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Contribution to the knowledge of variability of the penis bone (baculum) in *Canis lupus* from Slovakia (Carnivora: Canidae)

Príspevok k poznatkom o variabilite penisovej kosti (bakula) *Canis lupus* zo Slovenska (Carnivora: Canidae)

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Abstract. Despite the large number of studies on variability of the baculum (os penis) in several species of carnivores, there are very little detailed data on the Eurasian wolf (*Canis lupus*). The aim of this study was to investigate quantitative characteristics of the baculum size and relationships between the measurements and to describe variability in baculum morphology of individuals from Slovakia (Western Carpathians). The study presents morphological variation in twelve traits of the baculum based on an analysis of 24 mature males collected in Slovakia during the years 1961–1984. The descriptive statistics revealed that the bacula were variable in size. Moreover, a statistical analysis showed a strong positive correlation between several traits, mainly for the weight of the baculum, laterolateral thickness (proximal), dorsoventral thickness (middle), laterolateral thickness (distal) and width of the *sulcus urethralis*. Moreover, baculum size was correlated with body length in adult males. The positive correlation between the length and width dimensions of the penis bone, especially of the proximal and distal end, could explain their relations with protection of the bone and urethra from fracture during copulation.

Key words. Anatomy, variability, os penis, Eurasian wolf, Slovakia, Carpathians.

INTRODUCTION

The baculum (os penis) is an extraskeletal bone located in the glans tissue at the distal end of the penis, dorsal to the urethra of members in several mammalian orders (e.g. Kratochvíl & Kratochvíl 1976, Abramov 2002, Larivière & Ferguson 2002, Baryshnikov et al. 2003, Ferguson & Larivière 2004, Dixson & Anderson 2004, Dixson et al. 2004, Dyck et al. 2004, Krawczyk & Malecha 2009, Malecha et al. 2009, Krawczyk et al. 2011, Sharir et al. 2011, Schwery et al. 2011, etc.). Moreover, its proximal end abuts the distal end of the *corpus cavernosum*. According to Sharir et al. (2011), morphology and size of the baculum vary greatly among species, so that its species-specific shape is often used as a diagnostic taxonomic character.

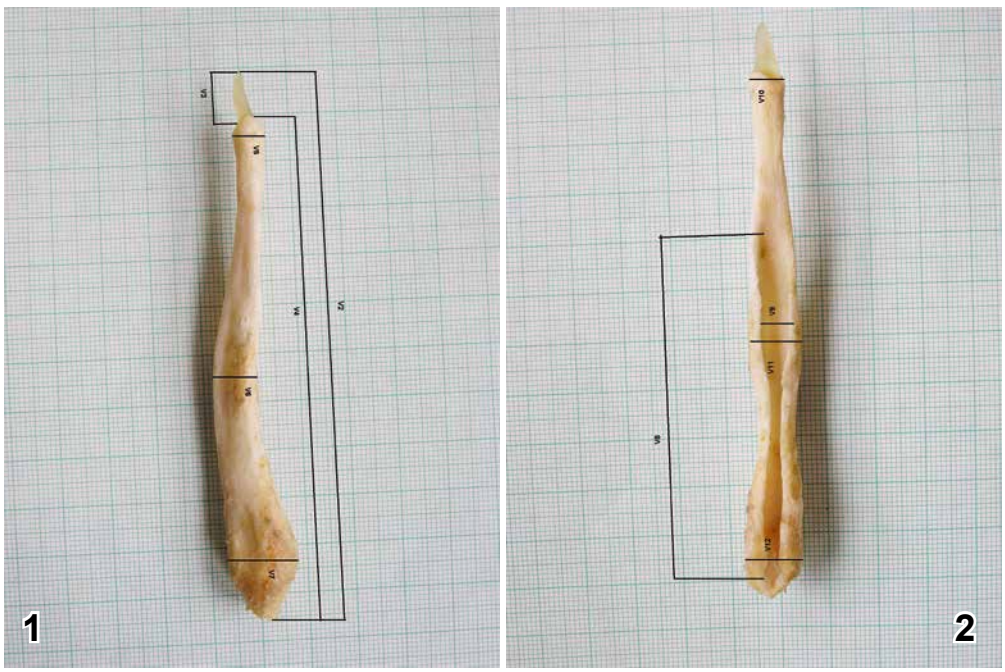
Based on the aforementioned studies, it can be concluded that there is no single interpretation of its function. For instance, the baculum can play a several structural and functional roles across species e.g. in mechanical support; protection of the urethra from compression; enabling protracted copulations; stimulation of the female reproductive tract; provision of information about male size or quality during intromission; reproductive isolation etc. Data on the anatomy of the baculum in the family Canidae were published by several authors (Burt 1960, Harrison

& Bates 1989, Larivière & Ferguson 2002, Dixson & Anderson 2004, Gültiken et al. 2004, Sharir et al. 2011, Čanády 2013, etc.). Sharir et al. (2011) showed that in the dog it serves as a channel for the urethra, in the wolverine it is forked at the tip and in the raccoon it is s-shaped and terminates in an enlarged condyle.

On the other hand, morphological variability of the baculum in the Slovakian population of *Canis lupus* has not been investigated so far. The present study contributes to the knowledge of quantitative characteristics of the size of the baculum and describes its variability.

MATERIAL AND METHODS

For the morphological analysis of the baculum, 24 specimens of penis bones from adult males of *C. lupus* were available. The bones used in this study were taken from the collection of the Department of Natural History of the Šariš Museum in Bardejov, Slovakia. The individuals were collected near the town of Bardejov (north-eastern Slovakia, 49° 17' N, 21° 17' E, West Carpathians). The bones were collected, determined and prepared by Tibor Weisz, a former curator of the Museum (Panigaj 1985), during autumn and winter seasons (from November to March) in the years 1961–1984. Information about the locality, date and age were obtained from the catalogue and protocol cards attached to the evidence from the collections of the Museum. Sexually mature and immature individuals were identified according to several skull traits. We also investigated whether the size of the baculum was correlated with body length (LC). The data on body length were obtained from catalogue cards (Čomor & Čanády 2011).



Figs. 1, 2. Measurements taken in the baculum of *Canis lupus*. 1 – lateral view. 2 – ventral view.
Obr. 1, 2. Merané rozmery na penisovej kosti *Canis lupus*. 1 – bočný pohľad. 2 – ventrálny pohľad.

Table 1. Descriptive statistics of measured characters of the baculum (os penis); weight in grams, others in millimetres. Legend: n – number; min–max – range margins; M – mean; SD – standard deviation; CV – coefficient of variance

Tab. 1. Základná štatistika meraných znakov penisovej kosti (os penis); hmotnosť v gramoch, ostatné v milimetroch. Vysvetlivky: n – počet; min–max – okraje rozpätia; M – priemer; SD – štandardná odchýlka; CV – koeficient variancie

character	n	min–max	M±SD	CV
V1 – weight of the baculum	22	0.80–5.70	2.48±1.50	58.30
V2 – length of the baculum with cartilaginous end	2	109.20–109.70	109.40±0.36	0.32
V3 – length of the cartilaginous end	2	10.31–11.34	10.83±0.73	6.73
V4 – length of the baculum without cartilaginous end	24	68.11–110.50	91.53±12.11	13.23
V5 – dorsoventral thickness – distal	24	2.12–6.13	3.50±1.02	29.12
V6 – dorsoventral thickness – middle	24	3.82–9.03	6.27±1.42	22.58
V7 – dorsoventral thickness – proximal	24	4.85–13.59	8.26±2.10	25.44
V8 – length of sulcus urethralis	24	57.98–82.66	70.27±7.81	11.12
V9 – width of sulcus urethralis	24	2.92–5.18	4.10±0.61	14.87
V10 – laterolateral thickness – distal	24	2.01–6.74	4.26±1.14	26.66
V11 – laterolateral thickness – middle	24	5.04–9.97	7.04±1.35	19.10
V12 – laterolateral thickness – proximal	24	5.21–10.91	7.25±1.42	19.60

Baculum measurements included twelve variables. The length of penis bones was taken with a digital calliper with the accuracy of 0.01 mm, and their weight was taken with digital scales to the nearest 0.01 gram. All specimens were measured and evaluated following the studies by Gültiken et al. (2004) and Čanády (2013): V1 – weight of the baculum, V2 – length of the baculum including the cartilaginous end, V3 – length of the cartilaginous end, V4 – length of the baculum (without cartilaginous end), V5 – dorsoventral thickness (distal), V6 – dorsoventral thickness (middle), V7 – dorsoventral thickness (proximal), V8 – length of the sulcus urethralis, V9 – width of the sulcus urethralis, V10 – laterolateral thickness (distal), V11 – laterolateral thickness (middle), V12 – laterolateral thickness (proximal) (Figs. 1, 2).

The obtained dataset was evaluated using the following statistical characteristics: minimum and maximum (min–max), mean (M), standard deviation (SD) and coefficient of variation (CV). The normal distribution was tested by the D'Agostino-Pearson omnibus test and the Shapiro-Wilk normality test. The principal component analysis (PCA) was performed for the dataset of measurements excluding weight of the baculum to discover structures in data. Before the analysis, the measurements were log-transformed to reduce intra-sample variation and to improve normality.

Statistical comparison of the data was carried out using standard methods (McDonald 2008). All analyses were performed using MS Excel 2003 for Windows XP and the statistical analysis system GraphPad Prism version 5.01 (GraphPad Software, Inc., San Diego, California, USA). The principal component analysis (PCA) was carried out using the Statistical Software Origin Pro 8.6. (Microcal Software Inc., Northamptom, USA).

RESULTS AND DISCUSSION

Descriptive statistics of the studied variables from Slovakia are presented in Table 1. Overall, values of the CV were higher in several baculum traits, suggesting a generally larger variability, which is also indicated by the PCA factors. The results showed that the most variable parts of the baculum were dorsoventral thickness (distal), laterolateral thickness (distal), dorsoventral thickness (proximal) and dorsoventral thickness (middle). On the contrary, the length of the baculum

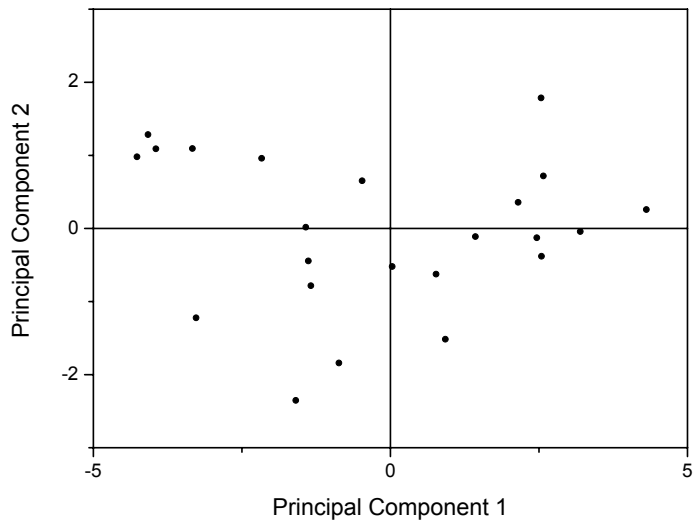


Fig. 3. Results of the PCA for body length and baculum variables. The ordination diagram shows the position of individual scores on PC1 and PC2.
Obr. 3 Výsledok PCA analýzy pre dĺžku tela a merané znaky penisových kosti. Graf znázorňuje hodnoty pre skóre prvých (PC1) a druhých (PC2) hlavných komponentov.

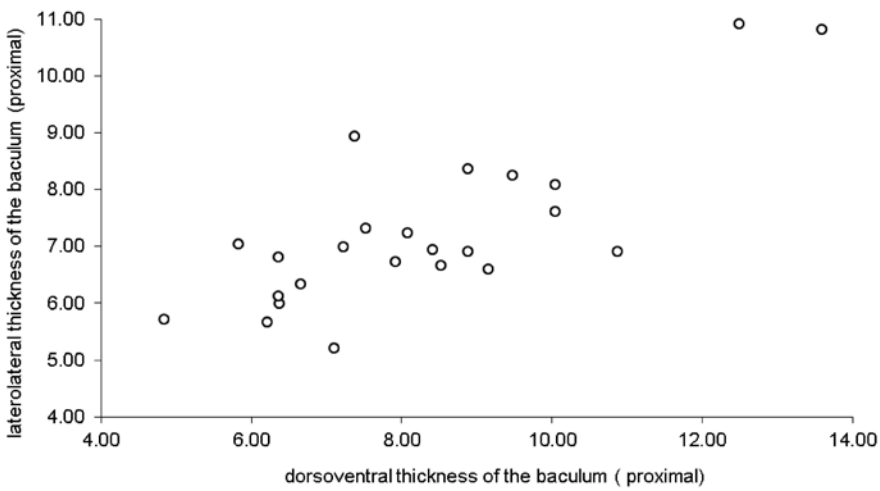


Fig. 4. Relationship between the dorsoventral thickness (proximal) and the laterolateral thickness (proximal) of the baculum.
Obr. 4. Vzájomný vzťah medzi dorzoventrálnou hrúbkou (proximálna časť) a laterolaterálnou hrúbkou (proximálna časť) penisovej kosti.

Table 2. Correlation matrices of the baculum (os penis) variables and body length. The upper number indicates the correlation coefficient values; the lower number represents the P-value. For abbreviations of the body length and baculum variables see Table 1

Tab. 2. Korelačná matica medzi meranými znakmi baculum (os penis) a dĺžky tela. Horné číslo predstavuje hodnotu korelácie, spodné číslo hodnotu P. Skratky rozmerov dĺžky tela a bacula viď tab. 1

	LC	V1	V4	V5	V6	V7	V8	V9	V10	V11
V1	0.853									
	0.001									
V4	0.646	0.871								
	0.001	0.001								
V5	0.764	0.843	0.681							
	0.001	0.001	0.001							
V6	0.838	0.905	0.797	0.746						
	0.001	0.001	0.001	0.001						
V7	0.745	0.851	0.737	0.686	0.721					
	0.001	0.001	0.001	0.001	0.001					
V8	0.476	0.737	0.876	0.605	0.644	0.576				
	0.050	0.001	0.001	0.010	0.001	0.010				
V9	0.435	0.421	0.401	0.398	0.514	0.355	0.167			
	0.050	0.050	NS	NS	0.050	NS	NS			
V10	0.464	0.451	0.204	0.676	0.276	0.414	0.301	0.042		
	0.050	0.050	NS	0.001	NS	0.05	NS	NS		
V11	0.790	0.854	0.765	0.719	0.810	0.789	0.617	0.376	0.320	
	0.001	0.001	0.001	0.001	0.001	0.001	0.010	NS	NS	
V12	0.853	1.000	0.871	0.843	0.905	0.851	0.737	0.421	0.451	0.854
	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.050	0.050	0.001

without cartilaginous end, the length of sulcus urethralis and the width of sulcus urethralis were the least variable. These results are consistent with those obtained in the red fox (Čanády 2013). Schwery et al. (2011) and Čanády (2013) showed that a lower variability in the length of the penis bone and a greater variability in its thickness (together with positive correlations between the measured parts of the baculum) can play an important role in increasing strength of the bone and preventing its possible fracture during copulation. Some data on the length of the baculum in several species of Canidae were shown by Burt (1960), Larivière & Ferguson (2002) and Dixson et al. (2004). A comparison of our data with the published results shows that the length of the baculum in *C. lupus* from Slovakia was very similar to the previous record. Values of the principle component analysis (PCA) are given in Tables 2, 3 and Fig. 3. The analysis confirmed a strong correlation between several variables (Table 2), but mainly for the weight of the baculum and laterolateral thickness (proximal) ($n=24$, $r=1.000$, $P<0.001$), weight of the baculum and dorsoventral thickness (middle) ($n=24$, $r=0.905$, $P<0.001$), and dorsoventral thickness (middle) and laterolateral thickness (proximal) ($n=24$, $r=0.905$, $P<0.001$). Moreover, baculum size was strongly correlated with body length (LC) of sexually mature males (Table 2).

The obtained results showed the first two principal components (PC1–PC2) to explain 79.46% of the variance. The first principal component (PC1) explained 69.50% of the total variance and was correlated mainly with the weight of the baculum (V1, $r=0.355$, $R^2=0.126$), latero-lateral thickness (proximal) (V12, $r=0.355$, $R^2=0.1126$) and dorsoventral thickness (middle)

(V6, r=0.331, R^2=0.110). The second factor (PC2) accounted for 9.96% of variance only and was correlated with laterolateral thickness (distal) (V10, r=0.775, R^2=0.601). Finally, the third principal component (PC3) accounted for 8.22% of variavce and was highly associated with the width of the sulcus urethralis (V9, r=0.660, R^2=0.436, Table 3).

The positive correlation between the length and width dimensions of the penis bone, especially of the proximal and distal end (Figs. 4, 5), could explain their relations with protection of the bone and urethra from fracture during copulation (Baryshnikov et al. 2003, Schwery et al. 2011, Čanády 2013). Similarly, Schwery et al. (2011) assume that increasing thickening might at least partially explain a continued increase in bacular weight after the growth in length stagnates.

Based on our results, it can be concluded that the penis bone is variable in size and structure in the Slovakian population of *Canis lupus*. These results are in accordance with the data obtained in several species of carnivores by other authors (Abramov 2002, Larivière & Ferguson 2002, Baryshnikov et al. 2003, Ferguson & Larivière 2004, Malecha et al. 2009, Krawczyk et al. 2011).

Sharir et al. (2011) confirmed that the canine baculum is long and tapers in the proximo-distal direction. The proximal end (base of the baculum) located in the body of the penis just caudal to the bulbus glandis is quite broad. It is thicker dorso-ventrally than from side to side. The distal end (tip) of the bone is small in diameter and it is extended by a slightly curved fibrocartilagenous projection. The proximal two thirds of the bone are indented ventrally by a distinct groove in which the penile urethra and corpus spongiosum reside. During erection, the corpus spongiosum receives the greater part of the blood through the artery of the bulb of the penis.

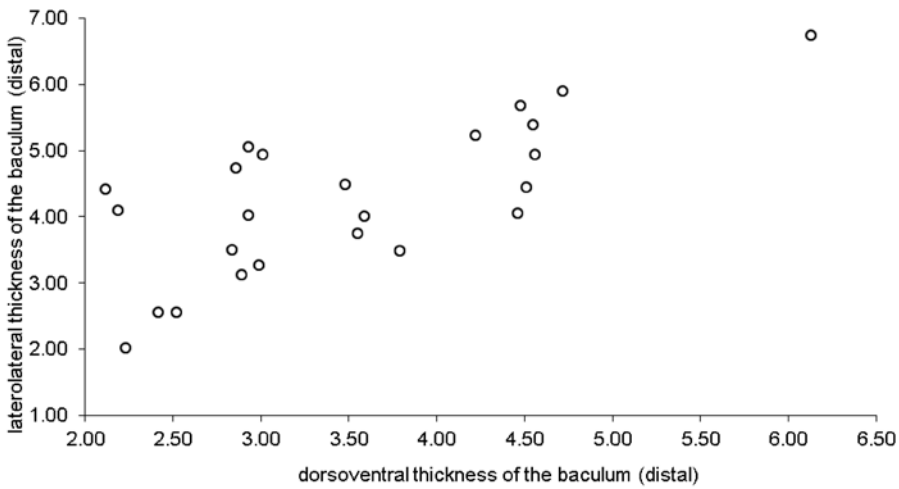


Fig. 5. Relationship between the dorsoventral thickness (distal) and the laterolateral thickness (distal) of the baculum.
Obr. 5. Vzájomný vzťah medzi dorzoventrálnou hrúbkou (distálna časť) a laterolaterálnou hrúbkou (distálna časť) penisovej kosti.

Table 3. Values of latent roots and loadings factor of the PCA for the three main components (PC1–PC3): their eigenvalues percentage (variability %) and cumulative percentage (cumulative %) expressions. For abbreviations of the body length and baculum variables see Table 1
Tab. 3. Hodnoty latentných koreňov a záťaží jednotlivých rozmerov pre prvé tri hlavné komponenty (PC1–PC3). ako aj ich percentuálne a kumulatívne percentuálne vyjadrenie. Skratky rozmerov dĺžky tela a bacula viď tab. 1

	PC1	PC2	PC3
LC	0.317	0.058	0.252
V1	0.355	–0.001	–0.045
V4	0.319	–0.229	–0.328
V5	0.316	0.280	0.156
V6	0.331	–0.188	0.063
V7	0.312	0.028	–0.008
V8	0.274	–0.032	–0.559
V9	0.172	–0.470	0.660
V10	0.175	0.775	0.218
V11	0.321	–0.080	–0.032
V12	0.355	–0.001	–0.045
eigenvalue	7.645	1.095	0.904
variance (%)	69.50	9.96	8.22
cumulative (%)	65.50	79.46	87.68

Moreover, according to BURT (1960), the shape of the baculum is fairly uniform in members of the family Canidae. The author therefore suggests that there is a rather close relationship between genera within this family, much closer than that found in Mustelidae or Procyonidae. A deep urethral groove extends from the base (*Canis*, *Vulpes*, *Alopex*) or from near the base (*Urocyon*) to near the distal end of the bone. These observations are in accordance with our data on penis bones from the Slovak population of *Canis lupus*. Nevertheless, further analysis is needed to fully understand the importance and function of the baculum in the mating system of the Eurasian wolf.

SÚHRN

V práci sú prezentované výsledky morfometrického výskumu penisových kostí vlka euroázijského (*Canis lupus*) zo Slovenska. Materiál pozostávajúci z 24 penisových kostí bol získaný zo zbierok Šarišského múzea v Bardejove. Rovnako boli použité somatické údaje získané excerpovaním z katalógových kariet a protokolov múzea. Celkovo bolo vyhodnotených dvanásť metrických znakov. Výsledky analýz potvrdili variabilitu v meraných znakov ako aj koreláciu medzi viacerými znakmi.

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