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Skull Morphometric of Hares Collected from Three Geographic Regions in Sudan

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A B S T R A C T

This study was based on 96 hares (*Lepus sp*.) obtained from three geographic regions separated by the Nile and it's tributaries in Sudan during 2012 and 2015, in order to determine the skull craniometric variations. The parameters measured were the anterior nasal width (ANW); external nasal length (ENL); foramen incisivum length (FIL); foramina incisive width (FIW); facial tubercle length (FTL); internal nasal length (INL); lower cheek tooth row length (LCTRL); upper cheek-tooth row length (UCTRL); mandible height (MH); mandible length (ML); palatal lh (PL); posterior nasal width (PNW); post palatal width (PPW); posterior zigomatic width (PZW); rostral width (RW); smallest frontal width (SFW); tympanic bulla length (TBL); tympanic bulla width (TBW); and width between facial tubercles (WFT). It was found that the parameters from east and west of the Nile were similar, but greater than their counterparts between the Blue Nile and the White Nile tributaries of the Nile.). Tympanic bulla width was wider in males compared with females. It is concluded that hares from the three regions are likely not conspecific but are sexually dimorphic.

Introduction

Environmental factors are important determinants of postnatal skull ontogeny (Hall, 1990) and final body size (Yom-Tov and Geffen, 2006). The body and skull sizes of animals are usually considered positively correlated with a decrease in temperature. This is known as Bergmann's rule. Although body mass is the most common reference point for size (Meiri *et al*., 2004), food availability and fasting endurance are the main determinants of body size (Millar and Hickling, 1990), and seasonal changes in body mass have been observed in many mammalian species. Thus, unlike body mass, the skeleton of mammals is a comparatively stable feature. Liao *et al*. (2006) revealed that Bergmann's rule is not universally valid for interpreting animal body size clines, particularly in large mammalian species. Contrarily, Yom-Tov

(1967) stated that Israeli hares showed direct clinal variation from south to north in body and cranial measurements, depending on the mean annual temperature and precipitation.

The term skull has been used to describe the entire skeleton of the head. The skull is both a highly modular and a highly integrated structure. The skull is divided into three primary units, the face, neurocranium and basicranium. The brain case provides protection for the brain and opening for cranial nerve connections, the bone of the face provides a location and protection for the organs of special senses and openings for the digestive and respiratory system. The skull is a mosaic of many bones, mostly paired, but some median and unpaired fit closely together to form a single rigid construction (Reece 2009; Dyce *et al*., 2010).

The shape of the head and skull influences the dynamic of the locomotion and balance. The specific characteristics of a skull often reflect the animal methods of feeding and effect on the muscle of mastication (Olude and Olopade, 2010). Skulls differ largely, not only between different species and breeds but also between individuals of the same breeds, age and sex (Koing and Liebich, 2004). Studies of the skull of different animal species continue to be a growing area of applied research, the values obtained from such studies are used in osteoarcheological and morphological fields (Shawulu *et al.,* 2011; Yahaya *et al.,* 2011).

The objective of this study was to determine the general skull measurements of hare populations from three geographically separated regions: East of the Nile, West of the Nile and between the Blue Nile River and the White Nile River, and to test that hare populations in the three regions are neither conspecific nor sexually dimorphic.

Materials and Methods

This study was based on skulls of 96 hares obtained from three geographically separated regions in Sudan during 2012 and 2015. Field work was performed under the surveillance of Wildlife Conservation General Administration. The study focused on variation in measurements of skulls belonging to the *Lepus* sp. form three regions which were East of the Nile, West of the Nile and between the Blue Nile River and the White Nile river (Table 1).

Skull measurements

Twenty parameters of the skull bones were measured for hares collected from the regions with digital calipers to the nearest0.01 mm, following Riga *et al*. (2001) method. The parameters were the anterior nasal width (ANW); external nasal length (ENL); foramen incisivum length (FIL); foramina incisive width (FIW); facial tubercle length (FTL); internal nasal length (INL); lower cheek tooth row length (LCTRL); upper cheek tooth row length (UCTRL); mandible height (MH); mandible length (ML); palatal length (PL); posterior nasal width (PNW); post palatal width (PPW); posterior zigomatic width (PZW); rostral width (RW); smallest frontal width (SFW); tympanic bulla length (TBL); tympanic bulla width (TBW); and width between facial tubercles (WFT) (Fig 1 and Fig. 2).

Measurements were subjected to analysis of Variance, LSD for means' separation and T-test by using SPSS version 22.

Results and Discussion

The data analysis was presented in table (2). Among the 20 skull measurements, only 8 (40 %) measurements varied among the three geographic regions, these were anterior nasal width (ANW), external nasal length (ENL), lower cheek tooth row length (LCTRL), upper cheek tooth row length (UCTRL), mandible height (MH), tympanic bulla length (TBL), Posterior nasal width (PNW) and Tympanic bulla width (TBW).

Anterior nasal width (ANW) was wider ($P < 0.001$) in the western region (11.70 ± 90 mm, n = 19) and the eastern region (11.43 ± 1.1 mm, n = 59) than the region between the two rivers (10.59 ± 0.5 mm, n = 18). The same trend was indicated by the (PNW) which was about equal in the western region (17.12 ± 1.8 mm, n =19) and eastern region (16.92 ± 2.1 mm, n = 59) but was wider ($P < 0.019$) than the region between the two rivers (15.51 ± 1.7 mm, n = 18). TBW was different among the three regions ($P < 0.001$); it was about the same in the western and the eastern region (8.43 ± 0.6 mm vs 8.52 ±0.9 mm, n = 19 and 59, respectively) but narrower between the two rivers (6.77 ± 1.3 mm, n = 18).

External nasal length (ENL), TBL and MH had similar trends. ENL in the Western and the Eastern geographic regions were about equal (31.87 ± 2.7 mm vs 31.77 ± 3.5 mm) but were longer ($P < 0.03$) than ENL between the two rivers (29.46 ± 3.4 mm). Having a similar trend as ENL, respective values of TBL in the Western region were 13.5 ± 0.7 mm, (n = 19), in the Eastern region 13.17 ± 1.2 mm (n = 59). TBL in these two regions, however, were wider ($P< 0.001$) than their counterpart between the two rivers. Similarly, MH in the western region (37.10 ± 2.6 mm n = 19) and the Eastern region (36.35 ± 3.6, n = 59) were equal, but were longer ($P < 0. 045$) than that between the two rivers (34.46 ± 2.8, n = 18).

Lower cheek tooth row length (LCTRL) and upper cheek tooth row length (UCTRL) had similar trend. LCTRL in the Western and the between the two rivers geographic regions were about equal (14.62 ± 1.0 mm vs 14.10 ± 1.1 mm) but were wider ($P < 0.007$) than LCTRL in the Eastern region (13.69 ± 1.2mm).UCTRL in the Western and the between the two rivers geographic regions were about equal (14.47 ± 1.1 mm vs 13.69 ± 1.0 mm) but were wider ($P < 0.027$) than UCTRL in the Eastern region (13.62 ± 1.0mm).

All the skull measurements of males and females were equal except tympanic bulla width (TBW) which was different ($P < 0 .01$) among the three geographic regions (Table 3). Generally, TBW in the males was wider (8.00 ± 1.1 mm, n = 19) than that of the females (7.72 ± 1.0 mm, n = 19), suggesting that hares are sexually dimorphic.

Table.1 Skullsof hares examined from three geographic regions in Sudan.

Geographic region	Female	Male	Total
East of River Nile.	29	30	59
West of the River Nile.	10	9	19
Between Blue and White Rivers.	13	5	18

Table.2 some skull measurements of hares collected from three geographic regions in Sudan (2012 and 2015).

Geographic region	Parameter								
	ANW	ENL	FIW	FTL	INL	FIL	LCTRL	UCTRL	MH
East (n = 59)	11.43±1.1[a]	31.77±3.5[a]	8.71±0.9	8.46±0.9	28.64±3.4	19.65±2.2	13.69±1.2[b]	13.62±1.3[b]	36.35±3.6[a]
West (n = 19)	11.70±0.9[a]	31.87±2.7[a]	8.74±0.9	8.38±0.6	29.04±2.5	19.73±2.2	14.62±1.0[a]	14.47±1.0[a]	37.10±2.6[a]
Between Blue and White Nile (n= 18)	10.59±0.5[b]	29.46±3.4[b]	8.57±0.8	8.11±0.9	26.76±3.9	18.78±2.2	14.10±1.1[ab]	13.69±1.1[ab]	34.46±2.8[b]
95 % Confidence	11.12-11.53	30.66-32.05	8.51-8.87	8.20-8.55	27.68-29.06	19.06-19.94	13.73-14.21	13.55-14.05	35.45-36.83
P-values	0.001	0.032	0.823	0.350	0.076	0.290	0.007	0.027	0.045

ANW: Anterior nasal width.
ENL: External nasal length.
FIW: Foramina incisive width.
FTL: Facial tubercle length.
INL: Internal nasal length.
FIL: Foramen incisivum length.
UCTRL: Upper cheek-tooth row length.
LCTRL: Lower cheek-tooth row length.
MH: Mandible height.
ML: Mandible length.

Cont. **Table.2** some skull measurements of hares collected from three geographic regions in Sudan (2012 and 2015).

Regions.	Parameter									
	PNW	PPW	RW	SFW	TBL	TBW	PL	PZW	TL	WFT
East (n=59)	16.92±2.1[a]	7.02±0.8	21.51±1.4	12.33±0.8	13.17±1.2[a]	8.52±0.9[a]	31. 17±3.2	37.60±2.6	78.18±6.7	33.92±2.5
West (n=19)	17.12±1.8[a]	6.96±0.6	21.67±1.1	12.31±0.9	13.50±0.7[a]	8.43±0.6[a]	31.38±3.0	38.10±1.9	79.54±4.9	34.88±2.2
Between Blue and White Nile (n=18)	15.51±1.7[b]	6.77±0.6	21.61±0.9	12.31±0.9	12.22±0.9[b]	6.77±1.3[b]	29.86±3.1	37.48±2.0	75.30±6.8	33.19±1.9
95%Confedance	16.29-17.11	6.82-7.11	21.30-21.82	12.10-12.45	12.83-13.29	7.59-8.13	30.32-31.61	37.20-38.15	76.59-79.23	33.49-43.46
P-valuses	0.019	0.431	0.88	0.751	0.001	0.000	0.256	0.678	0.124	0.094

PNW: Posterior nasal width.
PPW: Post palatal width.
RW: Rostral width.
SFW: Smallest frontal width
TBL: Tympanic bulla length
TBW: Tympanic bulla width
PL: Palatal length.
PZW: Posterior zigomatic width.
TL: Total length.
WFT: Width between facial tubercles
.

Table.3

Table.3 Some skull measurement of hares' sex collected from three geographic regions in Sudan (2012 and 2015).

Sexes	Parameter									
	ANW	ENL	FIW	FTL	INL	FIL	LCTRL	UCTRL	MH	ML
Male (n=44)	11.29±1.0	31.48±3.5	8.64±0.9	8.4±0.8	28.36±3.4	19.49±2.0	14.06±1.3	13.88±1.3	36.17±3.4	57.47±4.80
Female (n=52)	11.33±2.0	31.14±3.4	8.71±0.9	8.35±0.9	28.28±3.5	19.40±2.3	13.87±1.1	13.71±1.3	36.01±3.5	56.62±4.86
P-values	0.728	0.686	0.760	0.096	0.785	0.176	0.692	0.349	0.513	0.313

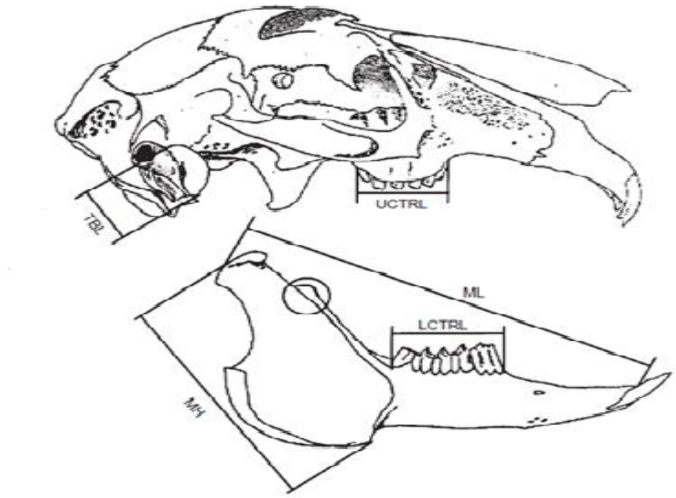
ANW: Anterior nasal width
ENL: External nasal length
FIW: Foramina incisive width.
FTL: Facial tubercle length.
INL: Internal nasal length.
FIL: Foramen incisivum length.
UCTRL: Upper cheek-tooth row length.
LCTRL: Lower cheek-tooth row length
MH: Mandible height.
ML: Mandible length.

Table 3:Cont. : Some skull measurement of hares sex collected from three geographic regions in Sudan (2012 and 2015).

Sex	Parameter									
	PNW	RW	PPW	SFW	TBW	TBL	PL	PZW	TL	WFT
Male (n=44)	16.74±2.0	21.47±1.3	7.07±0.8	12.07±0.8	8.0±1.1	13.14±1.1	30. 98±3.1	37.65±2.8	78.1±6.4	34.03±2.3
Female (n=52)	16.58±2.0	21.62±1.3	6.9±0.7	12.47±0.9	7.72±1.5	12.95±1.2	30.83±3.3	37.63±2.0	77.63±6.8	33.88±2.5
P-values	0.810	0.795	0.868	0.739	0.013	0.361	0.156	0.09	0.257	0.63

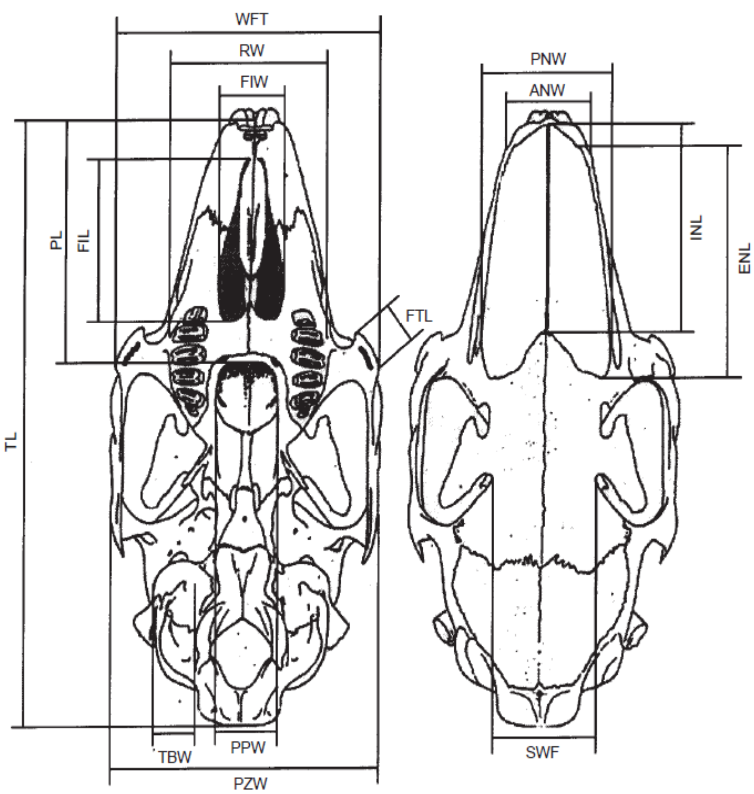
PNW: Posterior nasal width.
PPW: Post palatal width.
RW: Rostral width.
SFW: Smallest frontal width
TBL: Tympanic bulla length
TBW: Tympanic bulla widuth
PL: Palatal length.
PZW: Posterior zigomatic width.
TL: Total length.
WFT: Width between facial tubercles

Fig.1 The skull measurements of hares (Riga, *et al.*, 2001).



UCTRL: Upper cheek-tooth row length.TBL: Tympanic bulla length.
LCTRL: Lower cheek-tooth row length.MH: Mandible height. ML: Mandible length.

Fig.2 The skull measurements of hares (Riga, *et al.*, 2001).



PNW: Posterior nasal width.TBW: Tympanic bulla width.
WFT: Width between facial tubercles; ANW: Anterior nasal width. ENL: External nasal length
FIL: Foramen incisivum length; FIW: Foramina incisive width; INL: Internal nasal length.
FTL: Facial tubercle length; PL: Palatal length; PPW: Post palatal width; RW: Rostral width.
PZW: Posterior zigomatic width. SFW: Smallest frontal width, TL: Total length.

The study findings that ANW, PNW, TBW, ENL, TBL and MH have larger sizes in the western and the Eastern geographic regions than those in the region between the Blue Nile and the White Nile rivers this give three implications. First, patterns of craniometric variations in hares comply with Bergmann's rule that states that within a broadly distributed taxonomic clade, populations and species of larger size are found in colder environment, and species of smaller sizes are found in warmer regions; second, an increase in skull size is related to increase in food availability (Yom-Tov and Geffen, 2006). Furthermore, the geographical barriers prevent range expansions of terrestrial species such that isolation periods have had a decisive importance in determining differentiation in mammals (Schmitt, 2007). Third, craniometric variations reflect genetic variations andhabitat types. While the LCTRL and UCTRL have wider sizes in the western and the between the Blue Nile and the White Nile rivers geographic regions than those in the eastern region and this attributed to the high humidity and rich nutrition. The researcher suggests that variations of skull features are caused by species adaptation to climatic conditions and habitat type. In addition, results found 12parameters of skull measurements, no varied among the three geographic regions, more or less revealed agreed with Demirbas *et al.,* (2013) they found Turkish hares did not show a direct clinal variation from south to north in body and cranial measurements depending on the mean annual temperature and precipitation. Also this research in line with Temizer and Önel (2011) they determined that there was no difference in terms of cranial measurements between Malatya and Elazığ specimens in Anatolia, where the populations are close to each other.

Skulls differ largely, not only between different species and breeds but also between individuals of the same breed, age and sex (Koing and Liebich, 2004). The specific characteristics of a skull often reflect the animal methods of feeding and effect on the muscle of mastication (Olude and Olopade, 2010). Historically, subspecies of hares are basically classified on the morphological features of the skull and teeth (Suchentrunk *et al*., 2003; Palacios *et al*., 2008). Xin (2003) suggests that analysis of skull development between different animal species exposed to different selection pressure can contribute to understanding of geographical variations of particular populations, as well as life history strategies and evolutionary change. Yoram and Shlomith (2012) they found that skull size of the red fox (but not of that of thejackal and the hare) increased significantly during the 20th century.

The study indicated that only TBW could be useful for determining sexual dimorphism in hares, this was more or less agreed with Krunoslav *et al.,* (2014) who reported significant variations in skull measurements between hares due to location, tending to be greater for hares from the northwest Croatia region. But no variations in measurements according to sex were not significant for both sites

In conclusion, hares occurring East, West of the Nile and between the Blue Nile and the White Nile are sexually dimorphic but are likely not conspecific.This study is the first to use skull measurements for hares populations in Sudan. Further research may study to verify this.

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