

The inner ear of caviomorph rodents: phylogenetic implications and application to extinct West Indian taxa

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Appendix S2

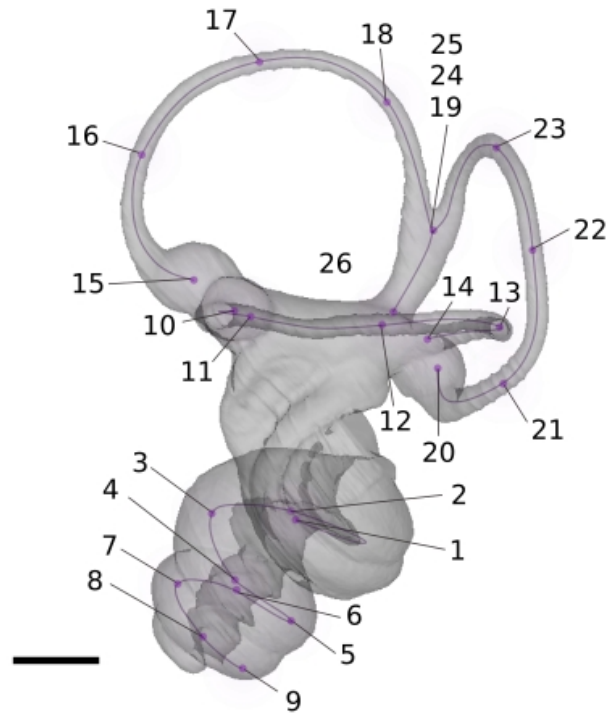


Fig. 1 Position of the landmarks used for creating the curves on the left inner ear of *Pattonomys carrikeri* (USNM 498985). Scale = 1mm

Table 1 Landmarks used for curve definition

N°	Name	Definition
1	Helix basis	Point centered below the cochlear fenestra, on the secondary lamina
2	Helix mediodorsal	Most mediodorsal point of the first turn of the cochlea
3	Helix anterodorsal	Most anterodorsal point of the first turn of the cochlea
4	Helix laterodorsal	Most laterodorsal point of the first turn of the cochlea
5	Helix posterodorsal	Most posterodorsal point of the second turn of the cochlea
6	Helix medioventral	Most medioventral point of the second turn of the cochlea
7	Helix anteroventral	Most anteroventral point of the second turn of the cochlea
8	Helix lateroventral	Most lateroventral point of the second turn of the cochlea
9	Helix posteroventral	Most posteroventral point of the third turn of the cochlea
10	Canalis lateralis ampulla	Center of the ampulla of the lateral semicircular canal
11	Canalis lateralis anterolateral	Most anterolateral point of the lateral semicircular canal
12	Canalis lateralis lateral	Most lateral point of the lateral semicircular canal
13	Canalis lateralis postero-lateral	Most posterolateral point of the lateral semicircular canal
14	Canalis lateralis posterior	Most posterior point of the lateral semicircular canal
15	Canalis anterior ampulla	Center of the ampulla of the anterior semicircular canal
16	Canalis anterior anteroventral	Most anteroventral point of the anterior semicircular canal
17	Canalis anterior posterodorsal	Most posterodorsal point of the anterior semicircular canal
18	Canalis anterior posterodorsal	Most posterodorsal point of the anterior semicircular canal
19	Crus commune apex*	Junction between the anterior and posterior semicircular canal
20	Canalis posterior ampulla	Center of the ampulla of the posterior semicircular canal
21	Canalis posterior posteroventral	Most posteroventral point of the posterior semicircular canal
22	Canalis posterior posterodorsal	Most posterodorsal point of the posterior semicircular canal
23	Canalis posterior anterodorsal	Most anterodorsal point of the anterior semicircular canal
24	Crus commune apex*	Junction between the anterior and posterior semicircular canal
25	Crus commune apex	Junction between the anterior and posterior semicircular canal
26	Crus commune base	Junction between the common crus and the vestibule

*redundant landmarks removed from the geometric morphometric analysis in R.

Table 2 Description of the starting and ending landmarks used for the curves definition and resampled semilandmarks

N°	Curve	Starting curve landmark	Ending curve landmark	Semilandmarks resampled
1	Cochlea	n°1	n°9	20
2	LSC	n°10	n°14	20
3	ASC	n°15	n°19	15
4	PSC	n°20	n°24	15
5	CC	n°25	n°26	5

SC: semicircular canal; ASC: anterior semicircular canal; LSC: lateral semicircular canal; PSC: posterior semicircular canal; CC: common crus

Geometric morphometrics protocol

All the landmarks were placed at the center of the lumen of the different parts of the inner ear (semicircular canals and cochlea). For the cochlea, two and a half turns were digitized as it is the minimal number of coils observed in our sample (Perier et al 2016; Schweizer et al 2017). Because the variation in the number of turns of the cochlea in the specimens of our sample is important (2.5 to 4.75 turns, see Online Resource 1), we couldn't digitize the morphology of the structure with the same amount of landmarks for all specimens. It would have been necessary to either add more landmarks to reconstruct the curves for specimens with longer cochleas, or to reposition the landmarks in spatially different positions across specimens. In both cases, this goes against the fundamental criteria of landmark positioning (Zelditch et al. 2012) and would have probably induced extreme strong artefactual distortion of the distances between landmarks, and therefore shape analyses, after Procrustes superimposition. Therefore, we worked under the assumption of homology of cochlear turns (Table 1; Fig. 1: landmarks n° 1-9) and completed the study with complementary linear measurements to account for the morphological variation of the cochlea.

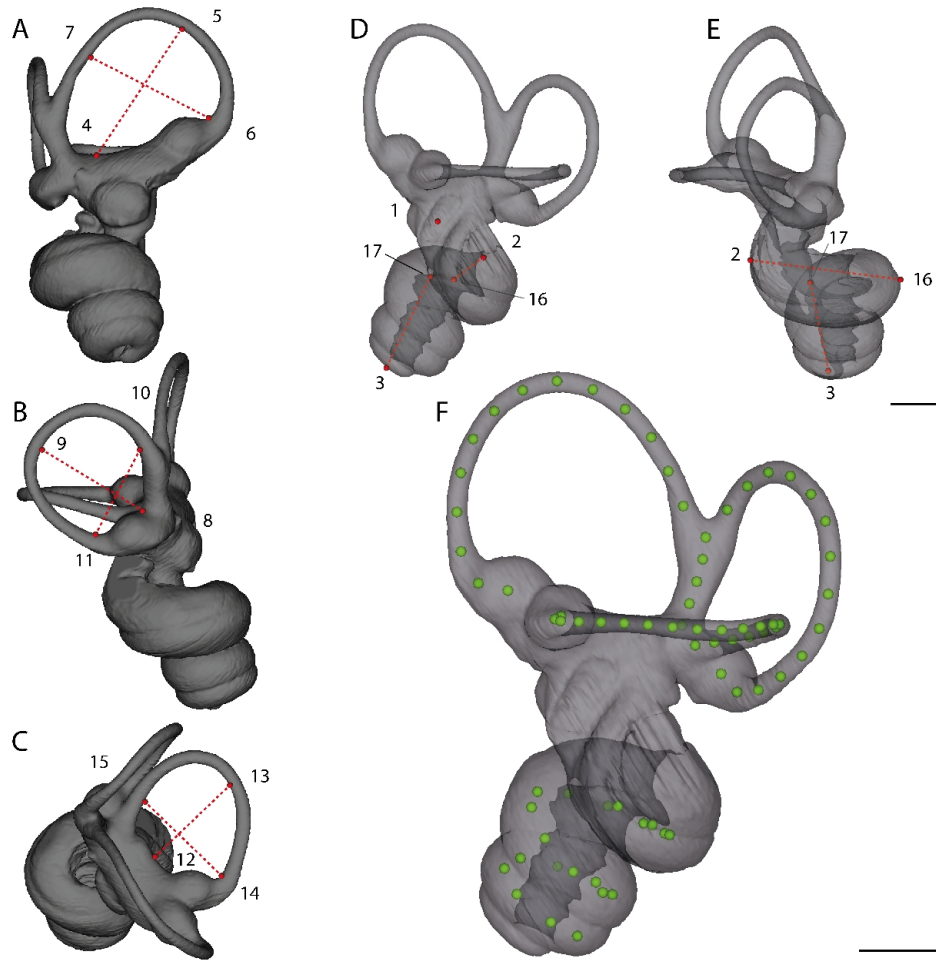


Fig. 2 Landmarks used for linear measurements (A-E) and semilandmarks sampling (F) of the left inner ear of *Pattonomys carrikeri* (USNM 498985). (A) Landmarks 4-5 were used to measure the height of the ASC, and landmarks 6-7 its width. (B) Landmarks 8-9 were used to measure the height of the PSC, and landmarks 10-11 its width. (C) Landmarks 12-13 were used to measure the length of the LSC, and landmarks 14-15 its width. (D-E) Landmarks 2-16 were used to measure the width of the cochlea, and landmarks 3-17 the height of the cochlea. Upper scale is used for (A-E), and lower scale for (F). Scale bars = 1 mm

Table 3 Landmarks from the linear measurements

N°	Name	Definition
1	Fenestra vestibuli	Center of the vestibular fenestra
2	Fenestra cochlea	Center of the cochlear fenestra
3	Helix apex	Ventral-most point of the helix of the cochlea
4	Canalis anterior inferior	Inferior-most point of the inner side of the anterior semicircular canal
5	Canalis anterior superior	Superior-most point of the inner side of the anterior semicircular canal
6	Canalis anterior ampulla	Anterolateral-most point of the inner side of the anterior semicircular canal, next to the anterior ampulla
7	Canalis anterior common crus	Posteromedial-most point of the inner side of the anterior semicircular canal
8	Canalis posterior inferior	Inferior-most most point of the inner side of the posterior semicircular canal
9	Canalis posterior superior	Superior-most point of the inner side of the posterior semicircular canal
10	Canalis posterior ampulla	Anterolateral-most point of the inner side of the posterior semicircular canal, next to the posterior ampulla
11	Canalis posterior common crus	Posterolateral-most point of the inner side of the posterior semicircular canal
12	Canalis lateral proximal	Proximal-most point of the inner side of the lateral semicircular canal, in contact with the vestibule
13	Canalis lateral distal	Distal-most point of the inner side of the lateral semicircular canal
14	Canalis lateral anterior	Anterior-most most point of the inner side of the lateral semicircular canal, next to the lateral ampulla
15	Canalis lateral posterior	Posterior-most most point of the inner side of the lateral semicircular canal
16	Helix posteromedial	Posteromedial-most point of the first coil of the cochlea: it is the farthest away point from the fenestra cochlea
17	Helix junction	Center of the junction of the first and second turns of the cochlea

Table 4 Definition of the abbreviations used for the linear measurements in the specimen table of Appendix S1

Abbreviations	Definition
LS	Length of the skull
LN	Length of the nasal bone
IEH	Height of the inner ear
LCo	Length of the cochlea
HCo	Height of the cochlea
WCo	Width of the cochlea
ASCH	Height of the anterior semicircular canal
ASCW	Width of the anterior semicircular canal
PSCH	Height of the posterior semicircular canal
PSCW	Width of the posterior semicircular canal
LSCH	Height of the lateral semicircular canal
LSCW	Width of the lateral semicircular canal
Angle ASC-PSC*	Angle in degrees between the anterior semicircular canal and posterior semicircular canal
Angle ASC-LSC*	Angle in degrees between the anterior semicircular canal and lateral semicircular canal
Angle PSC-LSC*	Angle in degrees between the posterior semicircular canal and lateral semicircular canal
Radius ASC	Radius of curvature of the anterior semicircular canal
Radius PSC	Radius of curvature of the posterior semicircular canal
Radius LSC	Radius of curvature of the lateral semicircular canal
SCR	Mean of the radii of curvature of the semicircular canals
SCR_ratio*	Relative proportion of the semicircular canals
Co_ratio*	Cochlear aspect

All linear measurements are in millimeters (mm) with the exception of the angles, SCR_ratio and Co_ratio specified by an asterisk (*).

Linear measurements protocol

Radii of curvature of the SCs

Linear measurements follow the protocol of Spoor & Zonneveld (1998) for the semicircular canals (Fig. 2; Table 3). It allowed us to measure the radii of curvature of each of the SC (see Spoor et al 2007):

$$\text{Radius SC} = \frac{0.5 \times (\text{Height of the SC} + \text{Width of the SC})}{2}$$

Relative proportion of the the semicircular canals

$$\text{SCR/IEH}_i = \frac{\text{Mean of the } \sum \text{ of the radii of curvature of the semicircular canals}}{\text{Inner ear height}}$$

Angles of the SCs

First, mean planes of the SC were calculated from all their corresponding semilandmarks. Then, we measured angles between each of these planes to get angles between anterior and posterior SCs, anterior and lateral SCs, and posterior and lateral SCs (Schweizer et al 2017).

Cochlear aspect

Measurements of the cochlea are inspired from Ekdale (2013) but differ as follow: in its study, the height of the cochlea is the maximal distance between the helix apex and the dorsal surface of the first coil, perpendicular to the width of the basal turn. Here, we considered the height of the cochlea as the distance between the helix apex, and the junction between the first and two coils. This position of the point is homologous and is easily repeatable in our sample. However, this has the disadvantage that it does not allow comparison with other groups in precedent studies.

The ratio of the cochlea was measured as follow:

$$R = \frac{\text{Height of the cochlea}}{\text{Width of the basal turn}}$$

Low cochlear ratio (from $R = 1.5$ to $R = 2$) characterizes a cochlea that is larger than taller, with a “flattened” aspect, whereas high cochlear (from $R = 2.5$ to $R = 3$) characterize a cochlea that is taller than larger with an “elongated” aspect. Finally, high cochlear ratio ($R > 3$) illustrates a “very elongated” aspect that is coupled with a high number of coils of the cochlea.

Number of turns of the cochlea

The number of turns (or coils) of the cochlea was measured in lateral view. Each time the cochlea crossed the dorsoventral axis from the middle of the fenestra cochlea, we added a whole turn. For the last turn of the cochlea, we looked at the position of the helix apex in ventral view and added one, two or three quarter of turns if it ended in posterior, medial or lateral parts of the cochlea. In the event that the coil ended in-between two orientations, we retained the lowest value.

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