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Research Article

Mandible Size and Shape of the Red Fox (*Vulpes vulpes*) and Golden Jackal (*Canis aureus*)

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Abstract | The carnivore mandible as a lower part of the facial skeleton has a unique morphological characteristic and importance for the taxonomy. This study aimed to investigate size and shape differences of the mandible of the red fox and golden jackal. The research included 17 adult red fox and golden jackal mandibles from B&H. The morphometric analysis was performed on the 11 measurements and geometric analysis evaluates shape variation between two species with ten landmarks. The study revealed that the mandible of the jackal was longer and of massive bone compared to fox mandibles. The most significant difference was the total length, the indentation between the condylar and the angular process, and the measurement from the aboral alveolus of the canine tooth to the condylar process. The molar teeth parameters show similar values, especially the carnassial teeth. PC1 and PC2, which account for the highest variation, account for 68.8% of the total variation. The present study provided morphometric and geometric data on red fox and golden jackal mandibles, which can be a significant resource in the taxonomy of carnivores.

Keywords | Craniometric, Geometric, Carnivores, Morphology

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INTRODUCTION

The red fox (*Vulpes vulpes*) and golden jackal (*Canis aureus*) both belong to the wild canid species present in Bosnia and Herzegovina (B&H). The golden jackal resembles a small wolf, with a more slender body, golden/yellowish fur and a long pointed muzzle. The European population ranges from the Balkans towards the Alps and, according to the data from 2014, the population in B&H was estimated to amount to 200-300 individuals (Jhala and Moehlman, 2004; Hadžiomerović et al., 2015). In 4 years the population increased substantially especially in the northern parts of B&H (Trbojević et al., 2018). The red fox has a smaller, long body, short legs, long ears and a long bushy tail. They adapt to a wide range of habitats, from tundra to desert, with huge urban populations in many European cities (Aulagnier et al., 2008). Cranial morphometry is crucial for taxonomy and has a major impact on the management and maintenance of the species. Several studies have been conducted regarding the craniometrics of carnivores, including dog (Onar, 1999; Ilgun et al., 2021), wolf (Okarma and Buchalczyk, 1993; Milenković et al., 2010; Khosravi et al., 2012; Gürbüz et al., 2020), fox (Gomes and Valente, 2016; Munkhzull et al., 2018; Magalhães et al., 2019), golden jackal (Monfared, 2013; Rezić et al, 2017) and lynx (Gomerčić et al., 2010; Dayan et al., 2017). Most of these studies include the mandible as the lower part of the facial skeleton. The carnivore mandible is characterized by strong teeth, a deep masseteric fossa, several mental foramina and a unique angular process (König and Liebich, 2004). Some recent investigations have used geometric analysis to reveal the shape differences rather than the size differences between the samples. This method focuses on analysis of data from

the position of the homologous landmarks which offer more appropriate data when compared with traditional morphometric studies (Slice, 2007; Gundemir et al., 2021).

The significant diversity of the carnivores' size, diet, behavior, and locomotion is reflected in their skull shape and size (Gittleman, 1985). In addition, geographical distribution reveals variations in the carnivores' skull morphometry (Meiri et al., 2005). The study aimed to investigate the morphometric aspects of the red fox and golden jackal mandibles from B&H, and to reveal their shape differences using the geometric morphometric method.

MATERIALS AND METHODS

Animals

The mandibles of 11 jackals and 6 red foxes were used in this study. The study materials were obtained from the Osteology Museum at the Department of Anatomy of the Veterinary Faculty, University of Sarajevo. The mandibles were collected between 2015 and 2017 after autopsy, so no living animal was killed to obtain any of the materials used in the study. Therefore, the study did not present any ethical concerns. The muscles, fascia and other structures were dissected, boiled and macerated to remove all fat. In the final phase, the mandibles were bleached with 3% hydrogen peroxide (Choudhary and Singh, 2015).

Osteometric analysis

A total of eleven measurements were taken using an electronic digital caliper (0.1 mm) and the results were expressed as the mean and standard deviation (SD). The measurement parameters were selected according to a previous study (Von Den Driesch, 1976; Avdić et al., 2013; Munkhzull et al., 2018) and the description is given in Figure 1. The independent t-test was used to reveal the osteometric measurement differences between the 2 groups. SPSS 22 package program was used for statistical analysis.

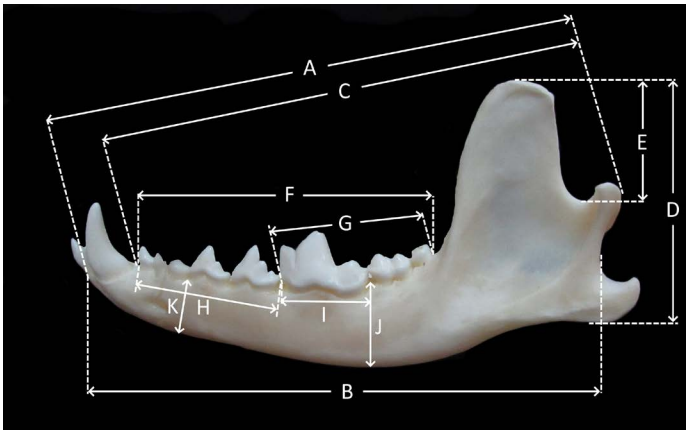

Figure 1: Parameters – jackal mandible.
A. Total length; B. Length indentation between the condyle and angular process; C. Length condyl-aboral C alveolus; D. Height of the vertical ramus; E. Height of the coronoid process; F. Length of the cheektooth row M3-P1; G. Length of the molar row; H. Length of the premolar row P1-P4; I. Length of the carnassial alveolus; J. Height of the mandible behind M1; K. Height of the mandible P2-P3

Geometric analysis

For the geometric morphometric analysis, the mandibles were photographed with a digital camera (Canon SX510 HS) from the same position and distance. The images obtained were converted from "jpg" files into a "TPS" file using the tpsUtil (Version 1.78) program. The ten landmarks shown in Figure 2 were placed using the tpsDig2 (Version 2.31) program (Rohlf et al., 2015). The data were saved as a "text" file and the MorphoJ (version 1.07a) program was used to visualize shape differences between red fox and jackal mandibles using discriminant function analysis. Principal component analysis (PCA) was performed to analyze the geometric analysis results statistically. Past (version 2.17c) statistical analysis program was used for PCA analysis. PC values explaining the highest variation were determined after the analysis. The results are given in tables. The terminology used in the study is in accordance with current anatomical terminology (NAV, 2017).

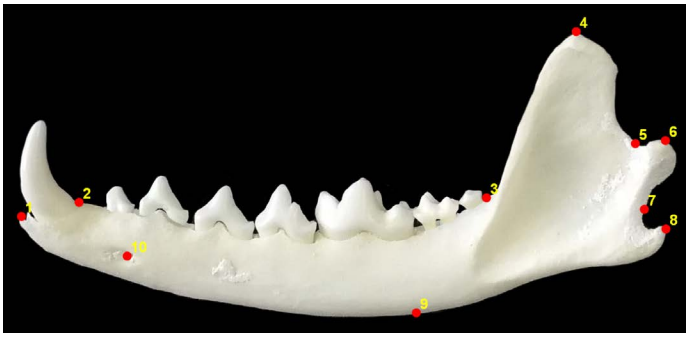

Figure 2: The points of the landmarks on red fox mandible.
1. Anterior end of the corpus mandibula; 2. Posterior edge of the canine alveolus; 3. Posterior edge of the teeth row; 4. Top of the coronoid process; 5. Level of the mandibular insicure; 6. Caudal edge of the condylar process; 7. Level between the condylar process and angular process; 8. Caudal edge of the angular process; 9. Ventral margin of the corpus mandibula at the level of posterior of the 1st molar alveolus; 10. Level of the first mental foramen

RESULTS AND DISCUSSION

The mandible consists of right and left halves, connected medially by a fibrocartilaginous symphysis (*synchondrosis intermandibularis*) in carnivores. Both halves are divided into a horizontal body (*corpus mandibulae*) and a vertical part (*ramus mandibulae*). The present study revealed that the mandible of the jackal was longer and of massive

bone in comparison with fox mandibles, which is clearly indicated by the measurements in Table 1. The most significant difference was the total length (A), the indentation between the condylar and the angular process (B), and the measurement from the aboral alveolus of the canine tooth to the condylar process (C). The total cheek tooth row (F) was longer in jackals due to their premolars, while the molar teeth parameters show similar values, especially the carnassial teeth (I). The coronoid process (E) and the ramus mandibulae (D) were larger in jackals with height parameters of 19.4 mm and 42.6 mm, while the fox coronoid and ramus heights were 16.7 mm and 35.6 mm, respectively. The molar part of the mandible body was slightly wider in jackal with a more convex ventral margin. The two mental foramina at the level of the P1 and P3 were present in fox mandible in all specimens, while jackal mandible has single foramen in the level of the second premolar.

Table 1: The measurements (mm) of the mandibles in red fox and jackal.

Parameters	Red fox		Jackal		P value
	N	Mean ± SD	N	Mean ± SD	
A	22	102.1 ± 4.8	12	117.7 ± 2.4	<.001
B	22	98.3 ± 4.8	12	113.2 ± 3.6	<.001
C	22	90.6 ± 4.3	12	103.7 ± 2.2	<.001
D	22	35.6 ± 2.2	12	42.6 ± 1.4	<.001
E	22	16.7 ± 1.4	10	19.4 ± 1.07	<.001
F	22	58.03 ± 2.5	10	64.3 ± 1.5	<.001
G	22	25.7 ± 1.04	12	25.4 ± 3.1	.991
H	22	32.3 ± 1.8	10	38.9 ± 3.6	.003
I	22	14.1 ± 0.6	10	14.3 ± 1.2	.733
J	22	13.1 ± 0.7	10	16.6 ± 1.6	.001
K	22	11.3 ± 0.6	10	14.3 ± 1.6	.006

The shape variation between red fox and golden jackal mandible was determined with 10 landmarks as shown in Figure 2. The differentiation between red fox and jackal mandible was identified in several positions of the landmarks (Figure 3A). The extension and the direction of the differentiations between fox and jackal mandible were shown in Figure 3B. The ventral margin of the mandible body was more convex in the jackal at the level of landmark 9. The cheek tooth row was longer in fox mandible as shown in landmark 3. The condylar process was more massive and wider in the jackal when compared with the fox which is identified at the level of landmarks 5 and 6. Also, landmark 8 identified a stronger angular process in the jackal mandible.

PCA results are shown in Table 2. In total, 10 principal components were found. PC1 and PC2, which account for the highest variation, account for 68.8% of the total variation.

Table 2: PCA result of the mandibles in red fox and jackal.

PC	Eigenvalue	% variance
1	0,000239237	39,885
2	0,000173446	28,916
3	7,47412E-05	12,461
4	4,02184E-05	6,7051
5	3,17053E-05	5,2858
6	1,70342E-05	2,8399
7	1,27579E-05	2,1269
8	8,62367E-06	1,4377
9	2,05615E-06	0,34279
10	1,2878E-33	2,147E-28

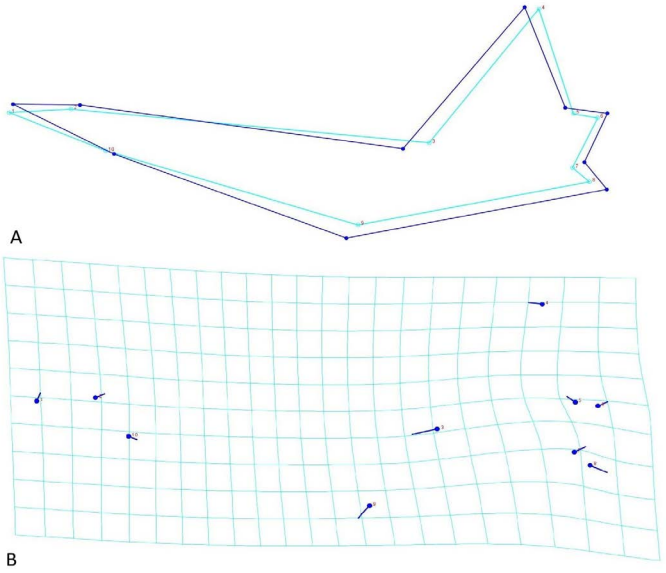

Figure 3: Geometric morphometric analysis.
A. Lineal representation of the shape differences between red fox and golden jackal; B. Landmark representation of shape differences of mandible between red fox and golden jackal

Mandible morphology is closely associated with food habits and biomechanical performance. The carnivore mandible, along with its teeth, has been developed for tearing meat and biting with great force. The osteometric analysis of the mandible showed significant differences between carnivores, and even within the same species. The present study included 11 measurements of a total of 17 adult red fox and golden jackal mandibles from BandH. A detailed osteometric analysis of the red fox and golden jackal mandible has been reported in several studies. The total length of the red fox mandible was 9.6 ± 3.3 cm and corsac fox 9.1 ± 0.8 cm according to Munkzul et al. (2018), in the hoary fox 99.67 ± 1.14 mm according to Magalhaes

et al. (2019), in golden jackals 11.2 ± 3.46 cm according to Monfared (2013). In other carnivores such as the lynx, the total length of the mandible was 102.6±5.2 mm according to Gomerčić (2010), 93.45 ± 2.98 mm according to Dayan et al. (2017) and in the wolf 190.4 ± 7.7 mm according to Okarma and Buchalczyk (1993). Our study revealed a significant difference between the total length of the fox (102.1 ± 4.8 mm) and jackal (117.7 ± 2.4 mm) mandibles, but this was similar to previous studies. Also, the total height of the vertical ramus was reported in two fox species as 3.7 ± 0.1 cm and 3.2 ± 0.2 cm (Munkhzull et al., 2018) in the golden jackal as 6.0 ± 0.58 cm (Monfared, 2013), in the lynx as 38.92 ± 1.63 mm, 44.1 ± 3.2 mm, (Gomerčić et al., 2010; Dayan et al., 2017) and in the wolf as 76.3 ± 3.8 mm (Okarma and Buchalczyk, 1993). The present study revealed similar values as in foxes from Mongolia (35.6 ± 2.2 mm), while the total height for the jackal was 42.6 ± 1.4 mm, which was significantly smaller compared with the study of jackals from Iran. This value should be taken with caution since that study measured the maximum mandibular height from the ventral margin of the mandible, while our study measured the total height of the vertical ramus. The total cheek tooth row was longer in the red fox in comparison with the corsac fox, at 5.9 ± 0.2 and 5.0 ± 0.4 cm (Munkzul et al., 2018). Our findings were similar to the results for the red fox (58.03 ± 2.5 mm), but for the golden jackal the values were higher (64.3 ± 1.5 mm). Surprisingly, the size of the carnassial alveolus was similar in the present study in fox and jackal, and in accordance with a previous investigation of the red fox but more than double the size in the wolf, at 29.3 ± 1.2 mm (Okarma and Buchalczyk, 1993).

CONCLUSIONS AND RECOMMENDATIONS

The present study provides morphometric and geometric data on red fox and golden jackal mandibles, which can be a significant resource in the taxonomy of carnivores.

NOVELTY STATEMENT

The difference between the red fox and golden jackal mandible were revealed by traditional (osteometric) and developing technology (geometric) and obtained values can be a reference for future morphological and clinical studies.

AUTHOR'S CONTRIBUTION

All authors have equally contributed to this manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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