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MORPHOLOGICAL PATTERNS OF THE LONG LIMB BONES IN THE LESSER BANDICOOT RAT, *BANDICOTA BENGALENSIS* (RODENTIA: MURIDAE)

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Abstract: We examined the morphological patterns of long limb bones in the Lesser Bandicoot rat (*Bandicota bengalensis*) using univariate, bivariate and multivariate statistical analyses. A total of 18 morphometric measurements were taken using 30 adult specimens (11 males and 19 females) of *B. bengalensis*. The univariate analysis revealed non-significant right-left difference in the longest limb bones. Therefore, right side limb bones were used for further analyses. For most of the limb bone measurements, the mean values of the males were slightly larger than that of the females. However, the coefficient of variation did not differ significantly between the sexes. Most measurements of the fore limb and hind limb bones were significantly correlated with the length of respective bones. Allometric analysis exhibited isometry for many of the variables of humerus, ulna, femur, and tibia against the length of respective bones. These trends were also implied by the principal component analysis, as high factor loadings were observed for 80% and 75% variables of the forelimb and hindlimb, respectively. The epicondylar regions of the stylopodial bones (humerus and femur) and the width of radius showed non-significant correlation and/or negative allometry. Finally, our results suggest slightly male-biased sexual size dimorphism in the long limb bones and the growth patterns of the bone parts are greatly variable might be linked to the individual bone functions.

***Key words*:** Allometry, lesser bandicoot rat, limb bone, morphology, variation.

INTRODUCTION

The bone is living tissue that constitutes the skeletal parts in most of the vertebrates (Lee and Einhorn 2001). It provides a frame to support the bodies and contributes to forming the animal body shape (Lee and Einhorn 2001; de Buffrénil *et al.* 2021). The limb bones are important parts of the appendicular skeleton, which remain connected to the axial skeleton through the pectoral and pelvic girdles (Jones *et al.* 2013). The forelimbs and hindlimbs are two major parts of the limb bones (Jones *et al.* 2013). Humerus, radius, and ulna are the main parts of the upper-limb skeleton (Casteleyn and Bakker 2019).

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The humerus is the longest bone of the forelimb and mostly consists of a proximal extremity, a shaft, and a distal extremity (Olawoye 2011; Kabakci *et al.* 2017). Radio-ulna remains joined with one another and is situated between the elbow and carpus (Olawoye *et al.* 2011). At the distal end of the radio-ulna, the styloid process is eventually developed (Olawoye *et al.* 2011). Femur, tibia, and fibula are the long bones, among the hind limb parts (de Araújo *et al.* 2012). The hind limb is structured in a way where the proximal part of the femur articulates with the acetabulum of the pelvic girdle through the femoral head and articulates distally with the tibia-fibula (Rommel and Reynolds 2009). The femur is robust and cylindrical structure and contains the femoral head and trochanters in the proximal part (Pérez *et al.* 2017). Besides, fibula is a slender structure and remains fused with tibia (Salami *et al.* 2011).

The growth rates of limb bone parts generally exhibit quick divergence in rodents (Cooper 2019). The enlargement of the long bones of the forelimb and hindlimb is typically faster than the shorter bones (Rolian 2008; Cooper 2019). Although limb bone morphology in rodents and other mammalian species has been studied by several researchers (Kuncova and Frynta, 2009; Olawoye *et al.* 2011; de Araújo *et al.* 2012; Coutinho *et al.* 2013; Janis and Martin-Serra 2020; Montoya-Sanhueza *et al.* 2020), most of them emphasized on details of the variation of postcranial structure, locomotory behavior, evolutionary diversity, and functional anatomy. However, along with growth patterns of the limb bones with body size, growth patterns of the limb bone parts against the length of respective bones are important to understand the anatomical structures of the appendicular skeleton. The sex differences of the long limb bones and their parts are also important in morphological analysis. Moreover, vertebrate limbs are an ideal system to investigate the relationship between the organisms and their environment, as these anatomical units are primarily used for locomotion (Biewener 1990; Cooper 2019).

B. bengalensis is a murid rodent and a predominant rat of South Asia (Pacheco 2019). It is widely distributed in Bangladesh and considered the most problematic rodent species (Chakma 2009). In Bangladesh, some morphometric relationship of *B. bengalensis* was only described by Khalequzzaman and Hossain (1999) from a store house at the Natore district. Besides, the detail morphological analysis of the limb bones of *B. bengalensis* has not yet been studied in Bangladesh. Therefore, the purpose of our study is to provide a greater understanding of the variation of long limb-bone morphology in *B. bengalensis* using several statistical analyses.

MATERIAL AND METHODS

Studied specimens: This study was carried out at the campus of the University of Chittagong during October 2021 to October 2022. A total of 30

adult specimens (11 males and 19 females) of *B. bengalensis* were analyzed, which were captured from the Chittagong University campus and its surrounding area followed by the guidelines of the American Society of Mammologists (Gannon *et al.* 2007). The eruption and wears of the molar teeth were used to determine the age of the specimens (Voss and Marcus 1992). Moreover, the mammary glands in females and the penis in males served as the indicators of the sexes of *B. bengalensis* (Shoma *et al.* 2015). The Animal Ethics Review Board (AERB) of the Faculty of Biological Sciences, University of Chittagong [Reference number–AERB-FBSCU-20230202-(2)] has provided ethical approval for conducting this study.

Bone preparation: Bone preparation is a process where different steps like removing soft tissues from the bone, washing the bone, drying the bone, bone articulation and entitling are included (Onwuama *et al.* 2012). In this study, bones were prepared using the chemical method (Onwuama *et al.* 2012). After euthanizing, the specimens were dissected using scalpel, forceps, and scissors. Then the fleshes were removed as much as possible from the bones. The bones were then dipped into several buckets which contained 3% and 5% NaOH solution and kept the buckets under the sun for several hours. After a few hours the bones were collected and washed out thoroughly in running water. Then the bone parts were dried.

Bone measurements: A total of 18 measurements were taken for the limb bone parts (humerus, radius, ulna femur, and tibia) of the appendicular skeleton following several previous studies with slight modification (Kuncova and Frynta 2009; Coutinho *et al.* 2013; Woodman and Stabile 2015) (Fig. 1). For the forelimb bones, we measured four parameters for the humerus: deltoid length of humerus (DLH), width of humerus (WH), diameter of the epicondyles of humerus (DEH), and length of humerus (HL); two for the radius: length of radius (LR) and distal width of radius (RDW); as well as four for the ulna: total length of ulna (UL), functional length of ulna (FUL), olecranon length (OL), and width of ulna (WU) (Fig. 1). For the hindlimb bones, five parameters were measured for the femur: femur length (FL), functional femur length (FFL), width of femur (WF), distal extension of the greater trochanter (DMT), and epicondylar breadth of the distal femur (FEB); and three for the tibia: tibia length (LT), proximal tibial length (LT1), and distal width of tibia (TDW) (Fig. 1). All measurements were taken using slide calipers of an accuracy of 0.1 mm.

Statistical analyses: We calculated the arithmetic mean (M), standard deviation (SD), and coefficient of variation (CV) for all measurements of long limb-bone morphology. We used the Mann-Whitney U-test to analyze the significance of right-left difference in the longest limb bones and sexual dimorphism for each variable (Biswas and Motokawa 2019; Biswas *et al.* 2020).

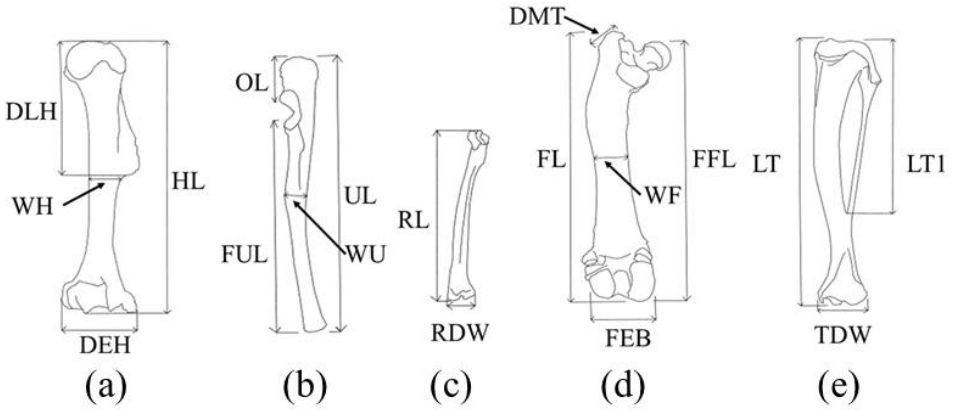

Fig. 1 Measurements of fore-limb bones [(a) humerus, (b) ulna and (c) radius] and hind-limb bones [(d) femur and (e) tibia] in *Bandicota bengalensis*.

The Pearson correlation coefficient was used to examine the correlation patterns of limb bone variables with the total length of the respective bones (Motokawa *et al.* 2003; Suzuki *et al.* 2012). Moreover, Allometric analysis was conducted for combined data set of both sexes. This analysis was done for the limb bone parts (humerus, radius, ulna, femur, and tibia) separately. The total length of humerus (HL), radius (RL), ulna (UL), femur (FL), and tibia (LT) were used as an independent variable in this analysis (Suzuki *et al.* 2011). An allometric formula, $\log y = \alpha \log x + \beta$, was used in our study, where y is the morphological traits of interest, α is the coefficient of allometry, and x is the independent variable (Huxley and Teissier 1936; Suzuki *et al.* 2012; Biswas and Motokawa 2019). The coefficient of allometry was assessed using the ordinary least-square (OLS) regression (Biswas and Motokawa 2019).

We also conducted the principal component analysis (PCA) to analyze the intraspecific variation of limb bone variables based on the correlation matrix of log-transformed data (Motokawa *et al.* 2003; Biswas *et al.* 2020). The significance level for all statistical tests was set at 5%. A statistical program, PAST (ver. 4.12b) (Hammer *et al.* 2001), was used to analyze the morphological data of the long limb bones.

RESULTS AND DISCUSSION

Patterns of overall variation in long limb bones: The summary statistics of the humerus, radius, ulna, femur, and tibia are presented in Table 1. No significant difference was found between the right and left side variables of the total length of the humerus (Mann-Whitney $U = 433.5$, $P > 0.05$) and femur (Mann-Whitney $U = 428$, $P > 0.05$). Therefore, the right sided values were used for further analyses.

Table 1. Summary statistics of the measurements (mm) of the long limb bones (humerus, radius, ulna, femur, and ulna) in *Bandicota bengalensis* (SD, Standard deviation; CV, Coefficient of variation; n, Sample size)

Bones	Variables	All (n=30)			Male (n=11)			Female (n=19)		
		Mean ± SD	Range	CV	Mean ± SD	Range	CV	Mean ± SD	Range	CV
Humerus	DLH	12.25 ± 0.69	10.7 - 13.6	5.61	12.61 ± 0.59	11.2 - 13.6	4.66	12.05 ± 0.67	10.7 - 13.2	5.55
	WH	2.88 ± 0.22	2.5 - 3.2	7.54	2.91 ± 0.23	2.5 - 3.1	7.76	2.86 ± 0.22	2.5 - 3.2	7.56
	DEH	5.77 ± 0.30	5.1 - 6.4	5.18	5.95 ± 0.32	5.5 - 6.4	5.44	5.66 ± 0.23	5.1 – 6.0	4.13
	HL	23.14 ± 1.14	20.6 – 25.0	4.94	23.75 ± 0.98	21.8 – 25.0	4.11	22.79 ± 1.11	20.6 – 25.0	4.86
Radius	RL	19.94 ± 0.87	18.3 - 21.7	4.37	19.96 ± 0.92	18.5 - 21.3	4.61	19.92 ± 0.87	18.3 - 21.7	4.35
	RDW	2.57 ± 0.23	2.2 – 3.0	8.82	2.65 ± 0.19	2 .3 – 3.0	7.22	2.52 ± 0.23	2.2 – 3.0	9.30
Ulna	UL	25.32 ± 1.12	23.2 - 27.3	4.41	25.26 ± 1.18	23.6 – 27.0	4.67	25.29 ± 1.11	23.2 - 27.3	4.38
	FUL	21.65 ± 0.95	9.7 - 23.7	4.32	21.87 ± 0.88	20.5 - 23.2	4.01	21.52 ± 0.99	19.7 - 23.7	4.60
	OL	3.71 ± 0.37	2.9 - 4.4	9.87	3.59 ± 0.49	2.9 - 4.4	13.61	3.78 ± 0.26	3.5 - 4.4	6.98
	WU	2.05 ± 0.12	1.7 - 2.3	5.98	2.05 ± 0.15	1.7 - 2.3	7.34	2.04 ± 0.11	1.8 - 2.2	5.24
Femur	FL	30.44 ± 1.76	25.3 - 34.3	5.78	30.56 ± 2.17	25.3 - 32.5	7.09	30.36 ± 1.54	27.5 - 34.3	5.07
	FFL	29.30 ± 1.66	24.3 - 32.9	5.68	29.38 ± 2.06	24.3 - 31.1	7.00	29.26 ± 1.45	26.3 - 32.9	4.96
	WF	3.42 ± 0.32	2.5 - 4.0	9.45	3.45 ± 0.40	2.5 - 3.9	11.56	3.41 ± 0.28	2.9 - 4.0	8.29
	DMT	3.79 ± 0.40	3.0 - 4.3	10.47	3.82 ± 0.44	3.0 - 4.3	11.47	3.78 ± 0.38	3.1 - 4.3	10.16
	FEB	5.31 ± 0.37	4.9 - 6.3	7.02	5.53 ± 0.41	5.0 - 6.3	7.33	5.18 ± 0.29	4.9 - 5.9	5.69
Tibia	LT	31.30 ± 1.51	27.4 - 34.1	4.83	31.77 ± 1.77	27.4 - 33.5	5.57	31.02 ± 1.31	29.0 - 34.1	4.22
	LT1	20.55 ± 1.11	17.7 - 23.4	5.40	20.61 ± 1.25	17.7 - 22.0	6.05	20.51 ± 1.05	19.0 - 23.4	5.13
	TDW	4.87 ± 0.39	3.4-5.3	8.06	5.02 ± 0.34	4.1 - 5.3	6.72	4.78 ± 0.4	3.4 – 5.3	8.44

The overall length ranged from 20.6 to 25.0 mm (mean: 23.14; SD: ± 1.14) in humerus, 18.3 to 21.7 mm (mean: 19.94; SD: ± 0.87) in radius, and 23.2 to 27.3 mm (mean: 25.32; SD: ± 1.12) in ulna (Table 1). Moreover, the length varied from 25.3 to 34.3 mm (mean: 30.44; SD: ± 1.76) in femur and 27.4 - 34.1 mm (mean: 31.30; SD: ± 1.51) in tibia (Table 1).

Sex differences in long limb bones: Descriptive statistics revealed that mean values of the males were slightly larger than the females for most of the variables in humerus, radius, ulna, femur, and tibia (Table 1). In males, the humerus length ranged from 21.8 to 25.0 mm (mean: 23.75; SD: ± 0.98), radius length ranged from 18.5 to 21.3 mm (mean: 19.96; SD: ± 0.92), and the length of ulna ranged from 23.6 to 27.0 mm (mean: 25.26; SD: ± 1.18) (Table 1). In females, the length varied form 20.6 – 25.0 mm (mean: 22.79; SD: ± 1.11) for humerus, 18.3 to 21.7 mm (mean: 19.92; SD: ± 0.87) for radius, and 23.2 to 27.3 mm (mean: 25.29; SD: ± 1.11) for ulna (Table 1).

The femur length ranged from 25.3 to 32.5 mm (mean: 30.56; SD: ± 2.17) in males and 27.5 - 34.3 mm (mean: 30.36; SD: ± 1.54) in females (Table 1). Moreover, the length of tibia varied from 27.3 to 33.5 mm (mean: 31.77; SD: ± 1.77) in males and 29.0 - 34.1 mm (mean: 31.02; SD: ± 1.31) in females (Table 1). Significant differences between the males and females were detected for three variables [DLH ($U = 49$, $P < 0.05$), DEH ($U = 53$, $P < 0.05$) and HL ($U = 55$, $P < 0.05$)] in humerus, one variable [FEB ($U = 46.5$, $P < 0.05$)] in femur, and one variable [TDW ($U = 51.5$, $P < 0.05$)] in tibia. However, there were no significant differences in CV values between the males and females in humerus ($U = 7$; $P = 0.885$), ulna ($U = 6$; $P = 0.665$), femur ($U = 6$; $P = 0.210$) and tibia ($U = 3$; $P = 0.663$).

Our results showed that the long bones were larger in males than females of *B. bengalensis*. Univariate analysis demonstrated that most variables of humerus were significantly larger in males than those of females, which supporting previous findings (de Bakker *et al.* 2018; Khan *et al.* 2020). In identifying sex, the maximum length of the humerus showed the accuracy of 81% and 94% in the males and the females, respectively (Khan *et al.* 2020). Epicondylar breadth showed the accuracy of 78% and 67% in the males and the females, respectively to identify the sex (Khan *et al.* 2020). Epicondylar breadth was also found to be the best indicator in discriminating between the sexes (Soni *et al.* 2013). de Bakker *et al.* (2018) also reported that adult male rats possessed larger and stronger bones. Sexual selection and defense of a territory are typically believed as two important factors for the sexual size dimorphism in mammals (Ralls 1977). Extensive studies would be desirable to explain the evolutionary factors of sexual size differences in long limb bones. However, CV

values did not differ significantly between the sexes. This pattern was also reported for the variables of skull morphology in other rodents (Sather 1956; Pankakoski *et al.* 1987; Biwas and Motokawa 2019; Biswas *et al.* 2020). Therefore, variability patterns might be similar, despite having male-biased sex differences in the long bones of *B. bengalensis* (Biswas and Motokawa 2019).

Correlation and allometric patterns of limb bones: As coefficient of variation did not differ significantly between the males and females, correlation patterns were evaluated for the combined data sets of both sexes. In humerus, all variables showed strong positive correlation with HL. Among three variables, DLH had large correlation coefficients ($r > 0.8$) (Table 2). The allometric coefficients ranged from 0.439 (DEH) to 0.983 (DLH) (Table 2). Among three variables of humerus, isometry was found for the DLH and WH; negative allometry was detected for the DEH (Table 2). In radius, RDW showed non-significant correlation with RL (Table 2), therefore allometric pattern was not evaluated for this variable. In ulna, all variables showed significant correlation with UL. Among the variables, FUL showed large correlation coefficients ($r > 0.8$) (Table 2). The allometric coefficients ranged from 0.947 (FUL) to 1.473 (OL). The result of allometric coefficients demonstrated that three variables of ulna showed isometry against UL (Table 2).

In femur, three variables (FFL, WF, DMT) showed significant correlation with FL (Table 2). Among the correlated variables of femur, FFL exhibited large correlation coefficients ($r > 0.8$) (Table 2). The allometric coefficients ranged from 0.958 (DMT) to 1.298 (WF). The allometric patterns indicated isometric relationship for all correlated variables (FFL, WF and DMT) against FL (Table 2). In tibia, LT1 and TDW showed very significant correlation with LT (Table 2). Out of two variables, LT1 showed a large correlation coefficient ($r > 0.8$). The allometric patterns also exhibited isometry for these two variables (LT1 and TDW) with LT (Table 2).

Principal component analysis: In the fore-limb bones, the first four principal components explained 89.25% of the total variation (Table 3). Among these components, PC 1 accounted for the largest variance (61.43%) and PC 2, PC 3, PC 4 explained 11.43%, 9.38% and 7.02% of the variances, respectively (Table 3). PC 1 demonstrated high factor loadings (> 0.50) for three variables (DLH, WH and HL) in humerus, for all variables (UL, FUL, OL and WU) in ulna, and for one variable (RL) in radius (Table 3). Two scatter plots were prepared using scores of the 1st and 2nd (PC 1 and PC 2) and 2nd and 3rd (PC 2 and PC 3) principal component variables (Fig. 2). These plots displayed that the values mostly overlapped between the sexes (Fig. 2).

In hind-limb bones, the first four components accounted for 94.03% of the total variance, of which PC 1 explained 60.77% of the variation (Table 4). PC 1

Table 2. Correlation and bivariate allometric analysis of limb bone morphology in *Bandicota bengalensis* based on log-transformed combined data of sexes, in which HL, UL, RL, FL, LT were acted as the independent variable for the variables of humerus, ulna, radius, femur, and tibia, respectively (r, Pearson's correlation coefficient; r2, Coefficient of determination; α, Allometric coefficient; I, Isometry, N, Negative allometry, n.s., non-significant, and P_{ISO}, Deviation from isometry)

Bones	Variables	r	r^2	P	α	t	P_{ISO}
Humerus	DLH	0.861	0.742	< 0.05	0.983 I	8.976	> 0.05
	WH	0.615	0.378	< 0.05	0.949 I	4.128	> 0.05
	DEH	0.424	0.179	< 0.05	0.439 N	2.475	< 0.05
Ulna	FUL	0.955	0.912	< 0.05	0.947 I	17.011	> 0.05
	OL	0.642	0.412	< 0.05	1.473 I	4.426	> 0.05
	WU	0.713	0.508	< 0.05	0.987 I	5.379	> 0.05
Radius	RDW	0.249	0.062	0.185	0.500n.s	-	-
Femur	FFL	0.983	0.967	< 0.05	0.970 I	28.513	> 0.05
	WF	0.780	0.609	< 0.05	1.298 I	6.599	> 0.05
	DMT	0.519	0.270	< 0.05	0.958 I	3.217	> 0.05
	FEB	0.055	0.003	> 0.05	0.064n.s.	-	-
Tibia	LT1	0.901	0.811	<0.05	0.999 I	10.774	> 0.05
	TDW	0.501	0.251	<0.05	0.914 I	3.062	> 0.05

Table 3. Results of principle component analysis based on correlation matrix of log-transformed data of fore-limb bones (high factor loadings (> 0.50) are displayed in bold)

Bones	Variables	PC 1	PC 2	PC 3	PC 4
Humerus	DLH	0.813	0.249	0.221	-0.368
	WH	0.742	-0.0003	-0.088	0.266
	DEH	0.499	0.185	0.689	0.448
	HL	0.913	0.042	0.137	-0.272
Ulna	UL	0.936	-0.305	-0.050	0.055
	FUL	0.889	-0.393	0.157	-0.044
	OL	0.671	0.151	-0.506	0.427
	WU	0.813	0.118	-0.312	-0.181
Radius	RL	0.907	-0.328	-0.058	-0.009
	RDW	0.499	0.808	-0.059	-0.033
Eigenvalues		6.142	1.143	0.938	0.702
Variance (%)		61.425	11.431	9.376	7.018

Table 4. Results of principle component analysis based on correlation matrix of log transformed data of hind-limb bones (high factor loadings (> 0.50) are displayed in bold)

Bones	Variables	PC 1	PC 2	PC 3	PC 4
Femur	FL	0.972	0.032	-0.139	-0.065
	FFL	0.962	0.013	-0.153	-0.056
	WF	0.825	-0.303	-0.060	0.142
	DMT	0.629	-0.283	0.277	0.637
	FEB	0.051	0.938	0.032	0.319
Tibia	LT	0.931	0.214	0.009	-0.172
	LT1	0.904	0.111	-0.273	-0.137
	TDW	0.477	0.078	0.827	-0.280
Eigenvalues		4.861	1.117	0.882	0.663
Variance (%)		60.766	13.957	11.024	8.285

demonstrated high factor loadings (> 0.50) for all variables in femur (except FEB) and for two variables of tibia (LT and LT1) (Table 4). The scatter plots of first and second principal components (PC 1 and PC 2) and second and third components (PC 2 and PC 3) showed that the values of males and females are overlapped (Fig. 3).

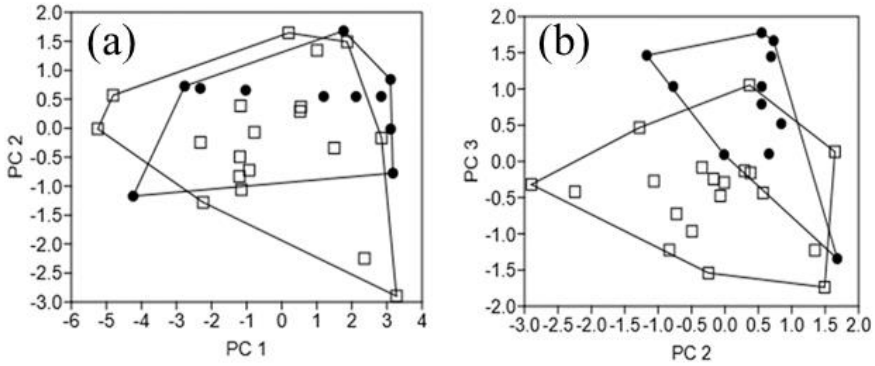

Fig. 2 Scatter plots of the 1st and 2nd (a) and 2nd and 3rd (b) principal component scores for the parameters of the fore-limb bones in *Bandicota bengalensis*. The male and female specimens are denoted by the solid and open circles, respectively.

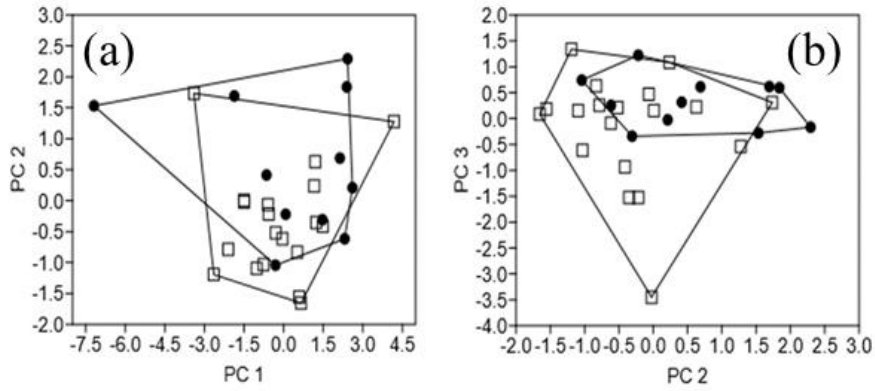

Fig. 3 Scatter plots of the 1st and 2nd (a) and 2nd and 3rd (b) principal component scores for the parameters of the hind-limb bones in *Bandicota bengalensis*. The male and female specimens are denoted by the solid and open circles, respectively.

We found that most variables of the long bones showed significant correlation with the length of respective bones. Moreover, bivariate allometric analysis indicated isometry for two variables in humerus, three variables in ulna, three variables in femur, and two variables in tibia. These patterns were also supported by the principal component analysis, as PC 1 showed high factors loading for 80% and 75% variables of the forelimb and hindlimb, respectively. PC 1 has been considered as the size component and high factor

loadings in PC 1 indicated that if one of the morphological parameters increases in size then the other parameters tend to increase (Biswas *et al.* 2020). These bone parts might have a role in muscle attachment and the morphological characteristics linked to muscle attachment showed strong allometry (Doube *et al.* 2009; Zhang and Ge 2014; Biswas and Motokawa 2019). However, non-significant correlation was found for the epicondylar region of the femur and the width of radius. Moreover, the epicondylar region of the humerus showed negative allometry with the humerus length. Non-linear scaling was also described in long bone curvature of other mammals (Bertram and Biewener 1990; Garcia and da Silva 2006). These patterns might be related to the functional stress on these regions of the stylopodial bones (Doube *et al.* 2009). These parts might have effective use for supporting loadings modes like bending and torsion during locomotion (Doube *et al.* 2009). Garcia and da Silva (2006) also reported that allometric patterns of the mammalian long-bones are influenced by bending loads. Therefore, correlation and allometric analyses suggested that growth patterns of the bone parts were not uniform, as no animal grows isometrically during the ontogenetic development (Cooper 2019).

CONCLUSION

This study demonstrated that the long limb bones were relatively larger in males than females of *B. bengalensis*, which could be explained by sexual selection. Furthermore, growth patterns of the bone parts were greatly variable and associated with functional requirements of the individual bones.

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LITERATURE CITED

BERTRAM, J. E. and BIEWENER, A. A. 1990. Differential scaling of the long bones in the terrestrial carnivora and other mammals. *Journal of Morphology,* **204**, 157-69.

BIEWENER, A. A. 1990. Biomechanics of mammalian terrestrial locomotion. *Science*, **250**, 1097-103.

BISWAS, J. K. and MOTOKAWA, M. 2019. Morphological analysis of static skull variation in the large Japanese field mouse, *Apodemus speciosus* (Rodentia: Muridae). *Mammal Study,* **44** (1), 51-63.

BISWAS, J. K., OSHIDA, T. and MOTOKAWA, M. 2020. Sexual dimorphism and variability of craniomandibular morphology in the Japanese giant flying squirrel, *Petaurista leucogenys* (Rodentia: Sciuridae). *Zoologischer Anzeiger,* **285** (4), 1-11.

CASTELEYN, C. and BAKKER, J. 2019. The anatomy of the common marmoset. In: *Common marmoset in captivity and biomedical research*. (Ed., Fox, J. G., Marini, R. P., Watchman, L. M., Tardif, S. D. and Mansfield.) Elsevier academic press, Pp. 17-41.

CHAKMA, S. 2009. *Bandicota bengalensis*. In: *Encyclopedia of flora and fauna of Bangladesh,* Vol. **27**. *Mammals*. (Ed., Ahmed, A. T. A., Kabir, S. M. H., Ahmad, M., Ahmed, Z. U., Begum, Z. N. T., Hassan, M. A. And Khondker, M.) Asiatic Society of Bangladesh, Dhaka, pp. 46-47.

COOPER, K. L. 2019. Developmental and evolutionary allometry of the mammalian limb skeleton. *Integrative and Comparative Biology,* **59**, 1356-1368.

COUTINHO, C. L., OLIVEIRA, J. A. and PESSO^A, L.M. 2013. Morphological variation in the appendicular skeleton of Atlantic Forest Sigmodontine rodents. *Journal of Morphology,* **274** (7), 779-792.

de ARAÚJO, F. A. P., SESOKO, N. F., RAHAL, S. C., TEIXEIRA, C. R., MÜLLER, T. R. and MACHADO, M. R. F. 2012. Bone morphology of the hind limbs in two caviomorph rodents. *Anatomia, Histologia, Embryologia*, **42** (2), 114-123.

de BAKKER, C. M. J., ZHAO, H., TSENG, W. J., LI, Y., ALTMAN-SINGLES, A. R., LIU, Y., LEAVITT, L., and LIU, X. S. 2018. Effects of reproduction on sexual dimorphisms in rat bone mechanics. *Journal of Biomechanics,* **77** (6), 40-47.

de BUFFR ÉNIL, V, de RICQL ÉS, A. J., ZYLBERBERG, L., PADIAN, K., LAURIN, M. and QUILHAC, A. 2021. *Vertebrate skeletal histology and paleohistology (Fist edition)*. Boca Raton, CRC Press. xii + 825 pp.

DOUBE, M., CONROY, A. W., CHRISTIANSEN, P., HUTCHINSON, J. R., SHEFELBINE, S. 2009. Three-dimensional geometric analysis of felid limb bone allometry. *PLoS One,* **4**(3), e4742. doi:10.1371/journal.pone.0004742.

GANNON, W. L., SIKES, R. S. and THE ANIMAL CARE AND USE COMMITTEE OF THE AMERICAN SOCIETY OF MAMMALOGISTS (2007). Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy,* **88**, 809-823.

GARCIA, G. J. M. and da SILVA, J. K. L. 2006. Interspecific allometry of bone dimensions: A review of the theoretical models. *Physics of Life Reviews,* **3**, 188-209.

HAMMER, Ø., HARPER, D. A. T. and RYAN, P. D. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica,* **4** (1), 9. https://doi.org/10.1016/j.jbiomech.2018.06.023

HUXLEY, J. S. and TEISSIER, G. 1936. Terminology of relative growth. *Nature,* **137**, 780-781.

JANIS, C. M. and MARTIN-SERRA A. 2020. Postcranial elements of small mammals as indicators of locomotion and habitat. *Peer J,* **8** (6), e9634. DOI: 10.7717/peerj.9634

JONES, J., REZAEE, A. and MAYHEW, P. 2013. Appendicular skeleton. (Accessed on 5 May 2023). https://doi.org/10.53347/rID-23107.

KABAKCI, A. D. A., BUYUKMUMCU, M., YILMAZ, M. T. and CICEKCIBASI, A. E. 2017. An osteometric study on humerus. *International Journal of Morphology,* **35** (1), 219-226.

KHALEQUZZAMAN, M. and HOSSAIN, M. 1999. Some morphometric relationship and population density of the lesser bandicoot rat, *Bandicota bengalensis* (Gray) in a store house. *Journal of Biosciences,* **7**, 31-34.

KHAN, M. A., GUL, H. and NIZAMI, S. M. 2020. Determination of gender from various measurements of the humerus. *Cureus,* **12** (1), e6598. Doi: 10.7759/cureus.6598

KUNCOVA, P. and FRYNTA, D. 2009. Interspecific morphometric variation in the postcranial skeleton in the genus *Apodemus. Belgian Journal of Zoology,* **139** (2), 133-146.

LEE, C. A. and EINHORN, T. A. 2001. The bone organ system: Form and function. In: *Osteoporosis (Second Edition), vol. 1.* (Ed., Marcus, R., Feldman, D. and Kelsey, J.) Science Direct. Academic Press. pp. 3-20.

MONTOYA-SANHUEZA, G., BENNETT, N. C., OOSTHUIZEN, M. K., DENGLER-CRISH, C. M. and CHINSAMY, A. 2020. Long bone histo-morphogenesis of the naked mole-rat: Histodiversity and intraspecific variation. *Journal of Anatomy,* **238** (6), 1259-1283.

MOTOKAWA, M., LIN, L. K. and MOTOKAWA, J. 2003. Morphological comparison of Ryukyu mouse *Mus caroli* (Rodentia: Muridae) populations from Okinawajima and Taiwan. *Zoological Studies,* **42** (2), 258-267.

OLAWWOYE, S., S., TOBECHUKWU, O., K., SUNDAY, M., M., JIBRIL, I., and ADENIYI, O., S. 2011. Morphological studies of the appendicular skeleton of the African giant pouched rat (*Cricetomys gambianus*) part (i) pectoral limb. *Journal of Veterinary Medicine and Animal Health,* **3** (7), 82-87.

ONWUAMA, K. T., SALAMI, S. O., ALI, M. and NZALAK, J. O. 2012. Effects of different methods of bone preparation on the skeleton of the African giant pouched rat (*Cricetomys gambianus*). *International Journal of Morphology,* **30** (2), 425-427.

PACHECO, V. 2019. A capture of a lesser bandicoot rat *Bandicota bengalensis* (Rodentia, Muridae) at Callao Port, Peru: anecdotal record or potential invasive alien species? *Revista Peruana de Biología,* **26** (4), 525-528.

PANKAKOSKI, E., VÄISÄNEN, R. A. and NURMI, K. 1987. Variability of muskrat skulls: measurement error, environmental modification and size allometry. *Systematic Zoology,* 36, 35-51.

PÉREZ, M. J., BARQUEZ, R. M. and DÍAZ, M. M. 2017. Morphology of the limbs in the semi-fossorial desert rodent species of *Tympanoctomys* (Octodontidae, Rodentia). *ZooKeys,* **710** (710), 77-96.

RALLS, K. 1977. Sexual dimorphism in mammals: avian models and unanswered questions. *The American Naturalist,* **111** (981), 917-938.

ROLIAN, C. 2008. Developmental basis of limb length in rodents: evidence for multiple divisions of labor in mechanisms of endochondral bone growth. *Evolution & Development,* **10,** 15-28.

ROMMEL, S. and REYNOLDS, J. E. 2009. Skeleton, postcranial. In: *Encyclopedia of Marine Mammals (Second edition).* (Ed., Perrin, W. F., Würsig, B., Thewissen, J.G.M.). Academic Press, pp. 1021-1033.

SALAMI, S. O., ONWUAMA, K. T., BYANET, O., IBE, S. C. and OJO, S. A. 2011. Morphological studies of the appendicular skeleton of the African giant pouched rat (*Cricetomys gambianus*) part (ii) pelvic girdle. *Journal of Veterinary Medicine and Animal Health,* **3** (7), 88-93.

SATHER, J. H. 1956. Skull dimensions of the great plains muskrat, *Ondatra zibethicus cinnamominus*. *Journal of Mammalogy,* **37**, 501-505.

SHOMA, S. F., FEEROZ, M. M. and HASAN, M. K. 2015. Morphometry of Asian House Shrew (*Suncus murinus*) in Jahangirnagar University Campus. *Bangladesh Journal of Zoology,* **43** (2), 313-319.

SONI, G., DHALL, U. and CHHABRA, S. 2013. Determination of sex from humerus: discriminant analysis. *Australian Journal of Forensic Sciences,* **45** (2), 147-152.

SUZUKI, S., ABE, M. and MOTOKAWA, M. 2012. Integrative study on static skull variation in the Japanese weasel (Carnivora: Mustelidae). *Journal of Zoology,* **288** (1), 57-65.

VOSS, R. S. and MARCUS, L. F. 1992. Morphological evolution in muroid rodents II. Craniometric factor divergence in seven Neotropical genera, with experimental results from *Zygodontomys*. *Evolution,* **46** (6), 1918-1934.

WOODMAN, N. and STABILE, F. A. 2015. Functional skeletal morphology and its implications for locomotory behavior among myosoricine shrews (Mammalia: Eulipotyphla: Soricidae). *Journal of Morphology,* **276** (5), 550-563.

ZHANG, Z. G. and GE, D. Y. 2014. Postnatal ontogenetic size and shape changes in the craniums of plateau pika and woolly hare (Mammalia: Lagomorpha). *Zoological Research,* **35**, 287-293.

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