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Macroanatomical investigations of the skulls of both genders of *Heliosciurus gambianus* (Gambian sun squirrel) and *Funisciurus anerythrus* (Thomas's rope squirrel)

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Abstract

Background The skull shape and morphometry have been used by several researchers to differentiate and classify species, breeds and also to age the specimen. This study highlights details of the gross morphometry of the skulls of two species of squirrels, *Heliosciurus gambianus* and *Funisciurus anerythrus*, using both sexes.

Results A total of thirty-one (31) linear morphometric parameters were measured on each skull specimen, relating to individual bones. Results were presented as mean ± standard deviation with significant difference at ($P < 0.05$). Linear measurements were similar in both genders, although some were negligibly higher in females (51.61% in *H. gambianus*, 70.96% in *F anerythrus*); no statistically significant difference was observed ($P > 0.05$). In spite of the similarity in shape, size and linear morphometric values obtained in both species, Pearson's correlation analysis of the skull height with other measured parameters gave widely differing results. Correlation data obtained may be used to understand better the pattern of the skull development in these squirrels, as well as how it differs from those obtained in other mammals. Examination of the dentition revealed a varied dental formula across the two species, relating to the presence or absence of the upper and lower premolars.

Conclusions The results obtained in this study may find application in the fields of comparative anatomy and forensics as well as provide basis for future research in ageing, skull development and feeding patterns in these species.

Keywords Skull morphometry, Dental formula, *Heliosciurus gambianus*, *Funisciurus anerythrus*, Squirrel

Background

Squirrels are warm-blooded rodents found indigenously in Africa, the Americas, Eurasia; they were introduced by humans to Australia (Boris et al., 2016). The squirrel family includes tree squirrels, ground squirrels, chipmunks, marmots (including woodchucks), flying squirrels, and prairie dogs, among other rodents. They make up a diverse group consisting of approximately 279 species, 51 genera and five subfamilies: Ratufinae, Sciurillinae, Sciurinae, Xerinae and Callosciurinae (Lurz, 2011; Thorington & Hoffmann, 2005).

Squirrels are generally small animals ranging in size from the African Pygmy squirrel at 7–10 cm in length and just 10 g in weight, to the Laotian giant flying squirrel at 1.08 m in length and the Alpine marmot which weighs from 5 to 8 kg (Thorington & Ferrell, 2006). They can survive in a wide variety of habitats, from tropical rainforest to the semi-arid desert, avoiding only the high

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polar regions and very dry deserts. They are herbivores, feeding predominantly on seeds and nuts but some feed on insects and even smaller invertebrates (Brown et al., 2014; Lurz, 2011). Squirrels have an excellent sense of vision, which is particularly important for their tree living lifestyle. They have an average lifespan of 5–10 years in the wild and up to 20 years in captivity (Essner, 2007; Thorington et al., 2012).

Skull size and shape have been widely used in medical research and also to study domestic animal populations and breeds (Heck et al., 2018, 2019). The skulls of most squirrels are short, with a short rostrum and an arched profile. The skull has a broad, tilted zygomatic plate that serves as the attachment point for the lateral branch of the masseter muscle. The superficial branch of masseter muscle originates on a prominent bump of bone on the side of the rostrum, called the masseteric tubercle (Hautier et al., 2010). They have small infraorbital foramen that is not enlarged to transmit muscle as it is in myomorphous (mice and rats) and hystricomorphous (cavies and guinea pigs) rodents (Cox & Jeffery, 2011).

These rodents have long jugals, well-developed postorbital processes and large bullae that are not inflated. The anterior ends of the jugals contact the frontals, and the palate is broad and relatively short, ending at the same level as the molar row. The zygomasseteric architecture of skulls is sciuromorphous (Cox et al., 2012; Hautier et al., 2010).

The Gambian sun squirrel (*Heliosciurus gambianus*) is a species of rodent in the family Sciuridae. It inhabits wooded savannah and other grassland with scattered trees, moving through the branches but sometimes descending to the ground (Grubb & Ekué, 2008; Kingdon, 2015). Thomas's rope squirrel (*Funisciurus anerythrus*) is also a species of rodent in the family Sciuridae, weighs between 200 and 220 g, has a head and body length ranging between 16 and 23 cm and a tail length between 13 and 20 cm (Kingdon, 2015; Thorington & Hoffmann, 2005).

Morphometry is the quantitative analysis of size, shape and has always been vital to taxonomic classification (Kraatz & Sherratt, 2016; Marques et al., 2021). Its diversification could be interpreted as the consequence of the contrasting impacts of developmental constraint and adaptation to ecological factors (Meloro, 2011). Commonly, the field of morphometrics is divided into traditional or multivariate morphometrics and geometric morphometrics. The former term refers to the application of multivariate statistics to linear measurements and ratios, whereas the latter concerns the development of coordinate-based methods (Webster & Sheet, 2010).

Traditional linear measurement analysis is fundamental for the quantitative comparison of morphological variation. There are few reports on information using linear measurement to determine the skull size and shape of these squirrels. This study therefore aims to compare the gross morphometry of the skulls of *Heliosciurus gambianus* and *Funisciurus anerythrus*.

Methods

Aim

The study aim was to conduct a macroanatomical investigation of the skulls of two species of squirrels—*Heliosciurus gambianus* and *Funisciurus anerythrus*, by analysing differences and similarities in the individual bones and dentition.

Study design and setting

Twenty-nine (29) squirrels of two different species, 9 of *Heliosciurus gambianus* squirrel (6 males, 3 females) and 20 of *Funisciurus anerythrus* (8 males, 12 females), were used for this study. The squirrels were estimated to be adults, based on weight, using previously documented references (Kingdon et al., 2015). Ethical approval was obtained from the Animal Care and Use Research Ethics Committee of the University (with ethical code number NHREC/UIACUREC/05/12/2022A). The squirrel heads were mostly sourced from different research units using squirrels, to make up the number. They were trapped in the wild, using cages with food as bait, from the University of Ibadan environment. All the squirrels were handled humanely, transported in cages and identified by an animal taxonomist using the field guides outlined in previous reports (Happold, 1987; Kingdon, 2015). They were euthanised with an intramuscular injection of xylazine 6 mg/kg and ketamine HCl at 150 mg/kg, adapted from previous reports (Igado et al., 2021). The animals were eviscerated and skinned, and all muscles were removed as much as possible. Animals were tagged individually for easy identification. All animals were humanely handled according to The Guide for Care and Use of Laboratory Animals, NIH, USA (2011).

Hot water maceration The heads were decapitated at the atlanto-occipital junction and macerated individually in labelled plastic containers. The skulls were macerated using the hot water maceration method as earlier described (Igado & Ekeolu, 2014).

Morphometry Linear skull measurements were determined with the aid of a digital vernier caliper, centimetre rule, mathematical dividers and compass to the nearest 0.01 mm (Igado, 2014; Igado & Ekeolu, 2014). A total of thirty-one (31) parameters were determined on each skull. Landmarks for all parameters are highlighted in Figs. 1, 2 and 3. The parameters measured were whole skull height (WSH); whole skull length (WSL); skull height without the mandible (SWHM

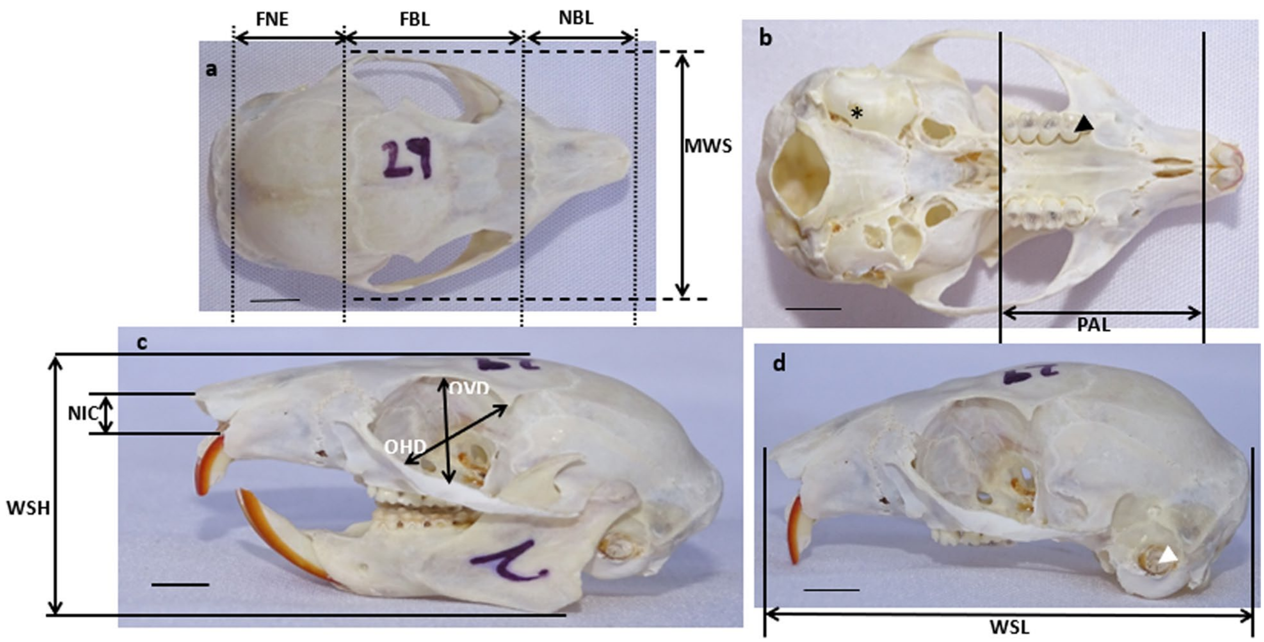

Fig. 1 Skull of the male Gambian sun squirrel (*Heliosciurus gambianus*). Dorsal view **a** of the male showing the length of the parietal—FNE, the total length of the frontal bone—FBL, the overall length of the nasal bone—NBL, and the maximum width of the skull, MWS, from zygoma to zygoma. Panel '**b**' is the ventral view, showing the length of the palate—PAL, black arrowhead indicates 1st premolar, and asterisk (*) indicates the bulla. Panels '**c**' and '**d**' are the lateral views with and without the mandible, respectively. OVD—vertical diameter of the orbit, OHD—horizontal diameter of the orbit, WSH—whole skull height, NIC—distance between nasal and incisive bones (accommodating the conchae), WSL—maximum skull length, white arrowhead indicates the auditory meatus. Scale bars—0.5 cm

1); maximum width of the skull (MWS); total length of the frontal bone (FBL); overall length of the nasal bone (NBL); length of parietal bone (FNE); length of the mandibular bone (MDL); mandibular symphysial length (MSL); length of palate (PAL): orbital height/vertical diameter (OVD); orbital width/horizontal diameter (OHD); height of the foramen magnum (FMH); width of the foramen magnum (FMW); occipital height (OCH); occipital height without foramen magnum (OCHW); maximum width of the occipital condyles (OCW); distance between the most medial points of the most rostral left and right mental foramen (RMF); length along a horizontal line, from the ventral limit of the mandibular foramen to the caudal border of the mandible (MFCB); length along a vertical line, from the ventral limit of the mental foramen to the ventral border of the mandibular foramen (MFMF); length along a vertical line, from the ventral limit of the mandibular foramen to the base of the mandible (MFMB); length along a vertical line, from the ventral limit of the mandibular foramen to the most dorsal aspect of the coronoid process (MFCP); length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the coronoid process (MDL-1); length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the mandibular condyle (condylar process) (MDL-2); length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the angular process (MDL-3); height of the mandibular body between the mid-point of premolar 1 and 2 and the mandibular base (HMP); thickness of mandible at molar 1 (TM-1); length of the mandible between the cranial and caudal angles (RAM); distance from the rostral tip of the nasal bone to the rostral tip of the incisive bone (NIL); height of the mandibular symphysis (HSPh); length of the mandibular symphysis (LSPh).

The foramen magnum index (FMI) was calculated as (FMH/FMW) × 100 and expressed in percentage.

All pictures were obtained with a Sony® Cyber-shot digital still camera (DSC-HX400/HX400V).

Statistical analysis

Linear morphometric values obtained were presented as mean ± standard deviation. Data obtained for sexes and between species were subjected to Student's t test, while relationship between parameters was determined by Pearson's correlation analysis. GraphPad Prism (v. 6) software package was used for this analysis, and values of $P < 0.05$ were considered statistically significant.

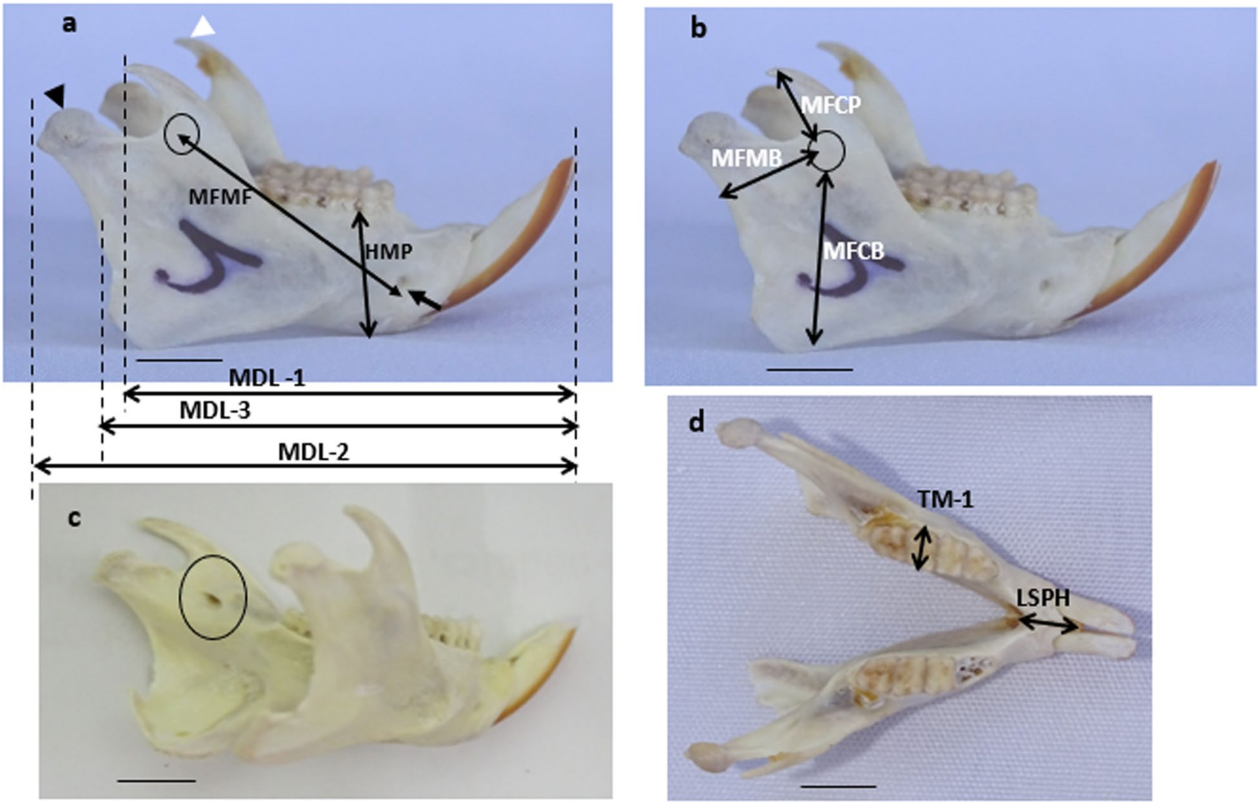

Fig. 2 Right lateral (**a** and **b**), latero-medial (**c**) and dorsal (**d**) views of the mandible of the male Gambian sun squirrel (*Heliosciurus gambianus*). MDL-1, 2 and 3 depict distance from the mandibular foramen (black circle) to the coronoid process, condylar process and angle of mandible, respectively; black arrow (in 'a')—mental foramen; white arrowhead—coronoid process; black arrowhead—condylar process; black circle depicts the position of the mandibular foramen, which is visible on the medial surface of the mandible (c); TM-1 is the thickness of the mandible at molar 1, while LSPH is the length of the mandibular symphysis. Scale bars—0.5 cm

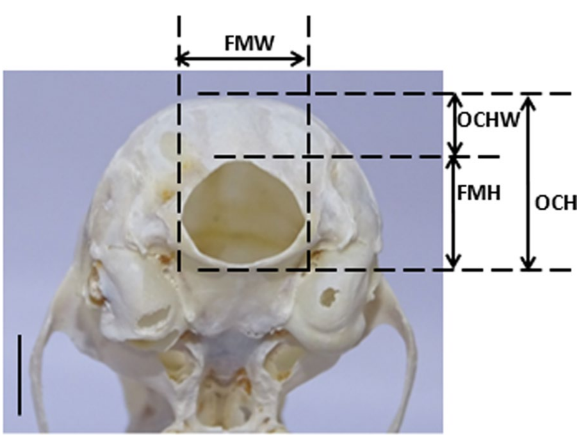

Fig. 3 Caudal (occipital) view of the skull of the male Gambian sun squirrel (*Heliosciurus gambianus*), the width of the foramen magnum (FMW), height of the foramen magnum (FMH), whole height of the occiput (OCH) and height of the occiput without the foramen magnum (OCHW)

Results

General appearance

The skulls of the two species were identical in shape, differing only in size, with *H. gambianus* being bigger than *F. anerythrus*. The skulls had the typical rodent appearance with very prominent and protruding upper and lower incisors. The zygoma was wide and prominent, while the nasal, frontal and parietal bones were flattened (Figs. 1, 2). The shape of the foramen magnum in both species was consistent in all specimens examined, having the typical circular appearance, but possessing a very slight notch at the dorsal aspect (Fig. 3). No sexual dimorphism was observed in any of the features.

Skull morphometry

The values obtained from morphometry for both species are presented in Table 1 as means ± standard deviation. Values obtained were similar in both genders; therefore, no statistically significant differences were observed. Although the females had more values which

Table 1 Skull morphometric values of the *Heliosciurus gambianus* and *Funisciurus anerythrus*, expressed as mean ± standard deviation

Parameter (mm)	*Heliosciurus gambianus*		*Funisciurus anerythrus*	
	Male	**Female**	**Male**	**Female**
WSH	24.61 (± 2.22)	23.16 (± 2.65)	22.00 (± 1.03)	22.39 (± 1.44)
WSL	45.28 (± 1.92)	45.99 (± 2.70)	42.08 (± 1.70)	44.14 (± 2.01)
SHWM1	17.97 (± 1.70)	17.19 (± 1.86)	18.16 (± 1.04)	17.61 (± 1.04)
MWS	23.33 (± 3.04)	25.37 (± 0.64)	19.72 (± 3.06)	21.17 (± 2.99)
FBL	18.56 (± 0.48)	17.87 (± 3.77)	19.51 (± 1.01)	19.22 (± 0.94)
NBL	13.40 (± 0.82)	14.14 (± 3.37)	12.26 (± 1.26)	12.42 (± 1.70)
FNE	16.23 (± 2.11)	15.98 (± 1.03)	14.96 (± 0.53)	15.07 (± 1.47)
MDL	25.93 (± 2.17)	20.46 (± 0.57)	27.19 (± 0.75)	24.94 (± 1.40)
MSL	4.614 (± 1.13)	4.27 (± 0.37)	4.12 (± 0.30)	4.30 (± 0.67)
PAL	32.42 (± 3.71)	32.60 (± 0.56)	30.26 (± 2.76)	29.84 (± 2.43)
OVD	11.39 (± 1.32)	12.82 (± 2.67)	9.65 (± 0.70)	10.22 (± 0.94)
OHD	15.81 (± 2.40)	17.96 (± 0.08)	11.99 (± 0.40)	14.95 (± 3.01)
FMH	6.31 (± 0.56)	6.03 (± 0.14)	5.92 (± 0.40)	6.50 (± 0.31)
FWM	7.04 (± 0.63)	6.55 (± 1.03)	6.65 (± 0.54)	7.07 (± 0.54)
FMI	90.05 (± 4.06)	93.46 (± 17.81)	89.05 (± 1.54)	92.36 (± 7.05)
OCH	12.12 (± 0.89)	12.95 (± 0.46)	11.42 (± 1.39)	12.26 (± 0.98)
OCHW	6.36 (± 0.79)	7.26 (± 0.59)	6.65 (± 0.66)	7.69 (± 2.05)
OCW	20.0 (± 1.97)	19.6 (± 1.04)	20.72 (± 2.79)	17.61 (± 4.33)
RMF	4.96 (± 0.78)	4.67 (± 0.75)	4.53 (± 0.56)	4.59 (± 0.51)
MFCB	9.20 (± 1.02)	9.94 (± 0.59)	7.42 (± 0.75)	8.20 (± 0.91)
MFMF	15.26(± 1.06)	15.47 (± 0.51)	13.75 (± 0.59)	14.73 (± 1.12)
MFMB	8.45 (± 1.08)	7.94 (± 0.92)	8.05 (± 0.23)	7.96 (± 0.46)
MFCP	5.92(± 0.55)	5.8 (± 0.47)	5.83 (± 0.49)	6.46 (± 1.14)
MDL-1	25.39(± 3.37)	26.31 (± 1.33)	25.71 (± 2.53)	24.51 (± 2.19)
MDL-2	27.95(± 1.01)	29.51 (± 0.56)	28.29(± 2.44)	28.45(± 1.85)
MDL-3	26.36(± 1.08)	27.5(± 0.28)	23.80(± 3.26)	25.04 (± 2.22)
HMP	8.47 (± 0.73)	7.25 (± 1.41)	8.08 (± 0.30)	7.83 (± 0.62)
TM-1	5.60 (± 1.06)	5.65 (± 0.36)	5.37 (± 0.30)	5.18 (± 0.44)
RAM	9.31 (± 0.52)	8.03 (± 3.66)	8.34 (± 1.08)	8.53 (± 1.01)
NIL	13.38 (± 1.12)	15.37 (± 2.02)	12.59 (± 2.24)	13.19 (± 1.91)
HSPH	4.35 (± 0.98)	5.31 (± 1.19)	4.09 (± 0.42)	4.26 (± 0.58)
LSPH	4.46 (± 1.00)	3.79 (± 0.21)	3.78 (± 0.55)	3.82 (± 0.30)

Definitions of abbreviations are given in materials and methods

were negligibly higher, this could not be regarded as of any importance (Table 1).

Correlating WSH with other parameters using Pearson's correlation (r) showed that for the *H. gambianus* skulls, WSH had significant positive correlation with OVD, FMW, RMF, HMP and TM-1 (0.74, 0.76, 0.67, 0.62 and 0.60, respectively) and significant negative correlation with OCHW (− 0.77) (Table 2).

In *F. anerythrus*, there was a significant positive correlation with RMF and MFCB (0.62 and 0.60, respectively). No negative correlation was recorded (Table 2).

Dentition

All squirrel teeth examined had generalized attrition, which were more pronounced on the occlusal surfaces of all the teeth. There was the presence of prominent orange-fringed stain on the labial surfaces, towards the cervical region, of all examined incisor teeth. Bone resorption was also observed in all examined skulls, especially on the upper molars (palatal surface).

Carious lesions were found on majority of the molars occlusally. There were no observable tooth fractures

Table 2 Pearson's correlation coefficient (*r*) of whole skull height (WSH) against other skull parameters

S/N	Parameters	*r* value	
		H. gambianus	*F. anerythrus*
1	WSL	0.31	0.13
2	SHWM1	− 0.08	− 0.02
3	MWS	0.01	0.12
4	FBL	− 0.51	0.24
5	NBL	− 0.46	0.01
6	FNE	− 0.03	0.28
7	MDL	0.09	− 0.02
8	MSL	0.32	0.35
9	PAL	0.31	0.06
10	OVD	0.74*	− 0.27
11	OHD	− 0.14	0.23
12	FMH	0.54	0.06
13	FWM	0.76*	0.18
14	OCH	− 0.46	0.42
15	OCHW	− 0.77*	0.47
16	CW	− 0.16	− 0.31
17	RMF	0.67*	0.62*
18	MFCB	0.04	0.60*
19	MFMF	0.26	0.14
20	MFMB	0.44	− 0.14
21	MFCP	0.47	− 0.18
22	DL-1	0.19	− 0.19
23	MDL-2	− 0.20	0.07
24	MDL-3	0.22	0.34
25	HMP	0.62*	0.54
26	TM-1	0.60*	0.02
27	RAM	0.35	0.45
28	NIL	− 0.43	− 0.14
29	HSPH	− 0.25	0.17
30	LSPH	0.38	0.27

Definitions of abbreviations are given in materials and methods

*Indicates values of parameters that are significant, positively or negatively correlating with WSH

or dental calculus (calcified dental plaque, composed mainly of calcium phosphate).

The dental formula varied greatly: $I^1/_{0-1}$ $C^0/_0$ $PM^{0-1}/_{0-1}$ $M^4/_4$ and was distributed thus:

$I^1/_1$ $C^0/_0$ $PM^0/_0$ $M^4/_4$—6 *H. gambianus* (3 males, 3 females) and 5 *F. anerythrus* (2 males, 3 females).

$I^1/_1$ $C^0/_0$ $PM^1/_0$ $M^4/_4$—2 *H. gambianus* (2 males, 0 females) and 9 *F. anerythrus* (4 males, 5 females).

$I^1/_0$ $C^0/_0$ $PM^1/_1$ $M^4/_4$—5 *F. anerythrus* (2 males, 3 females). No *H. gambianus* had this dental formula.

Discussion

Morphometry is an important tool in comparing morphological variations between population and species of animals, studying evolutionary changes, including impact of mutation on shape, size and developmental changes (Coker et al., 2020; Kraatz & Sherratt, 2016). Morphological changes and phylogenetic divergence can be tested using Sciurid morphology as a model, because the characteristics of their skeleton are considered to be both conservative and inclined to convergence (Cardini, 2003).

Generally, rodents have highly specialized masticatory musculature, the morphology being classified as the sciuromorph (squirrel-like), hystricomorph (porcupine-like) and myomorph (mouse-like). These descriptions of their skulls and masseter are useful in phylogenetic relationship studies (Hautier et al., 2010). Therefore, in this study we refer to the skull parameter as being sciuromorph.

The growth of the skull and its components in rodents is influenced by sex, breed or strain and their nutritional status. Differences in the cranial parameters of squirrels could be associated with sex, climate change and feeding habit (Bamidele & Akinpelu, 2019). Sexual dimorphism is a common phenomenon in animals, including the squirrel, that has been demonstrated among species, and it is ascribed to different selection pressure which could be natural (Lukas & Clutton-Brock, 2013). In this study, the female squirrels had higher measurements of skull parameters relative to the males. However, there were similarities in some cranial parameters in both sexes. The higher skull parameters in the females in this study could be attributed to the need for fecundity and nurturing of offspring. This result of higher cranial morphometric values in females is similar to previous reports in some other mammals, e.g. the Nigerian local dog (Igado, 2017) and the goat (Olopade & Onwuka, 2008). Reports on skull work on other species of the squirrel did not highlight sexual dimorphism (Bamidele & Akinpelu, 2020a, 2020b). Also, previous reports on weight differences show that the female *H. gambianus* weighed more and were bigger than the male species (Coker et al., 2020). This heavier weight may probably account for the higher cranial values (although not statistically significant), but the reverse was the case in the dog, where the males, although having heavier body weights, had most cranial parameters having lower values (Igado, 2011, 2017).

The skull height naturally increases as the animal advances in age and size. The significant negative correlation (− 0.77) observed in the *H. gambianus*, between the skull height (WSH) and the height of the occiput (OCHW), may probably indicate a relatively smaller neurocranium as the animal progresses in age. Also, the parameters showing a strong positive correlation (OVD, FWM, RMF, HMP and TM-1) with the skull height may indicate a slight change in shape as the animal advances in age. Age-related studies may help shed light on these theories.

The foramen magnum showed a slight variation from what was reported in the *Cricetomys gambianus*—the African giant rat (Olude et al., 2009) where the width of the foramen magnum was higher than the height, giving an oval shape, and the foramen magnum index ranging from 80 to 82%. In the current study, FMH was closer in values to FMW, resulting in a more circular shape of the foramen magnum, and FMI ranging from 89 to 94.4%. In the two rodents (*Cricetomys gambianus* and the 2 squirrel species) studied, the presence of a dorsal notch on the foramen magnum was constant.

In spite of the keen similarity in shape and size of the two species examined (Fig. 4), the correlation data were different, pointing at a possible difference or variation in their skull shape development patterns including ageing and feeding patterns.

The different dental pathologies observed on this species might be due to the different diets (Koyabu et al., 2009) over the course of time. We noticed pronounced generalized attrition on the occlusal surfaces of the teeth; this is quite strange because attrition is commoner on posterior teeth rather than anterior teeth. The abrasive nature of the diet taken might account for the occlusal attrition. Bone resorption is a complication from many dental maladies such as caries, periodontal diseases and dento-alveolar abscesses. Infections can spread from the primary site into the jaw bones ultimately leading to bone pathologies. Dental caries is not common in rodents because of the inhibitive combination of oral pH absence of cariogenic microflora and low sugar diet (Sainsbury et al., 2004). Though caries has been documented to be less common among free range species, we observed

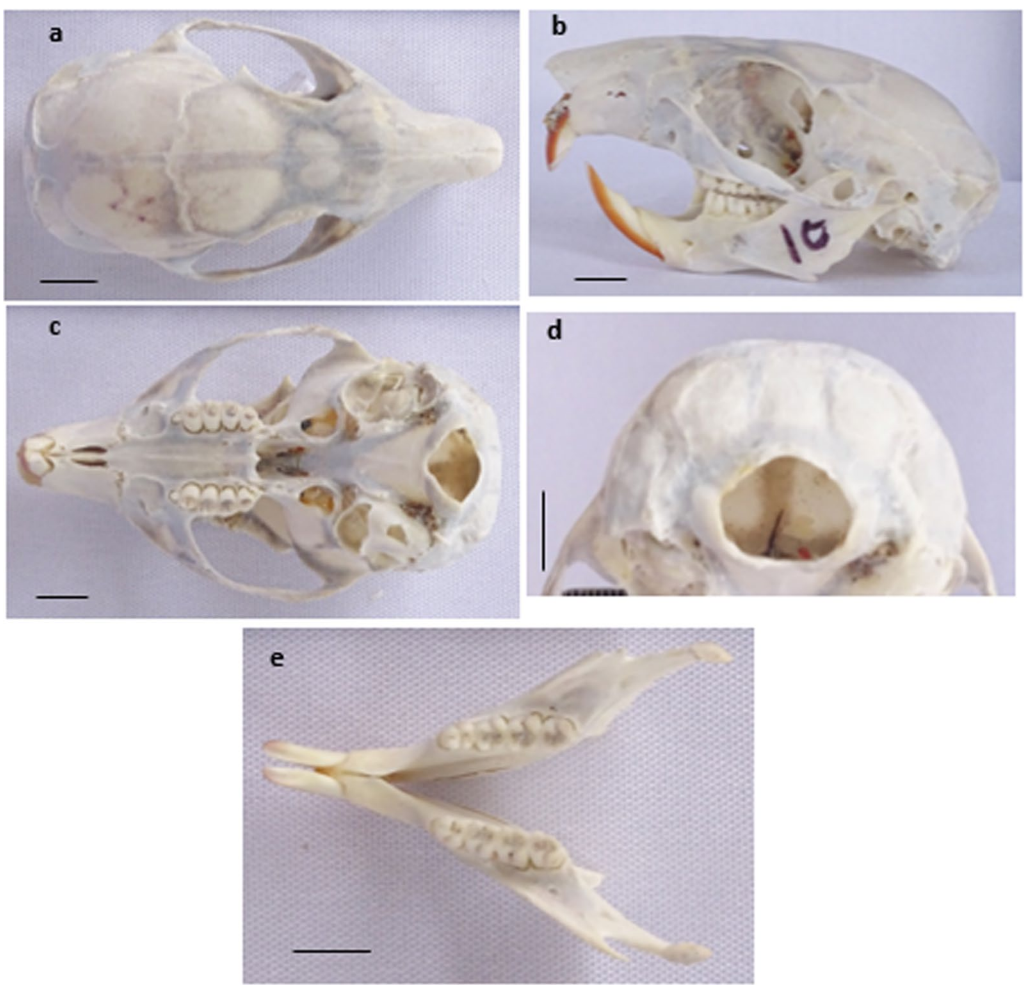

Fig. 4 Dorsal (**a**), lateral (**b**), ventral (**c**), occipital—showing foramen magnum (**d**) views of the skull, and dorsal view of the mandible of the male *Funisciurus anerythrus*. Skulls are similar to that of the *Heliosciurus gambianus*. Scale bars—0.5 cm

occlusal caries in majority of the animals. We opined that the squirrels might have been feeding on food remnants from garbage around the university staff quarters. Lack of observable tooth fractures or dental calculus might also be ascribed to the soft diet and its composition. There were variations in the dental formula of the different species of the squirrels. All the species observed in this study had 4 sets of molars, but the number of incisor and premolar varied with none having canine. Geographic variations, climatic gradients and sexual dimorphism have been documented to account for the variations observed in the dental formula of squirrel species (Watts, 1993). However, we are surprised by the variations observed even within the species used for this study. Human and animal species have developed various adaptive and evolutionary changes in their dentition (Sachdev et al., 2020). The total number of teeth in the species was either 20 or 22 which is in agreement with literatures that also studied the dentition of squirrels but in different species (Miles & Grigson, 1990; Mitchell & Carsen, 1967; Sachdev et al., 2020; Sainsbury et al., 2004).

Conclusions

In cases of surgical intervention or application of local anaesthesia, some of the landmarks highlighted in this study are easily accessible in a restrained animal, making them ideal parameters to assess the position or extent of some nerves. Moreover, data from this study may also be useful in the fields of comparative anatomy, archaeology and forensic odontology.

Abbreviations

WSH	Whole skull height
WSL	Whole skull length
SWHM 1	Skull height without the mandible
MWS	Maximum width of the skull
FBL	Total length of the frontal bone
NBL	Overall length of the nasal bone
FNE	Length of parietal bone
MDL	Length of the mandibular bone
MSL	Mandibular symphysial length
PAL	Length of palate
OVD	Orbital height/vertical diameter
OHD	Orbital width/horizontal diameter
FMH	Height of the foramen magnum
FMW	Width of the foramen magnum
OCH	Occipital height
OCHW	Occipital height without foramen magnum
OCW	Maximum width of the occipital condyles
RMF	Distance between the most medial points of the most rostral left and right mental foramen
MFCB	Length along a horizontal line, from the ventral limit of the mandibular foramen to the caudal border of the mandible
MFMF	Length along a vertical line, from the ventral limit of the mental foramen to the ventral border of the mandibular foramen
MFMB	Length along a vertical line, from the ventral limit of the mandibular foramen to the base of the mandible
MFCP	Length along a vertical line, from the ventral limit of the mandibular foramen to the most dorsal aspect of the coronoid process
MDL-1	Length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the coronoid process
MDL-2	Length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the mandibular condyle (condylar process)
MDL-3	Length of the lower jaw from the most rostral point of the dental bone to the most caudal projection of the angular process
HMP	Height of the mandibular body between the mid-point of premolar 1 and 2 and the mandibular base
TM-1	Thickness of mandible at molar 1
RAM	Length of the mandible between the cranial and caudal angles
NIL	Distance from the rostral tip of the nasal bone to the rostral tip of the incisive bone
HSPh	Height of the mandibular symphysis
LSPh	Length of the mandibular symphysis

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Protocol registration

Before the commencement of the study, the protocol for the study was prepared and was registered with the Animal Care and Use Research Ethics Committee (ACUREC) of the University of Ibadan, Ibadan, Nigeria.

Author contributions

IOO & FOM helped in conceptualization, data analysis, manuscript draft and editing; IOO, FOM & AAO generated the data. All authors approved of the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the ethical committee of the university—Animal Care and Use Research Ethics Committee (ACUREC).

Consent for publication

Not applicable. Animals were used throughout this study.

Competing interests

The authors declare that they have no competing interests.

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