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Preliminary osteometrical analysis of metapodium and acropodium bones of fallow deer (*Dama dama* L.) from the Brijuni Islands, Croatia

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ABSTRACT

The purpose of this study was to measure the length and width proportions of the metapodial bones and phalanges of fallow deer (*Dama dama* L.) from the Brijuni Islands (Croatia) and correlate those osteometrical values with body mass. The osteometrical analysis included 28 metapodial bones and 168 phalanges of seven individual fallow deer of known age, sex and weight. The descriptive statistics for the obtained measurements show that the variability coefficient is less than 10% for the metapodial bone measurements and the phalanges length values, and greater than 10% for the width measurements. Comparison of osteometrical values for all the bones with body mass shows a negative correlation. After excluding the measurement values for the three juvenile individuals, the correlation becomes highly positive. Width measurements correlate better with body mass than the length measurements. Osteometrical studies are invaluable as only these data derived from recent populations can be compared with ancient animal populations in interdisciplinary archaeo-zoological investigations.

Key words: fallow deer, Brijuni Islands, osteometrical analysis, Croatia

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Introduction

The fallow deer (*Dama dama* L.) belongs to the category of extant deer, of which there are two subspecies: European (*Dama dama dama*) and Mesopotamian (*Dama*

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dama mesopotamica). FLEMING (1749) described it as a medium height taxon of deer, somewhat smaller than the red deer (*Cervus elaphus* L.) but larger than the roe deer (*Capreolus capreolus* L.). Its distinguishing features are the broad palmate antlers, which are borne only by the males. The weight of fallow deer males (bucks) ranges from 60 to 80 kg, while the females (does) weigh 35-50 kg (DARABUŠ et al., 1990). The body weight of each individual can vary greatly depending on the season and the animals' condition, so in adult bucks weight before and after the mating season can vary by several tens of kilograms (JANICKI et al., 2007).

Fallow deer originate from the eastern Mediterranean, where they are domicile and from where they spread through human-mediated translocations to different middle and north European countries (JANICKI et al., 2007). Paul Kupelweiser, who bought the Brijuni Islands in 1893, introduced various animal species to these islands. Brijuni are a group of fourteen small islands in the Croatian part of the northern Adriatic Sea, along the western coast of the Istrian peninsula (Fig. 1). Between 1902 and 1908, fallow deer were imported to the Brijuni Islands, together with Axis deer (*Axis axis* L.) and mouflons (*Ovis musimon* Pall.) (ANONYMOUS, 2011). JOVIĆ (1982) measured three basic biometric characteristics of fallow deer from the Brijuni Islands (trunk length, wither height and caudal body height) dividing the animals by age and sex. These measurements showed that the caudal part (rump) of the body was elevated by an average of 2-8 cm relative to the cranial part of the trunk (wither). This research observed relatively small differences concerning body size, in reference to individual categories, which indicated a homogenous population (KOLIĆ, 1990).

Fig. 1. Location of the Brijuni Islands

Allometric scaling is an approach in which the size of the whole animal is proportionate to the dimension of its parts (REITZ and WING, 1999). It deals with the structural and functional consequences of changes in size or scale among otherwise similar organisms (SCHMID-NIELSEN, 1984). Mammals have exhibited a wide range of body forms and locomotor styles, and there is probably no single skeletal measures that have adequately predicted body mass (GINGERICH, 1990). Body proportion estimates in mammals are mostly based on osteometrical data and are related to age, sex, geographical area and individual variations (KLEIN and CRUZ-URIBE, 1984). An increase in body mass may lead to a disproportional increase in the mass and dimensions of skeletal elements. ALEXANDER et al. (1979) demonstrated the correlation of the length and width measurements of long bones relative to body mass by using the standard allometric formula: $Y = aX^b$. A logarithmical version of the formula simplifies the calculations: $\log Y = \log a + b (\log X)$ in which a = the intercept and b = the slope of the regression line. This function is the mathematical relation by which we can predict what values of Y variable (body weight, kg) correspond with given X variable values (bone measurements, mm).

The objective of this study was to measure the length and width proportions of the metapodial bones and phalanges of fallow deer from the Brijuni Islands and correlate those osteometrical values with body mass. This kind of investigation has become frequent in the last two decades, mostly in interdisciplinary archaeozoological studies, where only osteometrical values of recent populations can be compared with those derived from ancient animal populations (REITZ and WING, 1999).

Materials and methods

Fallow deer metapodial bones and phalanges were collected during regular hunting on the Brijuni Islands in October 2004. The processed bone remains came from a total of seven animals: 1. female, 7 years, 40 kg; 2. female, 3 years, 35 kg; 3. male, 6 months, 15 kg; 4. male, 2 years, 46 kg; 5. female, 2 years, 48 kg; 6. male, 8 years, 54 kg; 7. female, 6 years, 39 kg. The distal limb parts were initially boiled, the soft tissue remnants were mechanically removed and the bones were boiled again in a mild solution of detergent and then dried. A total of 84 measurements were recorded from the 14 os metacarpale III et IV as well as on 14 os metatarsale III et IV. The sample yielded 56 first (phalanx proximalis), second (phalanx media) and third (phalanx distalis) phalanges. 224 measurements were recorded from the first and second phalanges, while 168 measurements were recorded from the third phalange. All metapodial bones and phalanges included in the osteometrical analysis were measured according to VON DEN DRIESCH (1976) and this is shown in Fig. 2. The measurements were taken using movable gauges and the values obtained were rounded to an accuracy of 0.02 mm. Both left and right metapodial bones, as well as all of the phalanges, were measured. The differences between the right and left bones of the same animals were tested by t-test, as well as the differences between the same bones of males and females.

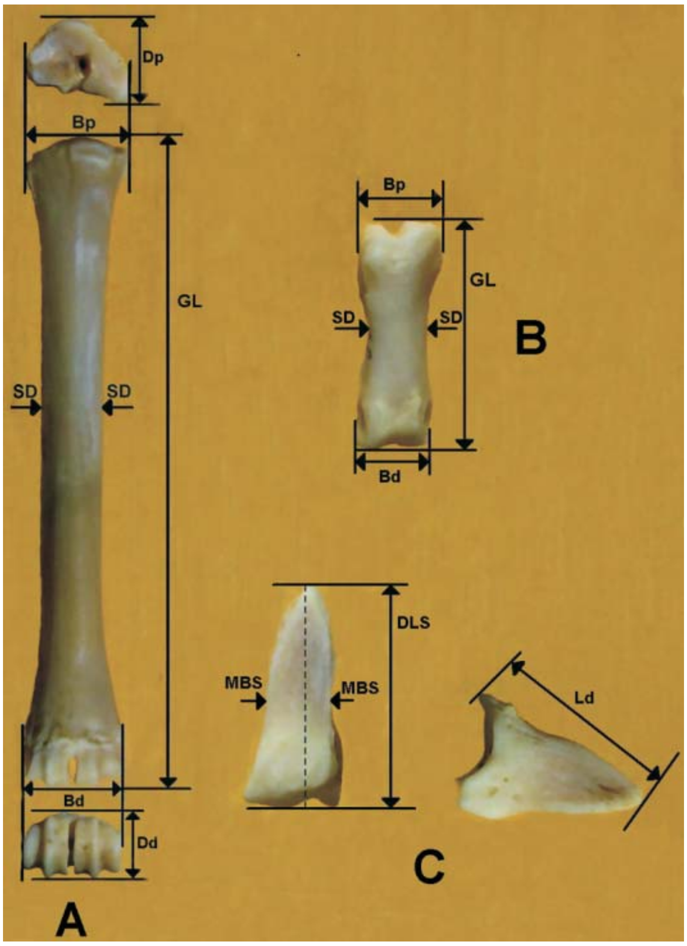

Fig. 2. Description of the measurements of (A) metapodial bones (above- proximal view; in the middle- dorsal view; below- distal view), (B) phalanx proximalis (dorsal view) and (C) phalanx distalis (left- viewof sole; right- lateral view) of fallow deer (according to VON DEN DRIESCH, 1976). GL - Greatest length; Bp - Greatest breadth of the proximal epiphysis; Dp - Greatest depth of the proximal epiphysis; SD - Smallest breadth of the diaphysis; Bd - Greatest breadth of the distal epiphysis; Dd - Greatest depth of the distal epiphysis; DLS - Greatest diagonal length of the sole (facies solearis); MBS - Middle breath of the sole (facies solearis); Ld - Length of the dorsal surface (facies parietalis).

The correlation between two features was investigated by means of linear correlation. Logarithms in base 10 of osteometric values and body masses were included in coordinate systems and the constant a (the Y-intercept) and the coefficient b (slope) were calculated using the allometric formula. Taking into account that the formula can be displayed as a trend equation $\log Y = \log a + b(\log X)$, in which Y indicates individuals mass in kilograms and X indicates osteometric value in millimeters, the correlation coefficient r, the determination coefficient r^2 and the probability p (0-1) were calculated. Since body mass was the quantity to be estimated, the dependent and independent variables were reversed (GINGERICH, 1990; SCOTT, 1990). The statistics program STATISTICA 9.0 (StatSoft.Inc., 1984-2010, Windows version) was used for data processing and statistical analysis. For the graphical displays, Excel (from the Microsoft Office 2007 program package) was used, as well as the aforementioned statistics program.

The research was carried out as a part of a scientific project with ethic committee approval and it was undertaken in accordance with Croatian laws and regulations.

Results

Descriptive statistics[1] of the metapodial bones measurements are shown in Table 1 and those of the phalanges in Table 2.

Table 1. Descriptive statistics of fallow deer metapodial bone measurements

Os metacarpale III et IV						
Measure	N	X ± SD	Min	Max	SE	CV%
Bp	14	26.79 ± 2.24	23.54	29.74	0.60	8.38
Dp	14	18.78 ± 1.62	16.64	21.24	0.43	8.62
GL	14	180.13 ± 11.76	160.20	195.10	3.14	6.53
SD	14	15.43 ± 1.69	12.80	17.67	0.45	6.64
Bd	14	26.09 ± 1.73	23.40	28.46	0.46	5.39
Dd	14	17.49 ± 0.94	16.08	18.79	0.25	7.02
Os metatarsale III et IV						
Measure	N	X ± SD	Min	Max	SE	CV%
Bp	14	24.84 ± 0.94	22.04	27.40	0.46	7.02
Dp	14	27.06 ± 2.02	23.58	29.65	0.54	7.47
GL	12	200.36 ± 12.69	178.90	214.40	3.66	6.33
SD	14	15.30 ± 1.42	12.78	17.32	0.38	9.29
Bd	14	27.44 ± 1.59	25.10	29.48	0.42	5.79
Dd	14	17.84 ± 0.88	16.30	18.87	0.23	4.49

N = number of measurements; X = mean; SD = standard deviation; Min = minimum; Max = maximum; SE = standard error of mean; CV% = coefficient of variation

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[1] Considering that this is approximately 800 osteometrical values, the raw data could not be included in the article due to lack of space in the magazine. The raw data are available from corresponding author or at http://www.nottingham.ac.uk/zooarchaeology/deer_bone/search.php

The *t*-test did not show any statistically significant differences between the left and right bones of the same individual. Logarithms of osteometrical values were correlated with logarithms of body mass values. All observed metacarpal and metatarsal osteometrical parameters correlated negatively with body mass. The bones of juvenile individuals, including one individual where the fusing of the distal epiphysis had not yet occurred (deer No. 3, a 6 month old male), as well as two individuals in whom the distal epiphysis had just fused and the epiphyseal line was clearly visible (male No. 4 and female No. 5), were included in this part of the research. These data were reanalyzed with the exclusion of these three individuals, because of the negative correlation (Table 3). Since the t-test did not prove any statistically significant differences between the remaining male and three females, the data were reanalyzed with logarithms for both sexes.

Table 2. Descriptive statistics of fallow deer phalanges measurements

Phalanx proximalis						
Measure	N	X ± SD	Min	Max	SE	CV%
Bp	56	14.16 ± 1.54	11.74	19.11	0.20	10.88
SD	56	10.30 ± 1.36	8.59	15.81	0.18	13.24
Bd	56	12.52 ± 1.06	10.71	14.48	0.14	8.52
GL	56	40.07 ± 3.02	34.32	45.40	0.40	7.54
Phalanx media						
Measure	N	X ± SD	Min	Max	SE	CV%
Bp	56	13.04 ± 1.12	10.20	15.19	0.15	8.64
SD	56	10.07 ± 0.83	8.74	11.94	0.11	8.32
Bd	56	10.82 ± 1.02	9.08	12.54	0.13	9.48
GL	56	27.48 ± 2.39	23.01	32.48	0.32	8.72
Phalanx distalis						
Measure	N	X ± SD	Min	Max	SE	CV%
DLS	56	32.45 ± 3.37	25.28	39.82	0.45	10.32
Ld	56	30.05 ± 2.82	23.64	34.80	0.37	9.41
MBS	56	5.90 ± 0.96	4.06	8.10	0.12	16.24

N = number of measurements; X = mean; SD = standard deviation; Min = minimum; Max = maximum; SE = standard error of mean; CV% = coefficient of variation

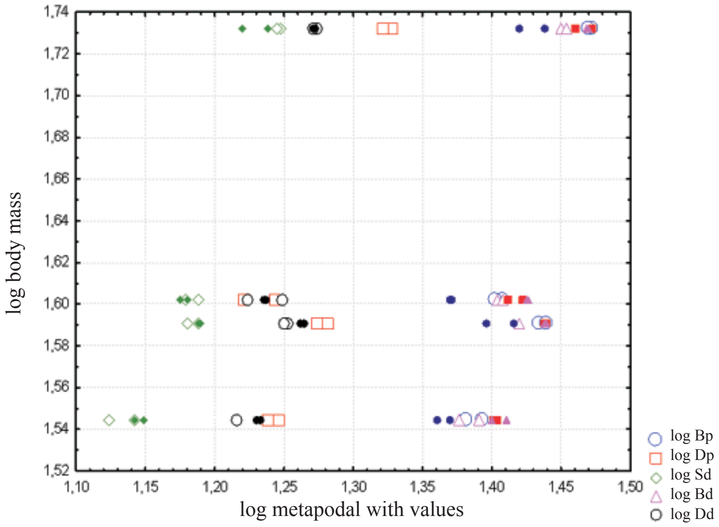
Table 3 shows that all osteometrical variables correlated positively with body mass in adult animals. In fact, some (SD and Bd of metacarpal bones, and Dp, SD and Bd of metatarsal bones) have correlated highly positively (correlation coefficient is higher than 0.9). Length measurements were less correlated, especially the greatest length (GL) of the metatarsal bones. Logarithmic values of width measurements for logarithmic values of the metacarpal and metatarsal bones and body masses for adult individuals were displayed in a coordinate system in Graphic chart 1. Values for the heaviest individual in the sample (No. 6) were clustered in the upper section of the chart and separated from the rest of the sample. Values for the smallest breadth of the epiphysis (SD), the greatest depth of the distal epiphysis (Dd) for all metapodial bones and the greatest depth of the proximal epiphysis (Dp) for metacarpal bones were clustered in the lower left section of the chart. Values for the greatest breadth of both proximal (Bp) and distal (Bd) epiphysis for all metapodial bones and the greatest depth of the proximal epiphysis (Dp) for metatarsal bones were clustered in the right section of the chart.

Table 3. The correlation coefficient r, the determination coefficient r^2, the probability p, and the trend equations for fallow deer metacarpal and metatarsal bone measurements excluding the juvenile individuals (No's 3, 4 and 5).

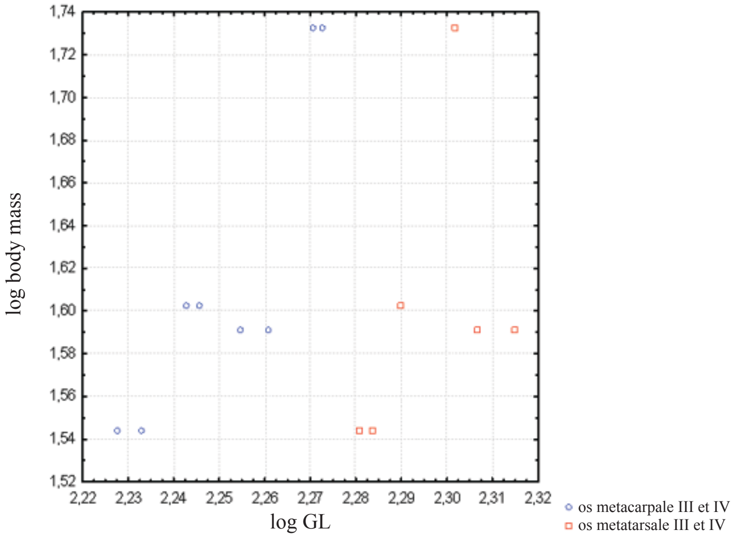
Os metacarpale III et IV				
Measure	r	r^2	p	Trend equation formula
Bp	0.8999	0.8099	0.0023	Y = -1.1769 + 1.9605*x
Dp	0.8464	0.7164	0.0080	Y = -0.4337 + 1.6163*x
SD	0.9623	0.9260	0.0001	Y = -0.3519 + 1.6593*x
Bd	0.9357	0.8755	0.0006	Y = -2.0467 + 2.5885*x
Dd	0.8688	0.7548	0.5494	Y = -1.9013 + 2.8278*x
GL	0.8806	0.7754	0.0051	Y = -7.2573 + 3.9421*x
Os metatarsale III et IV				
Bp	0.8092	0.6549	0.0150	Y = -1.2878 + 2.0861*x
Dp	0.9043	0.8177	0.0020	Y = -2.0935 + 2.5927*x
SD	0.9442	0.8916	0.4826	Y = -0.9564 + 2.1715*x
Bd	0.9386	0.8809	0.0004	Y = -2.4239 + 2.8167*x
Dd	0.7721	0.5962	0.0006	Y = -2.3185 + 3.1470*x
GL	0.4308	0.1856	0.0248	Y = -3.4334 + 2.1921*x

Table 4. The correlation coefficient r, the determination coefficients r^2, the probability p, and the trend equation for fallow deer phalanges measurements excluding the juvenile individuals (No's 3, 4 and 5).

Skeletal element	Measure	r	r^2	p	Trend equation formula
Phalanx proximalis	Bp	0.8706	0.7579	0.0000	Y = -0.4225 + 1.7786*x
	SD	0.8690	0.7552	0.0000	Y = -0.0228 + 1.63*x
	Bd	0.9118	0.8313	0.0000	Y = -0.3966 + 1.842*x
	GL	0.6806	0.4632	0.0000	Y = -1.2587 + 1.8005*x
Phalanx media	Bp	0.9240	0.8537	0.0000	Y = -0.5862 + 1.9696*x
	SD	0.9064	0.8216	0.0000	Y = -0.3399 + 1.9596*x
	Bd	0.8936	0.7985	0.0000	Y = 0.0659 + 1.5091*x
	GL	0.7050	0.4970	0.0000	Y = -0.4267 + 1.4273*x
Phalanx distalis	DLS	0.6177	0.3816	0.0002	Y = -0.9341 + 1.6697*x
	Ld	0.6174	0.3812	0.0002	Y = -1.5059 + 2.0887*x
	MBS	0.5286	0.2794	0.0019	Y = 1.023 + 0.7387*x



Graphic chart 1. Correlation of width measurements for metacarpal bones (marked with blank symbols), metatarsal bones (marked with full symbols) and of fallow deer body weight (juvenile individuals No's 3, 4 and 5 were excluded).



Graphic chart 2. Correlation of length measurements for metacarpal and metatarsal bones, and of fallow deer body weight (juvenile individuals No's 3, 4 and 5 were excluded).

Logarithmic values of length measurements (GL) for metacarpal and metatarsal bones for adult individuals and their body masses were displayed in a coordinate system in Graphic chart 2. In this case, the values for the heaviest animal were also separately clustered in the upper section of the chart, but the greatest length values for the metacarpal bones were somewhat lower than the largest length values of the metatarsal bones.

Inclusion of osteometric values for all phalanges of all animals has again resulted in negative correlation with body mass: in fact, all correlation coefficients r values came out negative. Although all proximal epiphysis of first and second phalanges were fused, a well-pronounced epiphyseal line was clearly visible on the juvenile individuals. After excluding the juvenile animals (No. 3, 4 and 5), the results shown in Table 4 were obtained. It is apparent that all observed measurements were positively correlated; in fact, all values for the first and second phalanges, except the greatest length (GL), were highly positively correlated (between 0.8 and 0.9).

Discussion

The investigated sample contains a small number of animals, particular in relation to male and female fallow deer, as well as limited age - range. Descriptive statistics of the measurements shows that the variability coefficient for the metapodial bones was less than

10% for all of the osteometrical values, that is, the variability was very low (PAPIĆ, 2008). However, the variability coefficient was higher than 10% for some phalange values or, more precisely, it equals 16.25% for the width measurements of the central facies solearis part (MBS) of the third phalanx, that is, the variability was relatively low. Consequently, it can be concluded that the investigated sample is statistically homogenous.

In mammals, after epiphyses fuse to the diaphysis, there is no further increase in length (GETTY, 1975) so the fusing stage can be very important in the study of age estimation (CARDEN and HAYDEN, 2006). Data about fallow deer age was mostly based on tooth eruption (MOORE et al., 1995) or on permanent tooth development stages (BROWN and CHAPMAN, 1991), but information about epiphyed fusion of fallow deer is extremely rare in the literature. One recent paper was published by CARDEN and HAYDEN (2006), in which sets of postcranial skeletal elements of 118 male and 92 female fallow deer from Phoenix Park, Dublin (Ireland), of known - age were summarised and a protocol for estimating the age of recent or archaeological bones was presented. In our research, all three phases of epiphyseal fusion were present: unfused, where epiphyses and diaphysis are separated; fusing, where thin irregular ridge (epiphyseal line) is visible between epiphysis and diaphysis and fused, where epiphysis is completely fused to the diaphysis and no epiphyseal line is visible. The distal epiphysis of the metapodial bones was completely separated on the 6 months old male (No. 3), which corresponded with mentioned protocol (CARDEN and HAYDEN, 2006). A pronounced epiphyseal line between the diaphysis and distal epiphysis was visible on the pair of two-year-old individuals of different sex (No. 4 and 5). In CARDEN and HAYDEN's (2006) investigation, incomplete fusing between the metapodial bones and their distal condyles had occured between 17-20 months in females (no data were available for males) and the fusing stage was completed by 20 months. Our sample has shown that complete fusion of the distal epiphysis of the metapodial bones had occurred at 2 years in both sexes. On the first and second phalanges of the juvenile individuals (No. 3, 4 and 5), an epiphyseal line between the proximal epiphysis and the body was visible. Bones of unfused and/or semi-fused epiphysis were usually not used in osteometric analyses, or, if they were, specific indication was required (REITZ and WING, 1999). One of the reasons for this was apparently the research presented here, because the osteometric values of all bones in correlation with body weight have resulted in a negative correlation coefficient. By excluding the bones with unfused and semi fused epiphysis, a positive correlation was obtained for all included variables. A statistically significant difference between single adult male and three adult females was not proven, although the logarithmic values of male were clustered in the upper section of the chart. Male body mass do not deviate from the weight of females because it was caught outside the breeding season where there was no seasonal increase in body mass, and the skeletal size is likely to remain stable (McELLIGOTT et al., 2001) regardless of the increase/decrease of body mass.

One of the purposes of this paper has been to publish a set of standard measurements of available fallow deer bones. Although this is a small sample with limited age range, this is an important initial study, which can complement and updated as the deer continue to be hunted. Measurements of bones and teeth are useful in comparisons with measurements of bones from archaeology sites (DAVIS, 1996). Between 2007 and 2008, group of researchers (SYKES et al., 2011) have developed a searchable online database containing archaeological records (including data for modern period animals) of fallow deer presence/absence, skeletal representation and metrics from all available zooarchaeological literature for Europe and Anatolia (Mesolithic to Post-medieval), which can be accessed online at http://www.nottingham.ac.uk/zooarchaeology/deer_bone/search.php. In the aforementioned important biometrical baseline and database, there was no data about Croatian deer at all, so osteometrical values from this research would be of great help for European biologists and archaeozoologists, although the fallow deer was imported to Croatia, on Brijuni Islands to be precise, only at the beginning of the 20th century.

Measurements of bones were also useful in distinguishing closely related species and could tell us more about size and shape (DAVIS, 1996). In POHLMEYER's (1985) investigations, the greatest length of the metapodial bones and the phalanges of 40 fallow deer of both gender and all age categories (from neonatal to 18 years old) was measured and compared with the same measurements of sheep (*Ovis aries* L.) and goat (*Capra hircus* L.). Our osteometrical values were in range of fallow deer measurements from this study. Although there were some morphological differences between sheep/goat and fallow deer, they were sometimes insufficient, especially in the fragmentary archaeological remains, so osteometrical measurements can be helpful in differentiating those species. Also, distinguishing those species by morphological and osteometrical methods was important in police or judicial purposes, especially given that molecular biology methods are still very costly.

Although it is known that bones situated more proximally on the limbs (e.g. humerus and femur) have yielded higher correlation coefficients (r) and determination coefficients (r^2) in relation to body mass, bones situated more distally on the extremities were also closely correlated to body mass (GINGERICH, 1990). In addition, SCOTT (1990) has demonstrated that non-length measurements of the postcranial skeleton and the proximal elements of limbs have shown a greater correlation with body mass than have the lengths of distal bones, although distal bones may have also scaled closely with body mass in less diverse taxa (i.e. cervids). This research has shown that the greatest length (GL) of the metatarsal bone has had the smallest correlation coefficient ($r = 0.4308$; $r^2 = 0.1856$), although the correlation was high ($r = 0.8806$; $r^2 = 0.7754$) for metacarpal lengths (GL). All width measurements of metapodial bones were highly correlated to body mass, in fact, the correlation coefficient was greater than 0.8 or 0.9. Additionally, the greatest length values (GL) for metacarpal bones were somewhat less than the greatest length values for metatarsal bones. As far as the phalanges were concerned, the length values were also correlated to body mass in a lesser degree than the width values.

The smallest width of the diaphysis (SD), the greatest dorso-plantar width of the epiphysis (Dd) for all metapodial bones and the greatest dorso-plantar width of the proximal epiphysis (Dp) for the metacarpal bones have given lower body mass logarithmic values, than the greatest latero-medial width for both proximal (Bp) and distal (Db) epiphysis for all metapodial bones and the greatest dorso-plantar width of proximal epiphysis (Dp) for the metatarsal bones.

Body proportion estimates can be based on osteometric data, but it was important to take into account variables like age, sex, geographical area, and individual variations that were not negligible (KLEIN and CRUZ-URIBE, 1984), as well as seasonal fluctuations of body weighs in males and females. Although the correlations between bone measurements from the distal parts of thoracic and pelvic limbs and body weight were determined here from three does and one buck, these data were still significant because it will be possible to use them in future research on fallow deer. Body mass is so important in ecology and functional morphology that we would do well to develop standard routines for interpreting body mass from tooth and bone size (GINGERICH, 1990). Trend equation formulas calculated in this research would be a good starting point for estimating body mass from metapodial bones and phalanges from archaeological and modern specimens of fallow deer from Croatia. Osteometric measurements will not only contribute to knowledge of the relationship between morphological values and carcass weight (or body mass), but will also improve the understanding of the visible morphology (ALPAK et al., 2009), in this case of the fallow deer, from archaeozoological material from the other countries where it occurs. Furthermore, there are little osteometric data on fallow deer from throughout its natural geographical range, especially for the phalanges, so this current study is a welcome initiative and a good starting point for further interdisciplinary professional and scientific researchers (anatomists, archeozoologists, biologists, hunters, forensic scientists). While this study represents an important initial step, more data should be collected and these will prove invaluable in other research studies on deer metrics.

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TRBOJEVIĆ VUKIČEVIĆ, T., I. ALIĆ, A. SLAVICA, M. POLETTO, S. KUŽIR: Osteometrijska analiza kostiju metapodija i članaka prstiju jelena lopatara (*Dama dama* L.) s Brijuna (Hrvatska). Vet. arhiv 82, 75-88, 2012.

SAŽETAK

Svrha ovog istraživanja bila je izmjeriti dužinu i širinu kostiju metapodija i članaka prstiju jelena lopatara (*Dama dama* L.) s Brijuna i usporediti dobivene osteometrijske vrijednosti s tjelesnom masom. U radu je obavljena osteometrijska analiza 28 kostiju metapodija i 168 članaka prstiju sedam jedinki jelena lopatara poznate dobi, spola i težine. Opisna statistika izmjera pokazuje da je koeficijent varijabilnosti kod izmjera metapodija i dužinskih vrijednosti članaka prstiju ispod 10%, dok je kod širinskih izmjera članaka prstiju iznad 10%. Usporedbom osteometrijskih vrijednosti svih kostiju s tjelesnom težinom korelacija je negativna. Izuzećem mjernih vrijednosti tri juvenilne jedinke korelacija postaje visoko pozitivna. Širinski su izmjeri bolje korelirani s tjelesnom težinom od dužinskih. Osteometrijska istraživanja su neprocjenjiva stoga što se samo podatci dobiveni od današnjih populacija mogu usporediti s populacijama drevnih životinja u interdisciplinarnim arheozoološkim istraživanjima.

Ključne riječi: jelen lopatar, Brijuni, osteometrijska analiza, Hrvatska