerular filtration rate, increasing the volume of the glomeruli and resulting in increased volume and renal mass in several mammal species, including rats, dogs and humans (FINCO, 1999; HAMMOND; JANES, 1998; SCHRIJVERS et al., 2002). Thus, it can be speculated that the kidneys of *C. thous* populations to the south are bigger not only in proportion to body size but also in adapting to a diet

with a higher protein content than individuals in lower latitudes. The confirmation of this hypothesis would depend on a meta-analysis of the diet of these groups and comparative renal histomorphometry or serum biochemistry exams, or both, which are beyond the scope of this study.

The significant differences found in the renal dimensions between individuals of the same species from different biomes generate one more aspect to be considered in the cautious interpretation of the findings of imaging and necropsy examinations in veterinary practice. In addition to geographical origin, age and diet may eventually interfere with renal dimensions, and should be considered while interpreting. The sample group of the present study is composed of young free-living adults, while captive animals can have a differentiated diet and live substantially longer.

Renal dimensions did not differ significantly between antimeres in *C. thous*, as reported in domestic dogs (SAMPAIO; ARAUJO, 2002) and New Zealand rabbits (SANTOS-SOUSA et al., 2015), and different from human species, whose left kidney is significantly bigger (FERNANDES et al., 2002; SAMPAIO; MANDARIN-DE-LACERDA, 1989). In *L. gymnocercus*, the left kidneys had a tendency to be longer and wider than the right ones, although the difference was not significant ($p = 0.07$ and $p = 0.06$, respectively) (SOUZA et al., 2018). In domestic cats, only males had the left kidney bigger (STOCCO et al., 2016).

Most studies that present renal dimensions in dogs have methodology based on imaging methods. Some suggest indexes where the kidneys of male dogs are significantly bigger than of the females (LEE; LEOWIJUK, 1982; LOBACZ et al., 2012; MARESCHAL et al., 2007; SAMPAIO; ARAUJO, 2002; SOHN et al., 2016). In *C. thous*, no significant difference was found in the renal measures between sexes, when all specimens were compared and when separated by biomes. The absence of differences in renal dimensions between sexes was also documented in *L. gymnocercus* (SOUZA et al., 2018), New Zealand rabbits (SANTOS-SOUSA et al., 2015) and in human species (CHEONG et al., 2007; EMAMIAN et al., 1993).

In *C. thous*, the skeletopy of the cranial pole of the right kidney predominated at L1 level, while the left kidney in L2, that is, the right kidney, has a more cranial position. This positioning makes the kidneys of *C. thous*, especially the left one, free of costal coverage which would facilitate palpation of the abdominal wall during physical examination and its visualization in imaging diagnostic tests. This positioning was identical to what was described in domestic dogs and cats, including the right kidney located at the T13 level in some dogs (EVANS; LAHUNTA, 2013). According to a previous report, the feline renal skeletopy would be more caudal than in dogs and *C. thous*, with the cranial pole of the right kidney predominating at the level of L2 and the left at the level of L3 (STOCCO et al., 2016). In *Mustela putorius furo*, the

cranial pole of the right kidney is at the level of T14 and the left kidney at the level of L2 (EVANS; AN, 2014). In New Zealand rabbits, the male's cranial poles of right kidneys predominated at level T13, while female's predominated at L1, and left kidneys at level L2 in males and L3 in females (SANTOS-SOUSA et al., 2015). The cranial advancement of the right kidney is common to all domestic mammals, except in pigs (KONIG; MAIERL; LIEBICH, 2016).

In *C. thous*, LLV was significantly bigger than LRV, which is explained by the greater distance from the left kidney in relation to the caudal vena cava. This finding was identical in domestic dogs (EVANS; LAHUNTA, 2013), *L. gymnocercus* (SOUZA et al., 2018), domestic cats (STOCCO et al., 2016) and New Zealand rabbits (SANTOS-SOUSA et al., 2015). For the same reason, it would be expected that LRA was bigger than LLA, which did not occur in *C. thous*, in *L. gymnocercus* (SOUZA et al., 2018), not even in domestic felines (STOCCO et al., 2016), although mentioned in the domestic dog (EVANS; LAHUNTA, 2013). On the other hand, in New Zealand rabbits, LLA was significantly bigger than LRA (SANTOS-SOUSA et al., 2015). In absolute dimensions, the renal arteries of *C. thous* were about 5 mm smaller than those of *L. gymnocercus* (SOUZA et al., 2018), while the renal veins practically did not differ.

CONCLUSIONS

Finally, it can be concluded that the average size of the kidneys of *C. thous* differed in the two disjoint populations analyzed. This result reinforces the findings of measurements previously performed on the skulls of this species and by other factors to be clarified, such as the differences in protein or hydric intake. Veterinary procedures concerning the kidneys of this species should consider possible differences in size, depending on the habitat, captivity or age of the specimen.

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REFERENCES

BARR, F.J.; HOLT, P.E.; GIBBS, C. Ultrasonographic measurement of normal renal parameters. *Journal of Small Animal Practice*, v. 31, n. 4, p. 180-184, 1990.

BARR, F.J. Evaluation of ultrasound as a method of assessing renal size in the dog. *Journal of Small Animal Practice*, v. 31, n. 4, p. 174-179, 1990.

BUBADUÉ, J.D.M. et al. Character displacement under influence of Bergmann's rule in *Cerdocyon thous* (Mammalia: Canidae). *Hystrix*, v. 27, n. 2, p. 83-90, 2016.

CABRERA, A. On some South American canine genera. *Journal of Mammalogy*, v. 12, n. 1, p. 54-67, 1931.

CHEONG, B. et al. Normal Values for Renal Length and Volume as Measured by Magnetic Resonance Imaging. *Clinical Journal of American Society of Nephrology*, v. 2, n. 1, p. 38-45, 2007.

COURTENAY, O.; MAFFEI, L. Crab-eating fox *Cerdocyon thous* (Linnaeus, 1766). In: SILLERO-ZUBIRI, C.; HOFFMANN, M.; MACDONALD, D.W. (Ed.). *Canids: Foxes, Wolves, Jackals and Dogs. Status Survey and Conservation Action Plan*. Cambridge, OX: IUCN/SSC Canid Specialist Group, 2004. p. 32-38.

EMAMIAN, S.A. et al. Kidney Dimensions at Sonography: Correlation with Age, Sex, and Habitus in 665 Adult Volunteers. *American Journal of Roentgenology*, v. 160, n. 1, p. 83-86, 1993.

EVANS, H.E.; AN, N.Q. Anatomy of the Ferret. In: FOX, J.G.; MARINI, R.P. (Ed.) *Biology and Diseases of the Ferret*, Hoboken (NJ): Wiley Online Library, 2014, p. 23-67.

EVANS, H.E.; LAHUNTA, A. *Miller's Anatomy of the Dog*, 4th ed. St Louis, MO: Saunders Elsevier, 2013. 850p.

FERNANDES, M.R. et al. Normal renal dimensions in a specific population. *International Brazilian Journal of Urology*, v. 28, n. 6, p. 510-515, 2002.

FINCO, D.R. Effects of Dietary Protein Intake on Renal Functions. *Compendium on Continuing Education for the Practicing Veterinarian*, v. 21, n. 11, p. 5-10, 1999.

FREDO, G. et al. Natural Infection of Wild Canids (*Cerdocyon thous* and *Lycalopex gymnocercus*) with the Intraendothelial Piropiasm *Rangelia vitalii* in Southern Brazil. *Journal of Wildlife Disease*, v. 51, n. 4, p. 880-884, 2015.

HAMMOND, K.A.; JANES, D.N. The effects of increased protein intake on kidney size and function. *Journal of Experimental Biology*, v. 201, n. 13, p. 2081-2090, 1998.

HUNTER, L. *Carnivores of the World* Princeton, NJ: Princeton University Press, 2011. 240p.

KASPER, C.B. et al. Os carnivoros. In: GONÇALVES, G.L.; QUINTELA, F.M.; FREITAS, T.R.O. (Ed.) *Mamíferos do Rio Grande do Sul*, Porto Alegre, RS: Pacartes, 2014. pp. 161-190.

KONDE, L.R. et al. Ultrasonographic anatomy of the normal canine kidney. *Veterinary Radiology and Ultrasound*, v. 25, n. 4, p. 173-178, 1984.

KÖNIG, H.E.; MAIERL, J.; LIEBICH, H.G. Systema urinarium. In: KÖNIG, H.E.; LIEBICH, H.G. (Ed.). *Veterinary Anatomy of Domestic Animals*, 6th ed., New York, NY: Schattauer, 2016. p. 399-410.

LEE, R.; LEOWIJUK, C. Normal parameters in abdominal radiology of the dog and cat. *Journal of Small Animal Practice*, v. 23, n. 5, p. 251-269, 1982.

LOBACZ, M.A. et al. Effect of breed, age, weight and gender on radiographic renal size in the dog. *Veterinary Radiology and Ultrasound*, v. 53, n. 4, p. 437-441, 2012.

MACHADO, F.A.; HINGST-ZAHER, E. Investigating South American biogeographic history using patterns of skull shape variation in *Cerdocyon thous* (Mammalia: Canidae). *Biological Journal of the Linnean Society*, v. 98, n. 1, p. 77-84, 2009.

MARESCHAL, A. et al. Ultrasonographic measurement of kidney-to-aorta ratio as a method of estimating renal size in dogs. *Veterinary Radiology and Ultrasound*, v. 48, n. 5, p. 434-438, 2007.

MARTINEZ, P.A. et al. Bergmann's rule across the equator: a case study in *Cerdocyon thous* (Canidae). *Journal of Animal Ecology*, v. 82, n. 5, p. 997-1008, 2013.

MATTOSO, C.R.S. et al. Hematologic, serum biochemistry and urinary values for captive Crab-eating Fox (*Cerdocyon thous*) in São Paulo state, Brazil. Pesquisa Veterinária Brasileira, v. 32, n. 6, p. 559-566, 2015.

MENEZES, L.T. et al. Comportamento anatômico das artérias renais em cachorro do mato (*Cerdocyon thous* - Hamilton-Smith, 1839). Pubvet, v. 5, n. 12, p.1074, 2011.

NICKEL, R.; SCHUMMER, A.; SEIFERLE, E. Urogenital system. In: NICKEL, R.; SCHUMMER, A.; SEIFERLE, E. (Ed.) The viscera of the domestic mammals, 2nd ed., Berlin: Springer Verlag, 2017. p. 282-392.

PEÇANHA, S.V. et al. Arteria renal doble en *Cerdocyon thous*. Revista MVZ Cordoba, v.25, n. 1; p. e1713, 2020.

PENEREIRO, J.C. et al. Distribuições de Tendências Sazonais de Temperatura Média e Precipitação nos Biomas Brasileiros. Revista Brasileira de Meteorologia, v. 33, n. 1, p. 97-113, 2018.

PICCOLI, R.J. et al. Nefrectomia total unilateral em cachorro-do-mato (*Cerdocyon thous*). Acta Scientiae Veterinariae, v. 45, n. 1, p. 228, 2017.

RIBEIRO, C.T.; VEROCAI, G.G.; TAVARES, L.E.R. *Diectophyme renale* (Nematoda, Diectophymatidae) Infection in the Crab-eating Fox (*Cerdocyon thous*) from Brazil. Journal of Wildlife Diseases, v. 45, n. 1, p. 248-250, 2009.

SAMPAIO, F.J.; MANDARIN-DE-LACERDA, C.A. Morphometry of the kidney: applied study in urology and imaging. Journal of Urology, v. 95, n. 2, p. 77-80, 1989.

SAMPAIO, K.M.O.R.; ARAÚJO, R.B. Ultra-sonografia de características lineares e estimativas do volume de rins de cães. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia, v. 54, n. 3, p. 248-254, 2002.

SANTOS-SOUSA, C.A. et al. Morphometry and Vascularization of the Rabbit Kidneys (*Oryctolagus cuniculus*). International Journal of Morphology, v. 33, n. 4, p. 1293-1298, 2015.

SCHRIJVERS, B.F. et al. High protein-induced glomerular hypertrophy is vascular endothelial growth factor-dependent. Kidney International, v. 61, n. 5, p. 1600-1604, 2002.

SILVA, T.R.; NOGUEIRA, A.F.S.; SANTANA, A.E. Avaliação dos perfis bioquímicos hepático e renal em *Cerdocyon thous* (cachorro-do-mato) sororreagentes a *Leptospira* spp. no território brasileiro. Ars Veterinariae, v. 4, p. 9, 1993.

SILVA, A.S.L. et al. Mode B ultrasonography and abdominal Doppler in crab-eating-foxes (*Cerdocyon thous*). Pesquisa Veterinária Brasileira, v. 34, n. 1, p. 23-28, 2014.

SOHN, J. et al. Reestablishment of radiographic kidney size in Miniature Schnauzer dogs. Journal of Veterinary Medical Science, v. 78, n. 12, p.1805-1810, 2016.

SOUZA, E.C. et al. Caracterización anatómica de los riñones del Zorro Pampeano (*Lycalopex gymnocercus*): morfometría y vasos renales. Revista Electrónica de Veterinaria, v. 19, n. 5, p. 1-8, 2018.

STOCCO, A.V. et al. Is there a difference between the right and left kidney? A macroscopic approach in Brazilian Shorthair Cat. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia, v. 68, n. 5, p. 1137-1144, 2016.