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SUPPLEMENTARY ONLINE MATERIAL FOR

The origins of the cochlea and impedance matching hearing in synapsids

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Supplementary Online Material

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Figure S1. Skull of *Pristerodon mackayi* (SAM-PK-K1658) in lateral view.

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References

SOM 2. *Pristerodon mackayi*
http://app.pan.pl/SOM/app61-Laass_SOM/SOM_2.pdf

SOM 3. *Pristerodon mackayi*
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SOM 1. The taxonomy of the specimen.

Cryptocynodon schroederi is one of three species belonging to the genus *Cryptocynodon*, which is of uncertain validity, because the description of the type species *Cryptocynodon simus* by Seeley (1894) is based on an incomplete, poorly preserved dicynodont snout (BMNH R2582) (Angielczyk 2007). *Cryptocynodon schroederi* has been proposed to be a junior synonym of *Pristerodon mackayi*, because of its leaf-shaped palatine, the prominent, but not triangular, lateral dentary process and the presence of three postcanine teeth behind the caniniform tusk (Keyser 1993; King and Rubidge 1993; Cluver & King 1983; King 1988). As the investigation of MB.R 985, by means of neutron tomography, revealed new details of the hidden anatomy, the taxonomic position of *Cryptocynodon schroederi* will be reconsidered here. Except some features discussed below, MB.R.985 does not show any striking differences with *Pristerodon mackayi*. By virtually removing the mandible, the palate reveals the large leaf-shaped palatine, which is considered diagnostic for *Pristerodon* (Keyser 1993; King and Rubidge 1993). The relative large number of four to five postcanine teeth, and up to nine teeth on each side of the mandible is in the wide range of variability in the dentition of *Pristerodon mackayi* (Keyser 1993). An important difference to *Pristerodon buffaloensis,* which has been also considered as a junior synonym of *P. mackayi* (Keyser 1993), may be the ear anatomy of MB.R 985. Remarkably, MB.R.985 has a curved vestibule with a small cochlear cavity and a stapes, which is not fused with the quadrate. In contrast, Barry (1967) reconstructed a tubular vestibule without distinctive cochlear cavity for *Pristerodon buffaloensis* and he claimed that the head of the stapes is fused with the quadrate (Barry 1967). The latter has been shown to be a singular observation, because it could not be verified for other specimens of *Pristerodon mackayi* (Keyser 1993). Furthermore, it cannout be ruled out that the differences of the reconstructed inner ear are due to the method of reconstruction or due to the preservation of the specimen described by Barry (1967). A delicate feature such as the small cochlear cavity was probably difficult to observe in a serial grinded specimen. A second possible difference of MB.R.985 to *Pristerodon mackayi* may be the absence of the medial and lateral flanges of the surangulars, which were only present in *Pristerodon buffaloensis* (Barry 1967), but absent in all specimens of *Pristerodon* studied by Keyser (Keyser 1993). Most likely explanations for their absence are either that they are not preserved due to their delicate nature or that they are lost during preparation. In summary, it can be concluded that the assignment of MB.R 985 to *Pristerodon mackayi* is supported here.

Figure S1. Skull of *Pristerodon mackayi* (SAM-PK-K1658) in lateral view showing the ventral extent of the reflected lamina.

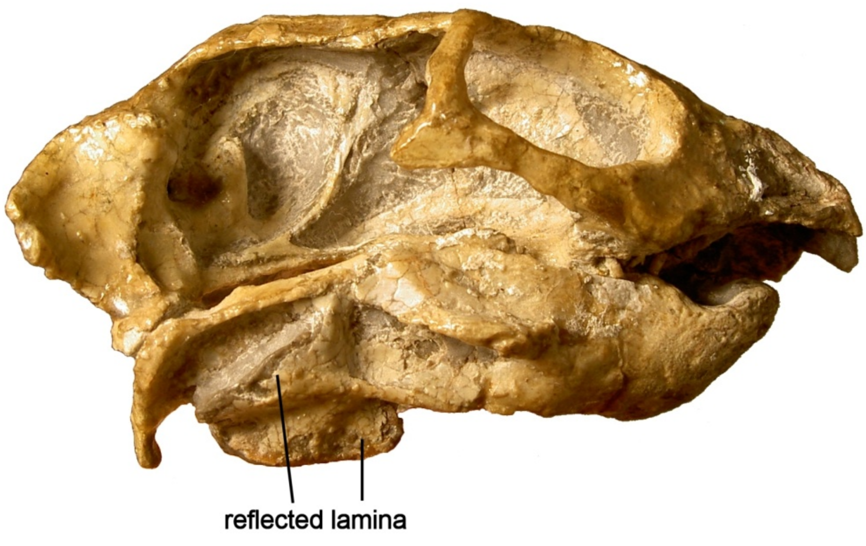

Figure S2. Skull of *Pristerodon mackayi* (SAM-PK-10153) in lateral view showing the ventral border of the reflected lamina and the elongated retroarticular process.

Table S1. Measurements of the skull, middle and inner ear structures of *Pristerodon sp.*, MBR 985.

Skull length (from the tip of the snout to the condyle)	78 mm
Maximum width of the skull in the occipital region	64.10 mm
Volume of the vestibule	75.14 mm^3
maximum anteroposterior length of the vestibule	4.95 mm
maximum mediolateral width of the vestibule	3.45 mm
Height of the vestibule	11.04 mm
Height of the inner ear (measured from the cochlea to the most distal point of the anterior semicircular canal)	14.20 mm
Length of cochlear cavity (measured from the ventral rim of the fenestra vestibuli to the apex)	3.07 mm
Height of anterior semicircular canal	3.78 mm
Width of anterior semicircular canal	4.91 mm
Diameter of anterior semicircular canal	0.42 mm
Height of posterior semicircular canal	2.67 mm
Width of posterior semicircular canal	3.83 mm
Diameter of posterior semicircular canal	0.59 mm
Height of lateral semicircular canal	3.36 mm
Width of lateral semicircular canal	3.08 mm
Diameter of lateral semicircular canal	0.66 mm
Length of crus commune	4.17 mm
Length of secondary crus commune	2.91 mm
Angle between anterior and posterior semicircular canal	78 °
Angle between anterior and lateral semicircular canal	78 °

Angle between posterior and lateral semicircular canal	82 °
Anteroposterior diameter of fenestra vestibuli	2.18 mm
Dorsoventral diameter of fenestra vestibuli	3.09 mm
Area fenestra vestibuli	5.28 mm^2
Volume of right stapes	43 mm^3
Length of right stapes	11.05 mm
Inclination angle of the long axis of the stapes in relation to a horizontal reference plane	~ 0°
Minimum diameter of stapedial footplate	3.53 mm
Maximum diameter of stapedial footplate	4.33 mm
Stapes footplate area	12 mm^2
Length of stapedial head	5.35 mm
Width of stapedial head	2.59 mm
Average volume of the quadrate-quadratojugal complex	342 mm^3
Length of the trochlea of the quadrate	8.51 mm
Width of the trochlea of the quadrate	6.97 mm
Height of the quadrate process	4.19 mm
Dorsoventral height of the quadratojugal	13.58 mm
Anteroposterior width of the quadratojugal	5.55 mm
Thickness of the quadratojugal near the suture to the quadrate	0.86 mm
Average volume of the articular	304 mm^3
Average volume of the angular	134 mm^3
Average volume of the surangular	234 mm^3

Where possible, measurements were taken on both sides of the cranium and averaged.

Table S2. Stapes footplate area and skull length of selected nonmammalian synapsids. Abbreviations: A, Anomodontia; BSPG, Bayerische Staatssammlung für Geologie und Paläontologie München, Germany; C, Cynodontia; F, fossorial; GPIT, Institut und Museum für Geologie und Paläontologie der Universität Tübingen, Germany; MCZ, Museum of Comparative Zoology, Cambridge, USA; MNB, Museum für Naturkunde Berlin, Germany; N, non-fossorial or uncertain, SMNS, Staatliches Museum für Naturkunde Stuttgart, Germany; T, Therocephalia. [a] only used for determination of the slope of the stapes; [b] according to Kammerer et al. (2011) *Dicynodon trigonocephalus* is a junior synonym of *Dic. huenei*; [c] Estimated from the incomplete skull described by Lucas & Heckert (2002); [d] Mean value of 8 stapes described by Camp & Welles (1956: 274); [e] Subadult specimen.

Species	Group	Life-style	Skull length (mm)	Stapes footplate area (mm^2)	Reference footplate area/ collection number	Reference lifestyle
Kawingasaurus fossilis	A	F	40.50	13.9	Laaß (2014), GPIT/RE/9272	Laaß (2014), Cox (1972)
Cistecephalus planiceps	A	F	48.82	19.7	BSPG 1932 I 56	Nasterlack et al. (2012), Cluver (1978), Kümmell (2009)
Lystrosaurus declivis	A	S	100	54.9	Cluver (1971), C 403; SMNS 16702[a]	King and Cluver (1991), Groenewald (1991), Retallack et al. (2003), Kümmell (2009),
Diictodon feliceps	A	S	100	22.0	Sullivan and Reisz (2005)	Smith (1987), Ray and Chinsamy (2003), Ray (2006), Kümmell (2009)
Niassodon mfumukasi	A	?N	63	17.7	Castanhinha et al. (2013)	Laaß (2014)
Pristerodon mackayi	A	?N	78	12.0	MNB, MB.R. 985	Ray and Chinsamy (2003), Ray (2006)
Suminia getmanovi	A	N	54	2.1	Rubczynski (2000)	aboreal (Fröbisch and Reisz 2011)
Dicynodontoides nowacki	A	N	172,6	86.4	GPIT, K35	Likely terrestrial (King 1985, Kümmell 2009)

Dicynodon huenei[b]	A	N	180	81.3	King (1981)	
Placerias gigas	A	N	600[c]	751.8[d]	Camp and Welles (1956), Lucas and Heckert (2002)	
Stahleckeria potens	A	N	475	490.9	GPIT, skull 1	terrestrial (Kümmell 2009)
Arctognathus nasuta	G	?N	170	32.6	GPIT/RE/7119	
Nothosollasia lückhoffi	T	?N	200	86.4	GPIT/RE/7143	
Glanosuchus sp.	T	?N	120[e]	8.0	Maier and van den Heever (2002)	
Brasilitherium riograndensis	C	?N	38,03	1.6	Rodrigues et al. (2013)	
Massetognathus pascuali	C	?N	83,64	4.1	MCZ 4258	
Procynosuchus delaharpeae	C	?S	110	15.1	Kemp (1979)	uncertain, probably aquatic (Kemp 1980) and/or semi-fossorial (Kümmell 2009)
Chiniquodon theotenicus	C	N	160	11.8	Kemp (2007)	terrestrial lifestyle, facultative burrower (Kümmell 2009)
Thrinaxodon liorhinus	C	S	80	7.1	Kermack et al. (1981: 103)	likely semifossorial (Kümmell 2009, Damiani et al. 2003)
Yunnanodon	C	N?	47	1.1	Luo (2001)	

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