OSTEOMETRIC ANALYSIS OF THE PELVIC BONES AND SACRUM OF THE RED FOX AND RACCOON DOG

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Abstract. Researchers of the forensic veterinary medicine and osteoarcheologists lack osteological parameters for case analysis or for identification purposes of bone remains on archeological sites. The goal of the current research was to measure the parameters of pelvic and sacral bones in the red fox and raccoon dog and to determine the differences between sex and species. The research was based on the examination of 85 skeleton collections of adult raccoon dogs (*Nyctereutes procyonoides*) and red foxes (*Vulpes vulpes*) compiled in 2003–2006 by the Department of Anatomy and Physiology of the Veterinary Academy, Lithuanian University of Health Sciences (LUHS). The osteometric analysis was performed by A. von den Driesch (1976) method. The comparison of osteometric data of sexes showed that pelvic bones of the male red foxes are longer and broader than those of females ($P<0.001$). The breadth of the sacrum and the breadth and height of the cranial articular surface ($P<0.01$) also are greater. Comparison of species showed that pelvic bones of the male red foxes are longer and broader across the body of the ischia than those of male raccoon dogs ($P<0.001$). The same is true about the length and breadth ($P<0.001$) of the cranial articular surface of sacrum. The pelvic bones of female raccoon dogs are longer ($P<0.01$) and broader between the ilium than those of female red foxes ($P<0.001$). The sacrum in the female raccoon dogs also is longer and broader ($P<0.001$) than in the female red foxes.

Keywords: Red fox, raccoon dog, pelvic bones, sacrum

Introduction. The bony pelvis is composed of two hip bones (*ossa coxae*), which in the ventral region are joined by the cartilaginous pubic symphysis (*symphysis pelvina*), and sacrum (*os sacrum*), which is joined in the dorsal portion of pelvic bones (König and Liebich, 2004; Evans and de Lahunta, 2012). The hip bone (*os coxae*) composed of ilium (*os ilium*), ischium (*os ischii*) and pubic bone (*os pubis*) is part of the structure of the hind leg skeleton (Evans and de Lahunta, 2012).

The morphological studies of appendicular skeletons of domestic and especially wild carnivores are scarce. The osteometric differences between sexes have been determined for raccoon dogs, red foxes and arctic foxes. However, the majority of researches are based on skull data; teeth are a common research object (Hidaka et al., 1998; Frafjord, 1992; Lynch, 1996; Szuma, 2008). The osteometric differences of long bones in males and females of the red fox have been investigated using the bone material collected in Canada (Bisaillon and Deroth, 1979; Monchot and Gendron, 2010).

The long bones of domestic dogs commonly are measured during the initial analysis of fossil bones uncovered during archaeological excavations and the osteometric and macroscopic data of fossil bones often are compared with the data of recent dogs (De Grossi Mazoorin and Tagliacozzo, 1997; Harcourt, 1974; Onar et al., 2002; Zinoviev, 2012). Excavations of ancient burials and territories of hill-forts often yield bones of wild carnivores, but it is hard to identify them without data on modern animals. Many long bones of red foxes have been found in Turkey and the measured parameters of these bones were compared with the parameters of recent foxes (Onar et al., 2005).

Analysis of unbroken bony pelvis is not a simple task as it is technically rather difficult to prepare naturally articulated preparations of pelvic bones and sacrum of good quality. For this reason, many investigations are conducted separately on pelvic bones or sacrum. Studies of sacrum in domestic carnivores are few. However, measurements of sacrum in various breeds of dogs have been done in abundance believing that these data will be helpful for surgical sciences (Ocal et al., 2006). In the system of human skeleton, sacrum is an important bone for identification of sex. Therefore, it is natural that osteometric investigations of human sacrum are abundant (Patel et al., 2005; Mazundar et al., 2012).

The reports on pelvic bone measurements in domestic dogs also are available. The current study represents an analysis of the differences of solid bony pelvis and individual pelvic bones in males and females (Sajjarengpong et al., 2003). The sexual dimorphism of pelvic bones and skull has been investigated at length using the osteological material of grey fox (Urocyon littoralis and Urocyon cinereoargenteus) (Schutz et al., 2009). Of great importance for morphological sciences is the study devoted to comparison of the fusion of the muscles of clouded leopard (endangered species) and domestic cat to pelvic bones containing a description of the specific traits of clouded leopard hip and thigh muscles (Carlon and Hubbard, 2012). Morphological investigations of bony pelvis in wild fauna species other than carnivores have been carried out based on the osteometric data about bats and squirrel monkeys (Nwoka, 2000; Gingerich, 1972).

Another intensively advancing research trend is represented by investigations of sacroiliac joint using roentgen, computer tomography and magnetic resonance. These investigations also are commonly carried out with different breeds of dogs. They are convenient for no necessity to accumulate osteological material; the measurements or other morphological investigations are conducted indirectly (Ondreka et al., 2013; Breit, 2001;

Snaps et al. 1998).

The objective of the current study was to measure the pelvic bones and sacrum of raccoon dogs and red foxes and to determine the differences between sex and species. The obtained results are expected to facilitate identification of fossil bones and to be helpful in forensics. They would complement the osteological information about the red foxes and, in particular, raccoon dogs in the rather limited European habitats. Moreover, these data also are important for reproductive sciences.

Material and methods. The research is based on the examination of 85 skeleton samples of adult raccoon dogs (*Nyctereutes procyonoides*) and red foxes (*Vulpes vulpes*) compiled in 2003–2006 by the Department of Anatomy and Physiology of the Veterinary Academy, Lithuanian University of Health Sciences (LUHS) including 40 samples of the red fox (18 males and 22 females) and 45 samples of the raccoon dog (23 males and 22 females). Only 56 samples were fit for sacrum analysis including 27 bones of the red fox (14 males and 13 females) and 29 bones of the raccoon dog (15 males and 14 females). Other samples were damaged either during hunting or during preparing and, therefore, unfit for osteometric analysis. The analysis included only the skeletons of adults whose epiphyseal lines were ossified. The sex was recorded in the registration book as determined during the examination of the carcasses before the preparation of bone material.

Fig. 1. **Measurements of pelvic bones:**

1. Greatest length (GL).
2. Greatest breadth across the coxal tuberosity (GBTc).
3. Smallest breadth of the shaft of ilium (SB).
4. Greatest breadth across the acetabula (GBA).
5. Smallest breadth across the bodies of the ischia (SBI).
6. Greatest breadth across the ischial tuberosity (GBTi).
7. Length of the acetabulum (LAR).
8. Inner length of the obturator foramen (LFo).

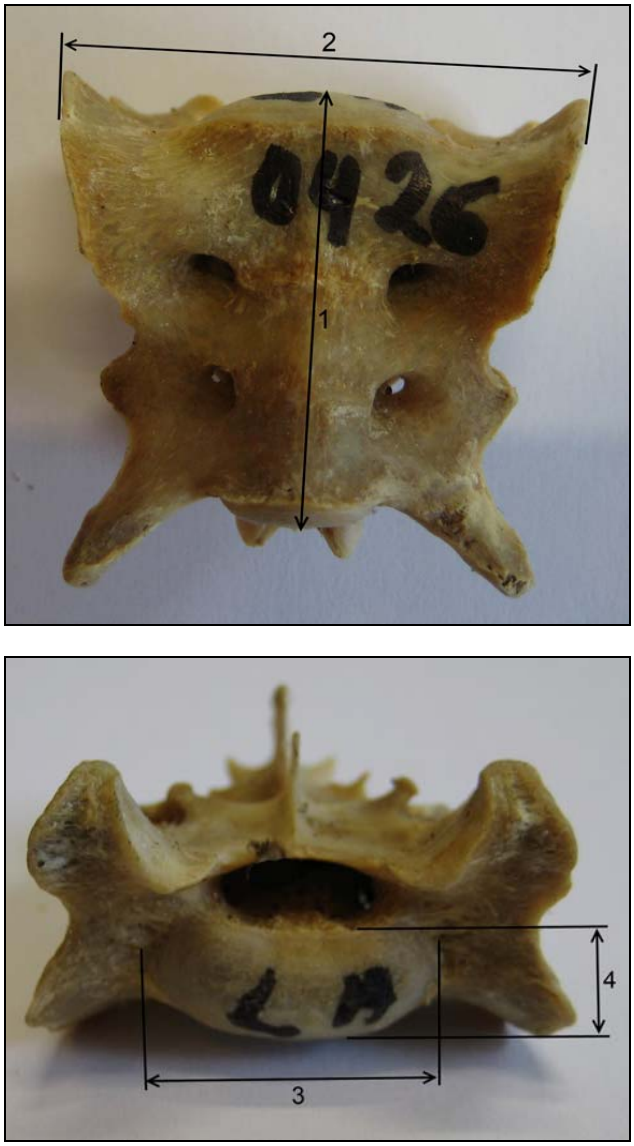

Fig. 2. **Measurements of sacrum:**

1. Physiological length (PL).
2. Greatest breadth (across the wings) (GB).
3. Greatest breadth of the cranial articular surface (BFcr)
4. Greatest height of the cranial articular surface (HFcr).

The osteometric analysis was performed by A. von den Driesch (1976) method. The osteometric measurements were conducted using mechanical sliding callipers with the margin of error 0.1 mm. The measurements are shown in Figs 1 and 2.

The statistical data analysis was performed using Microsoft Excel 2013 and tools available in the internet site "GraphPad QuickCalcs" (GraphPad Software Inc).

The number of variants (n), arithmetic mean of traits (x), standard deviation ((σ), variation coefficient of traits (Cv), and reliability coefficient of the differences between groups (Td) were calculated. The degree of probability of differences and standard values of Student's t criterion were determined using the Student's t-distribution Table. The data were regarded as statistically significant when P<0.05.

Results. The osteometric data were compared using the following scheme:

1. Between sexes: raccoon dogs – males and females; red foxes – males and females.

2. Between species: male raccoon dogs and male red foxes; raccoon dog females and red fox females.

Pelvic bones. Comparison of pelvic bones of female and male raccoon dogs showed that pelvic bones in females are 2 mm longer than in males (P<0.05) and the obturator foramen in males is 0.9 mm longer than in females (P<0.001) whereas the differences of other parameters are insignificant (P>0.05). Measuring of pelvic bones of female and male red foxes showed that pelvic bones in males are 7.33 mm longer than in females. The breadth across the coxal tuberosity (GBTc) is 2.8 mm, across the acetabula (GBA) 3.08 mm, across the bodies of the ischia (SBI) 2.16 mm, across the ischial tuberosity (GBTi) 3.79 mm greater in males than in females. The acetabulum (LAR) is 1.01 mm and obturator foramen (LFo) 1.83 mm longer in males than in females (P<0.001). Meanwhile, the difference of the breadth of the shaft of ilium (SB) is insignificant (P>0.05).

Table 1. **Main statistical indices of pelvic bones measurements**

Dimension (mm)	GL		GBTc		SB		GBA	
Raccoon dog (n 23, n 22)	♂	♀	♂	♀	♂	♀	♂	♀
P		*xx	xxx	xxx				xxx
X	92.91	94.91	57.28	56.89	5.95	6.01	53.33	53.10
σ	2.95	3.60	3.50	4.03	0.36	0.42	2.48	2.35
Cv.%	3.19	3.79	6.11	7.08	6.05	6.98	4.65	4.42
Min.	85.90	87.10	52.10	52.00	5.10	5.10	48.10	49.30
Max.	99.40	100.30	63.90	65.90	6.50	6.90	57.60	57.90
Red fox (n 18, n 22)	♂	♀	♂	♀	♂	♀	♂	♀
P	***xxx		***				***	
X	99.57	92.24	52.45	49.65	5.96	5.77	52.43	49.35
σ	2.65	3.28	2.81	2.90	0.39	0.43	1.77	2.09
Cv.%	2.66	3.55	5.35	5.84	6.54	7.54	3.37	4.23
Min.	95.30	85.90	48.20	43.10	5.20	5.10	49.30	45.40
Max.	103.80	97.20	58.50	53.50	6.70	6.40	55.90	53.70
Note: Differences between sexes: *** (P<0.001), ** (P<0.01), * (P<0.05), differences between species: xxx (P<0.001), xx (P<0.01), x (P<0.05)								

Table 2. **Main statistical indices of pelvic bones measurements**

Dimension (mm)	SBI		GBTi		LFo		LAR	
Raccoon dog (n 23, n 22)	♂	♀	♂	♀	♂	♀	♂	♀
P					***			xxx
X	45.22	44.60	59.59	58.47	17.69	16.79	15.29	15.55
σ	2.03	2.49	2.38	3.19	1.02	0.68	1.00	0.69
Cv.%	4.48	4.65	3.99	5.45	5.76	4.05	6.54	4.43
Min.	40.50	40.20	55.30	52.00	16.30	15.70	13.90	14.00
Max.	48.60	49.10	63.00	64.40	19.80	18.10	16.90	16.40
Red fox (n 18, n 22)	♂	♀	♂	♀	♂	♀	♂	♀
P	***xxx	xxx	***xxx	xxx	***xxx	xxx	***	
X	48.12	45.96	70.58	66.79	22.00	20.17	15.06	14.05
σ	1.69	1.20	2.77	1.96	1.48	1.14	0.69	0.61
Cv.%	3.51	2.61	3.92	2.93	6.72	5.65	4.58	4.34
Min.	44.70	43.90	64.10	63.00	19.50	18.70	13.90	13.10
Max.	52.20	47.90	76.20	70.20	24.20	23.30	16.20	16.10
Note: Differences between sexes: *** (P<0.001), ** (P<0.01), * (P<0.05), differences between species: xxx (P<0.001), xx (P<0.01), x (P<0.05)								

Comparison of pelvic bone parameters in males of both species of animals showed that pelvic bones of the red fox are 6.66 mm longer than those of the raccoon dog. Pelvic bones across the bodies of the ischia (SBI) are 2.9 mm and across the ischial tuberosity (GBTi) 10.99 mm broader in red foxes than in raccoon dogs. The obturator

foramen (LFo) is 4.31 mm longer in the red fox than in the raccoon dog (P<0.001). The breadth across the coxal tuberosity (GBTc) is 4.83 mm greater in raccoon dogs than in red foxes (P<0.001). The differences of the remaining parameters (SB, GBA and LAR) are insignificant (P>0.05). Comparison of pelvic bone parameters in females of both species showed that pelvic bones of the raccoon dog are 2.67 mm longer than those of the red fox (P<0.01). The pelvic bones across the coxal tuberosity (GBTc) are 7.24 mm and across the acetabula (GBA) 3.75 mm broader in the raccoon dog. The acetabulum (LAR) is 1.5 mm longer in the raccoon dog (P<0.001). The breadth of the pelvic bones across the bodies of the ischia (SBI) is 1.9 mm and across the ischial tuberosity (GBTi) 8.32 mm greater in female red foxes. The inner length of the obturator foramen (LFo) is greater by 3.38 mm in the female red foxes than in the female raccoon dogs (P<0.001). The difference of the breadth of the shaft of ilium (SB) is insignificant (P>0.05).

The main statistical indices are given in Tables 1 and 2.

Sacrum. Comparison of the measured parameters of sacrum in females and males showed that the breadth of the sacrum across the wings (GB) is 1.34 mm and the height of the articular surface is 0.38 mm greater in female raccoon dogs than in male (P<0.05). The breadth of the sacrum across the wings (GB) in males of the red fox is 1.80 mm, the breadth of the cranial articular surface (BFcr) 1.23 mm and the height of the cranial articular surface (HRcr) 0.36 mm greater than in females (P<0.01).

Comparison of the measured parameters of sacrum in the males of the studied species showed that the length of the sacrum (PL) in the raccoon dog is 1.89 mm greater than in the red fox (P<0.01). Length (BFcr) 1.99 mm and height (Hfcr) 0.95 mm of the cranial articular surface in the red foxes are greater than in raccoon dog (P<0.001). The physiological length and breadth differences in females of both species are very conspicuous: the physiological length (PL) of the sacrum in the females of the raccoon dog is 3.05 mm and the breadth (GB) 3.66 mm greater than in the females of the red fox (P<0.001). Yet the differences of the cranial articular surface are insignificant (P>0.05).

The main statistical indices are given in Table 3.

Table 3. **Main statistical indices of the measured sacrum parameters**

Dimension (mm)	PL		GB		BFcr		HFcr	
Raccoon dog (n 15, n 14)	♂	♀	♂	♀	♂	♀	♂	♀
P	xx	xxx		*xxx				*
X	27.54	28.11	31.93	33.27	14.16	14.70	6.59	6.97
σ	1.67	1.86	1.31	1.99	0.49	1.05	0.42	0.48
Cv.%	6.06	6.61	4.10	5.98	3.46	7.14	6.37	6.88
Min.	25.11	25.20	29.13	30.45	13.42	12.53	5.90	6.02
Max.	31.18	31.40	33.80	35.94	15.22	16.10	7.20	7.82
Red fox (n 14, n 13)	♂	♀	♂	♀	♂	♀	♂	♀
P			**		**xxx		**xxx	
X	25.65	25.06	31.41	29.61	16.15	14.92	7.54	7.18
σ	1.24	1.18	1.50	0.78	0.82	0.87	0.31	0.34
Cv.%	4.83	4.70	4.77	2.63	5.07	5.83	4.11	4.73
Min.	23.49	23.00	28.87	28.03	14.19	13.21	6.87	6.59
Max.	27.16	26.89	33.99	30.42	17.69	15.90	8.14	7.80
Note: Differences between sexes: *** (P<0.001), ** (P<0.01), * (P<0.05), differences between species: xxx (P<0.001), xx (P<0.01), x (P<0.05)								

Discussion. Sajjarengpong with co-authors (2003) measured 34 pelvic bones of crossbreed dogs and determined the statistically significant sexual dimorphism only of two parameters related with the distance between the ilium and pubis. These researchers did not find the differences determined by the method used by the authors of the current article. Meanwhile, during the present study, well-marked statistically significant differences were determined for almost all parameters of pelvic bones of the red fox: in males their values were higher than in females. Nwoha (2000) measured the pelvic bones of fruit-eating bats and found that the parameter of length in males was greater than in females but, in contrast, the breadth of the pelvic bones in females was greater than in males. These findings are in line with the data obtained by Gingerich (1972) who determined sexual dimorphism in adult squirrel monkeys yet pointed out that sexual dimorphism of pelvic bones is not characteristic of sexually immature individuals. Red fox, raccoon dog and domestic dog belong to the same family *(Canidae)*, but differences between sexes are very distinct. Differences of pelvic bones measurements of red foxes are very distinct, but in raccoon dogs and domestic dogs they are scarce. The very similar situation has been noticed before, when the author of the present article performed measurements of the skull. The skull differences of the red foxes between sexes were distinct, but in raccoon dogs they were scarce (Jurgelėnas, 2005).

Highly significant obturator foramen length differences have been identified by comparison of data on sexes and species. Sajjarenpong with co-authors (2003) determined that obturator foramen of the domestic dogs is

only slightly bigger in males than in females; the difference is statistically insignificant. Ventura with co-authors (1991) examined pelvic bones of water rat and found that obturator foramen of females is longer than that of males and differs in shape: in males it is oval and in females triangular. Evans (2012) determined various forms of obturator foramen, from oval to triangle of the domestic dogs. We think that the length measurements of obturator foramen are insufficient for distinguishing between sexes and species. Detailed investigations using more measurements are necessary.

Even four parameters out of eight in the female raccoon dogs are greater than in the female red foxes (GL, GBTc, GBA, and LAR). The GBTc parameter also is greater in males of both species. These data show that the breadth between the shaft of ilium in the male raccoon dogs is greater than in the red foxes whereas the pelvic bones in female raccoon dogs are higher and broader than in red foxes. The shape and size of pelvic bones depend on the following factors: weight of the foetus, specifics of parturition, peculiarities of carriage and attachment of muscles (Carrier et al., 2003). Schutz with co-authors (2009) reported that speed dogs, e.g. greyhounds, have larger, longer and narrower pelvic bones than dogs with shorter limbs, e.g. American Pit Bull Terriers who have smaller, shorter and broader pelvic bones. The results obtained during the current study, showing that the breadth between the shaft of ilium in the raccoon dogs is greater than in the red foxes, can be related with the weight of foetus and length of limbs. The cubs of the red fox weigh 100 g whereas the cubs of the raccoon dog weigh 120 g on the average (Macdonald, 2004; Kauhala, 2004). Carrier with co-authors (2005) pointed out that the size of cubs predetermines the breadth of the pelvic bones. Raccoon dogs are slow animals with shorter limbs whereas red foxes are speed animals that even can run at a speed of 48 km/h (Macdonald, 2004; Kauhala, 2004). Moreover, it has been determined that the long bones of the red fox are longer than those of the raccoon dog what confirms the above suggestion that the pelvic bones are broader in short-legged dogs.

Mazurdam with co-authors (2012) examined the human sacrum and determined that most of the sacrum parameters are greater in males than in females what also is in line with the results obtained in the present study showing that most of the sacrum parameters in males of the red fox are greater than in females except the length which is slightly greater than in females but the difference is statistically insignificant.

Conclusions:

1. The pelvic bones in the male red fox are longer and broader than in female. The differences of pelvic bone parameters are well-expressed and of high significance ($P<0.001$).

Pelvic bones can be useful only for identification of red fox sexes.

2. The pelvic bones of the male red fox are longer and broader in the ischium region than those of the male raccoon dog ($P<0.001$).

3. The pelvic bones in the female raccoon dog are longer ($P<0.01$) and broader across the shaft of ilium than in the female red fox ($P<0.001$).

Pelvic bones can be useful for distinguishing between the two animal species.

4. The breadth the sacrum and the breadth and height of the cranial articular surface in the male red fox are greater than in female ($P<0.01$).

5. The length and breadth of the cranial articular surface ($P<0.001$) in the male red fox are greater than in the male raccoon dog.

6. The sacrum of the female raccoon dog is longer and broader than that of the female red fox ($P<0.001$).

We found, that better remains cranial part of the sacrum in fossil bones material. So, statistical significant measurements of sacral breadth and other cranial part elements more important in practice investigation.

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