ON THE SKULL MORPHOLOGY OF RACCOON DOG (*NYCTEREUTES PROCYONOIDES*) AND RED FOX (*VULPES VULPES*)

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Abstract. The aim of this work was to perform analysis of the skull morphology of red fox and raccoon dog and to examine their frontal sinuses (*sinus frontalis*) with the help of the methods of comparative anatomy and computed tomography. A total of 71 skulls of adult animals were used, 38 of red fox (22 male and 16 female) and 33 of raccoon dogs (21 male and 12 female). The most distinct morphological features were found in cranium bones, especially in frontal and occipital bones. The mandible was found to have four distinctive morphological features concentrated in the mandibular ramus (*ramus mandibulae*). The frontal sinuses in raccoon dog, unlike in red fox, occupy the entire surface of the zygomatic processes and are divided into small cavities by well-developed osseous partitions that are very thin in red fox. Computed tomography performed for the sagittal skull area revealed two prominent osseous partitions in the median part of the frontal sinuses in raccoon dogs and one partition in red fox. The maximum length, width and height of the frontal sinus cavity are larger in red fox than in raccoon dog ($p < 0.001$).

Key words: raccoon dog, red fox, skull, morphology, computed tomography (CT)

INTRODUCTION

Out of six known raccoon dog (*Nyctereutes procyonoides* Gray) subspecies, *N. p. ussuriensis* migrated to the European part of Russia during the first half of the last century and later spread into other regions of Europe (Kauhala *et al.* 1998). Nowadays, the species is widely distributed across Europe (Mitchel-Jones *et al.* 1999). Raccoon dog reached Lithuania from Belarus in 1948, where it was introduced in 1936, and subsequently the second wave of migration followed from Latvia, where the species was introduced in 1948 (Logminas *et al.* 1982; Prūsaitė *et al.* 1988). Raccoon dog is widely distributed and common in Lithuania (Balčiauskas *et al.* 1999). Fox (*Vulpes vulpes*) and raccoon dog are poorly studied in Lithuania and the records concerned are very outdated (Prūsaitė 1960a, b). Lately, only the diet of both species has been the focus of scientific attention (Baltrūnaitė 2005, 2006).

Anatomical characteristics of different animal species and interspecific differences are determined by the method of morphological analysis. This method is not fully reliable to study peculiarities of the internal skull structure or interspecific differences, because it involves a vast amount of research material. Analysis of

the internal skull structure is greatly facilitated by computed tomography (Alpak 2003). This method helps to make a more precise assessment of normal and affected tissues, which would be impossible to achieve by an ordinary radiological examination (Fike *et al.* 1984). Recently, computed tomography has been also applied in osteological studies.

The aim of our study was to perform analysis of the skull morphology of red fox and raccoon dog and to examine their frontal sinuses (*sinus frontalis*) using the methods of comparative anatomy and computed tomography. Results of analysis of the cranial morphology of these two species could be useful in the studies of fossil bone material and in veterinary forensic investigation. Usually, only skull fragments constitute the material of zooarchaeological and veterinary expertise. The results of this study would contribute to interspecies identification of the discussed species.

MATERIAL AND METHODS

The skulls of foxes and raccoon dogs hunted in different regions of Lithuania from 2003 to 2005 were studied (5 samples were obtained from Jurbarkas district,

20 from Kaunas, 10 – Alytus, 8 – Tauragė, 9 – Kėdainiai, 7 – Utena, 1 – Telšiai and 11 from Zarasai districts). Only intact and bullet-hole-free skulls of adult animals with closed cranial sutures were used in the study. Heads were boiled, soft tissues were removed and skulls were dried. A total of 71 skulls were examined.

Overall, 45 skulls, 25 of red fox (13 male and 12 female) and 20 of raccoon dog (12 male and 8 female), were analysed by the method of comparative anatomy to determine macroscopically visible skull characters. Pictures were taken with a digital Hewlett Packard Photosmart M305 camera.

The frontal sinuses of 20 more skulls, of which 10 belonged to raccoon dog (7 male and 3 female) and 10 to red fox (7 male and 3 female), were analysed employing the computed tomography method. Computed tomography was performed using 6-slice ‘Somatom Emotion 6’ (Siemens) and 16-slice ‘Light speed’ (General Electric) tomographs. Slice thickness was 1 mm, increment 0.5 mm, table feed 2.5 mm, kernel AH 70 and AH 40. Two- and three-dimensional reconstructions were made. Measurements of the frontal sinus cavities were performed, the length was measured between the most distal oral and aboral sinus walls, the height was measured at the sinus apex, whereas the width between the lateral margins of both sinuses located in the zygomatic processes of the frontal bones. For macroscopic analysis of sinuses, the frontal bones of six more skulls, of which three were of red fox (2 males and 1 female) and three of raccoon dogs (2 male and 1 female) were abraded: at a surface level (frontal sinuses were opened after filing down the osseous plate), mid-level (to the median zygomatic processes of the frontal bones) and deep level (the processes of the zygomatic bones were filed down). Cranial description was based on Latin anatomical terms (ICVGAN 1994; Daugnora *et al.* 1998).

A standard statistical approach (mean and standard error, and Student *t*-test for the comparison of means) was used. The comparison of shares of skulls with specific character in both species was done using χ^2 method (2×2 tables). Calculations were done with Statistica for Windows ver. 6.0 (StatSoft 2004).

RESULTS

1. Macroscopic cranial analysis. The external sagittal crest (*crista sagitalis externa*) is more pronounced in raccoon dog and markedly extends into the frontal bone, but at the margin of the interparietal bone (*os interparietale*) this process is well developed in both red fox and raccoon dog. The external occipital crest

(*crista occipitalis externa*) in raccoon dog is more prominent than in red fox and divides the squamous part of the occipital bone (*squama occipitalis*) into two equal parts. The condylar canal (*canalis condylaris*) in red fox is double, whereas that in raccoon dog single. Eight out of 25 red fox skulls (accounting for 32%) possessed an open condylar canal in the ventral condylar fossa (*fossa condylaris ventralis*) (Fig. 1, B), the same was true for 3 out of 20 raccoon dog skulls (15%), but the difference was not significant ($\chi^2 = 1.74, p = 0.18$). The paracondylar processes (*processus paracondylaris*) in red fox extend ventrolaterally, whereas those in raccoon dog ventrally. The basilar part of the occipital bone in red fox (*pars basilaris*) is wider than in raccoon dog (Fig. 1, A). Both species have the foramen magnum (*foramen magnum*) of an oval shape, whereas the ventral margin of the foramen is V-shaped in red fox and more U-shaped in raccoon dog (Fig. 1, C). The ethmoidal foramen (*foramen ethmoidale*) is double in red fox and single in raccoon dog. The zygomatic processes of the frontal bones (*processus zygomaticus ossis frontalis*) in raccoon dog run in ventrolateral direction, whereas those in red fox in lateral. The frontal processes of the zygomatic bones (*processus frontalis ossis zygomatici*) in raccoon dog are much better pronounced than in red fox. The orbital sur-

Figure 1. The ventral surface of raccoon dog (left) and red fox (right) skulls. A – the basilar part of the occipital body is wider in red fox, B – the open condylar canal in the ventral condylar fossa, C – the V-shaped ventral margin of the foramen magnum in red fox and U-shaped in raccoon dog.

face (*facies orbitalis*) of the lacrimal bone is ventrally wider in raccoon dog than in red fox. *Insicura sphenoidalis* between the wings of the vomer (*ala vomeris*) is wider in raccoon dog than in red fox.

The end of the angular process of the mandible (*processus angularis*) in raccoon dog is blunt, whereas that in red fox is pointed (Fig. 2, B). The ventral margin of the mandible ramus (*ramus mandibulae*) in raccoon dog has a deep indentation, which is not marked in red fox (Fig. 2, A). The masseteric fossa (*fossa masseterica*) in red fox occupies nearly the entire surface of the ramus, whereas that in raccoon dog runs to the cervical line of the molar teeth (Fig. 2, C). The aboral margin of the mandible ramus located between the angular and articular processes in raccoon dog is arch-shaped, whereas in red fox it is hook-shaped.

2. Morphological analysis of frontal sinuses. Examination of the frontal sinus area in raccoon dog showed well-defined osseous partitions (Fig. 3), which are very thin in red fox (Fig. 4).

The frontal sinuses in raccoon dogs nearly fully overlap with the zygomatic processes, whereas in red fox no overlap was observed. Examination of the frontal bone area below the level of zygomatic processes revealed no clear morphological distinctions between the two species.

Figure 2. The lateral surface of the right mandible of raccoon dog (top) and of red fox (bottom), A – the ventral indentation of the mandible ramus, B – the angular process is blunt in raccoon dog and pointed in red fox, C – the masseteric fossa.

The serial skull sagittal sections were made with the help of computed tomography. Raccoon dog has two osseous partitions in the median part of the frontal sinuses (Fig. 5). Red fox has only one apparent partition (Fig. 6).

3. Osteometric analysis of frontal sinuses. The maximum lengths of the frontal sinuses found for red fox and raccoon dog were 40.3 ± 3.93 mm and 31.52 ± 1.98 mm; widths – 23.92 ± 1.42 mm and 18.51 ± 1.83 mm; heights – 10.44 ± 1.33 mm and 8.40 ± 0.94 mm, respectively. All measurements in red fox were found to be larger than in raccoon dog ($p < 0.001$).

Figure 3. The frontal sinuses of raccoon dog. The arrow indicates the osseous partitions.

Figure 4. The frontal sinuses of red fox. The arrow indicates the osseous partitions.

Figure 5. The sagittal section of the raccoon dog skull (computed tomography). The arrow indicates the osseous partitions.

Figure 6. The sagittal section of the red fox skull (computed tomography). The arrow indicates the osseous partitions.

DISCUSSION

Though studies on the skeletal morphology of wild predators are carried out on a rather large scale, we failed to find data of comparative approach to the skull morphology of red fox and raccoon dog. Studies on skull osteometry of red fox and raccoon dog were carried out in Lithuania (Jurgelėnas & Daugnora 2005), but comparison was not made.

Craniological studies on different raccoon dog subspecies were carried out in Finland (Kauhala *et al.* 1998). Japanese scientists compared the skulls of badgers (*Meles meles*) and raccoon dogs belonging to different families (Hidaka *et al.* 1998). Comparative craniological analysis was done for several predator species: dog, cat, badger, marten (*Martes foina*) and otter (*Lutra lutra*) (Karan *et al.* 2006). Studies of skull morphology of red fox (Sjøvold 1977) and variations in skull morphology of farmed arctic fox (*Alopex lagopus* L.) (Welling *et al.* 2001) were also conducted. Morphological variations, arrangement and pathological deformities of the dental structure of red fox were studied in Poland (Szuma 2000, 2002). Variations in the tooth structure of predator representatives were also analysed (Meiri *et al.* 2005). Israeli scientists also studied the impact of diet on the size of badger and red fox skulls (Yom-Tov *et al.* 2003).

Our comparative analysis revealed a well-pronounced external sagittal crest in raccoon dog. This anatomical peculiarity in raccoon dog was also reported by Hidaka *et al.* (1998). Our data also confirm a double condylar canal in red fox, reported by Sjøvold (1977). An open condylar canal was reported in red fox (Sjøvold 1977), but our results indicate that this canal was found in only 32% of red fox and 15% of raccoon dog skull specimens.

We found that the paracondylar processes in raccoon dog are directed ventrally, whereas in red fox ventrolaterally. The ventral direction of paracondylar processes is also observed in dogs, cats, badgers and martens (Karan *et al.* 2006). We also found that both species investigated possess an oval-shaped *foramen magnum*. The same shape for raccoon dogs was reported by Hidaka *et al.* (1998), whereas for dogs, cats, badgers and martens by Karan *et al.* (2006).

Well-articulated zygomatic processes of the frontal bones are typical of dogs, badgers and martens, whereas in cats they extend to the frontal processes of the zygomatic bones (Karan *et al.* 2006). These processes were also well developed in the species involved in our study, but their direction was different, ventrolateral in raccoon dog and lateral in red fox. A deep indentation in the ventral margin of the mandible ramus in raccoon dog was reported by Hidaka *et al.* (1998). The same indentation was also found in the skulls examined in our study. The accessory mental foramina in red fox were reported by Sjøvold (1977), but they were not confirmed by our data.

In classical veterinary literature, the frontal sinuses in domestic dog have two parts: lateral and median. The median part of the frontal sinus has no definite location; therefore various structural variations are possible depending on the shape of the skull (Nickel *et al.* 1987). The lateral part of the sinus in long-muzzled breeds is relatively large and that in short-muzzled dogs is small, whereas the median part is strongly reduced or absent (Evans & Christensen 1979).

The skulls of red fox and raccoon dog differ in their length; those of red fox are longer as compared to the skulls the latter species (Jurgelėnas & Daugnora 2005). Macroscopic examination of the frontal sinuses after the osseous plate was removed revealed osseous par-

titions that divide frontal sinuses into separate small cavities. These osseous partitions are very well pronounced in raccoon dog. A similar structure of frontal sinuses is characteristic of Japanese wolf and Akita dogs (Hideki *et al.* 1997).

After the abrasion of the frontal bone area to the median part of the zygomatic processes, we found that the frontal sinuses in raccoon dog nearly fully overlap with zygomatic processes. In contrast, the zygomatic processes in red fox are not interrupted by the frontal sinuses, which was confirmed by macroscopic and computed tomography examination. The overlap of frontal sinuses with zygomatic bones was reported in Beagle dogs by Fike *et al.* (1984), as well as in Akita dogs and Japanese wolves (*Canis hodophilax*) by Hideki *et al.* (1997).

Our results on differences in cranial morphology of red fox and raccoon dog can be used in the studies of fossil bone material, veterinary forensic investigations and in zoological research. In the first case, computed tomography is recommended as a method that does not require to destroy osseous material.

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USŪRINIO ŠUNS (*NYCTEREUTES PROCYONOIDES*) IR LAPĖS (*VULPES VULPES*) KAUKOLIŲ MORFOLOGINIS TYRIMAS

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SANTRAUKA

Šio darbo tikslas – atlikti rudųjų lapių ir usūrinių šunų kaukolių morfologinę analizę, ištirti kaktikaulio ančius (*sinus frontalis*) palyginamosios anatomijos ir kompiuterinės tomografijos metodais. Viso tyrimui panaudota 71 suaugusių žvėrelių kaukolių kaukolė, rudųjų lapių 38 (patinų 22, patelių 16), usūrinių šunų 33 (patinų 21, patelių 12). Atlikus morfologinę analizę ryškiausi ypatumai nustatyti kiaušo kauluose, ypač pakauškaulio ir kaktikaulio kauluose. Apatinis žandikaulis turi keturis ryškius morfologinius ypatumus, esančius apatinio žandikaulio šakoje (*ramus mandibulae*). Usūriniais šunims kaktikaulio ančiai užima beveik visą skruostinių ataugų plotą, rudosioms lapėms kaktikaulio ančiai į šias ataugas neįsiterpia. Usūriniais šunims kaktikaulio ančius į nedideles ertmes suskirsto gerai išreikštos kaulinės pertvaros, rudųjų lapių šios pertvaros labai plonos. Sagitalinėje kaukolės plokštumoje padarytos kompiuterinės tomogramos usūriniais šunims parodė dvi, rudosioms lapėms vieną ryškią pertvarą kaktikaulio ančių vidurinėje dalyje. Išmatavus kaktikaulio ančių ertmės didžiausią ilgį, aukštį ir plotį, rudųjų lapių visi šie matmenys yra didesni nei usūrinių šunų ($p < 0,001$).

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