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Short Communication

Virtual 3D-reconstruction facilitates identification of fragmented perameleomorph skull

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Abstract

The virtual 3D-reconstruction of a fragmented skull of a representative of Perameleomorphia (bandicoots and bilbies) using high-resolution surface scans proved to be a useful method for correcting its identification. Originally identified as and accordingly inscribed with *Chaeropus castanotis* (syn. *Chaeropus ecaudatus*), i.e. a southern pig-footed bandicoot, it turned out to be the skull of a southern long-nosed bandicoot (*Perameles nasuta*). The provenance of the skull remains obscure.

Key words: *Chaeropus*, *Perameles nasuta*, provenance, State Museum of Natural History Mannheim

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Introduction

According to the museum's records, but largely unknown, the vertebrate collections of the State Museum of the Natural History Museum Karlsruhe (SMNK) contain a purported, rather damaged skull of the southern pig-footed bandicoot (*Chaeropus ecaudatus*) (SMNK-MAM 3924), an extinct representative of Perameleomorphia (bandicoots and bilbies), formerly distributed in the semi-arid zone of New South Wales, Victoria, South Australia, Western Australia (Travouillon et al. 2019; Baker and Gynther 2023: 167ff.). Specimens of this species are very rare in natural history collections. According to Travouillon et al. (2019), ten specimens are kept in Australian museums, seven others in the Natural History Museum in London and one in the American Museum of Natural History, New York, but nowhere else. A recently described second extinct species of the genus, the northern pig-footed bandicoot (*Chaeropus yirratji*) is likewise rare and only known from fifteen specimens in Australian museums, as well as single specimens in the Natural History Museum London, the University Museum of Zoology, Cambridge and the Muséum national d'Histoire naturelle, Paris, respectively (Travouillon et al. 2019). Most of these specimens had been collected during a few collecting expeditions between 1838 and 1907 (Travouillon et al. 2019).

Figure 1. A. Present state of specimen SMNK-MAM 3924. The purported identification of the specimen had been inked on the top of the skull, reading *Chaeropus castanotis* (syn. *Chaeropus ecaudatus*); **B.** Detail of the right temporal region showing the writing "95" prefixed by an almost illegible short sequence of letters that might read "Mai". Scale bar: 10 mm (Photograph Mathias Vielsäcker, SMNK).

Specimen SMNK-MAM 3924 was received, together with numerous other zoological, palaeontological and geological specimens from the collections of the former State Museum of Natural History Mannheim, Baden-Württemberg, in 1977 (see also Lessmann and Manegold (2023)). The original label is missing, but the specimen bears a fading inscription in ink on the top part of the skull reading *Chaeropus castanotis* (Fig. 1A), which is a junior synonym of *C. ecaudatus* (Travouillon et al. 2019). The right temporal region is inscribed with the number 95 prefixed by an almost illegible short sequence of letters that might read "Mai", i.e. the German word for month of May (Fig. 1B). Probably, this inscription specifies either the date of collection or of receipt, i.e. May [18]95. Further information regarding the provenance of the specimen is lacking (but see Discussion).

The elements of skull SMNK-MAM 3924 are dissociated and most of the bones appear to be rather fragile, which hampers the evaluation of the original identification on the basis of morphological characters, but also the physical reconstruction of the specimen. Thus, we decided to undertake a virtual 3D-reconstruction of the skull by using a high-resolution surface scanner. The aim was to produce a naturalistic impression of the damaged skull that could be used for further comparisons with other museum's specimens and that could be easily shared with experts in Peramelemorphia that might either confirm or correct the original identification.

Material and methods

Scanning process

A handheld portable 3D-scanner of the type Artec Space Spider (2026) was used to scan the fragments of the disintegrated skull. According to manufacturer's specifications, the accuracy of this scanner is up to 0.05 mm with a resolution of up to 0.1 mm. It has a scanning speed of 7.5 frames per second (FPS) for objects with a minimum size of 5 mm. The lightweight (0.85 kg) device scans target-free and it scans the object's geometry as well as the colour of

its surface (https://www.artec3d.com/portable-3d-scanners/old/spider). The individual fragments of the skull were placed on a rotating platform to enable a 360° view. The fragments were scanned from 2 or 3 different angles as well as from their dorsal and ventral or lateral and medial side to capture their complete form. For scanning the two halves of the lower jaw, a so-called third hand, an aid usually used in soldering, was used to precisely capture the thin edges of the mediolaterally compressed elements. The highest sensitivity setting of the scanner was used for all scans to achieve best results.

Image processing

The generated scan files were further processed with the software ARTEC STUDIO 16 PROFESSIONAL. Unwanted elements, such as images of the scanned platform and artefacts, were removed manually. The two to three images of the same fragment taken from different views were merged into a single 3D-image. The different images were aligned with manually set markers. Incompletely reconstructed areas of the bony surface and other artefacts were edited by using the lasso selection and the fix-holes tools provided in the software's menu. In the last step, the texture was placed on the fragment surface before the stl-, mtl- and obj-files were exported.

Virtual reconstruction of the skull

The open source 3D modelling software BLENDER 4.1 was used to virtually assemble the skull from the fragments (https://www.blender.org, Blender Foundation 2026). Only the obj-file was uploaded to BLENDER. Published photographs of the skulls of *Chaeropus ecaudatus* and *Ch. yirratji* (Travouillon et al. 2019), as well as the actual specimen, were used as references for the skull reconstruction. Images of the finalised reconstructions were exported as tif-files with a resolution of 10,024 px × 9,077 px.

Results

3D-reconstruction

3D-images of six fragments could be aligned to an almost complete skull (Fig. 2) without adding missing elements or mirroring any scanned parts. However, attempts to scan the isolated teeth of the specimen remained unsuccessful. Scans of the mediolaterally compressed halves of the lower jaw proved to be susceptible to artefacts (i.e. bubble-like structures on the bone's surface) and had to be manually adjusted, i.e. they were removed using the lasso selection tool and the area was reconstructed by using the fix-holes tool and the surrounding surface as a template. Despite the high resolution of the scanner, slight structural differences between 3D-images and the original fragments were observed, which had to be manually corrected, though this did not affect any diagnostic characters for species' identification. The entire process of scanning the fragments, manual adjustment and virtual reconstruction took multiple days.

Species identification

Based on the 3D-reconstruction, the skull is identified as that of a southern long-nosed bandicoot (*Perameles nasuta*), a distant relative of the two *Chaeropus* species, which is still common in its range in eastern Australia and which even dwells in suburban gardens (Baker and Gynther 2023: 189). Several noticeable diagnostic features on the skull and jaw show that it does not belong to a species of *Chaeropus*. In general, the snout of the specimen is long and wide (Fig. 2A, C, E), whereas species of *Chaeropus* usually have a short and narrow snout. There is no accessory palatal fenestra present (Fig. 2E), while species of *Chaeropus* always have a pair of lateral and medial accessory palatal fenestra. In lateral view, the ventral edge of the maxilla appears almost straight (Fig. 2A), while, in species of *Chaeropus*, there is a deep curvature in the maxilla, elevating the canine and premolars well above the molars. The antorbital fossa (Fig. 2A) is weakly developed, while it is well developed and deep in *Chaeropus*. The zygomatic arch is thin in ventral view (Fig. 2E), while it is usually thick in *Chaeropus*, as the jugal twists posteroventrally and is usually visible as a large platform in both dorsal and ventral views. The dentary is very long (Fig. 2B), while it is usually short in *Chaeropus*. There is no triangular-shaped process at the base of the ascending ramus, expanding the dentary laterally, which is a feature that is present in *Chaeropus*. Features that identify the specimen as a representative of *Perameles* include the nasal terminating well anterior to the anterior margin of the orbit (Fig. 2C), primary foramen ovale being present, alisphenoid tympanic process is not hypertrophied (Fig. 2A). The lack of accessory fenestrae, the weak antorbital fossa and the short diastema between C1 and P1 (Fig. 2A) are only present in *Perameles nasuta* and northern long-nosed bandicoot (*P. pallescens*). The submasseteric crest is poorly expanded (Fig. 2B), suggesting it is most likely *Perameles nasuta* (more expanded in *P. pallescens*).

Discussion

Taking surface scans of the skull fragments and the following virtual 3D-reconstruction of a disintegrated skull turned out to be a rather quick method for obtaining images suitable to identify the specimen. Without extensive training in using the hard- and software, scanning took a few hours. The post-processing of the scans was completed within a working day, the virtual reconstruction of the skull within a couple of days.

The resolution of the 3D-scanner was, however, not sufficient for creating 3D-images of the isolated teeth. Furthermore, flat and thin objects, such as the lateromedially compressed dentary, proved to be difficult to scan: artefacts could not automatically be distinguished from the object's real surface leading to wrong surface reconstructions which had to be removed manually. However, all adjustments and corrections did not affect morphological structures that were crucial for identifying the specimen.

Unfortunately, the information on the actual size of the scanned objects could not be transferred from the software ARTEC STUDIO 16 PROFESSIONAL via the obj-files to BLENDER. Thus, a scale bar had to be adjusted manually in BLENDER, with a photograph of isolated fragments together with a scale bar serving as a template. The dimensional accuracy was successfully checked by

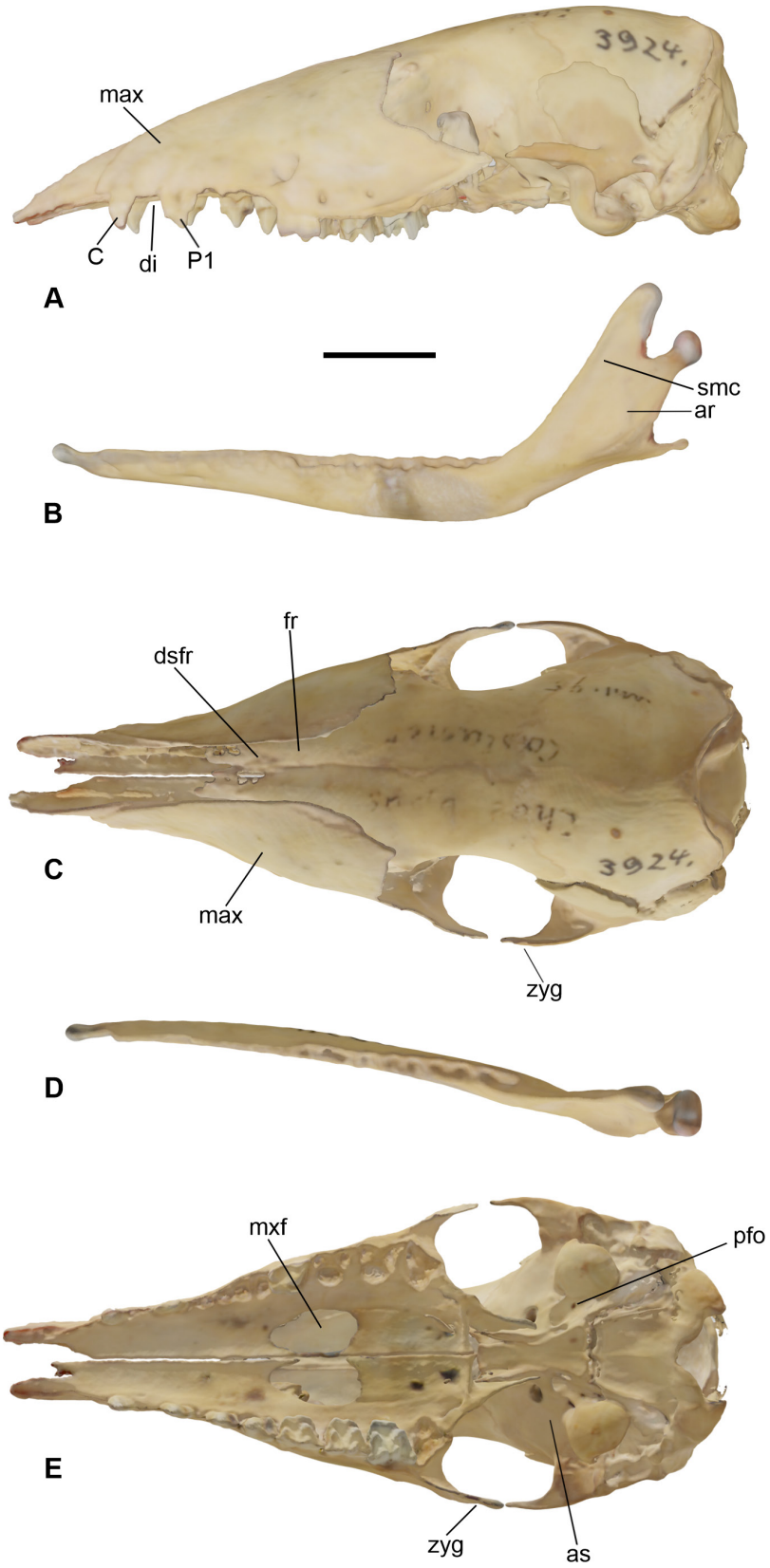

Figure 2. Virtual 3D-reconstructions of the skull and dentary of *Perameles nasuta* SMNK-MAM 3924 in lateral (**A, B**), dorsal (**C, D**) and ventral view (**E**). Abbreviations: ar = ascending ramus of dentary, as = alisphenoid, C = canine, di = diastema between C and P1, dsfr = distal suture of frontal marking the distal extension of nasal, fr = frontal, max = maxillary, mxf = maxillary fenestra, P1 = first premolar, pfo = primary foramen ovale, smc = submasseteric crest, zyg = zygomatic arch. Scale bar: 10 mm.

taking actual measurements of the left dentary and comparing them with those of its virtual reconstruction.

The virtual 3D-reconstruction of the fragmented skull clearly facilitates the skull's identification to species level, because it can be easily shared online and compared with other museums' specimens.

The Provenance of SMNK-MAM 3924, however, turned out to be difficult to clarify. Georg Arnold (1827–1896), who served as curator of the State Museum of Natural History Mannheim from 1876 until his death (Föhner 1909: 65), was in contact with German botanist Ferdinand von Müller (1825–1896) in Melbourne (Arnold 1894). Furthermore, Arnold's son Ernst went to Australia and collected insects in the area of Melbourne in the 1890s (Anonymous 1894: XIX; Arnold 1894). It seems not unlikely that either Ferdinand von Müller or Ernst Arnold forwarded the specimen in question to the natural history museum in Mannheim. The faded inscription of the skull probably reading "May 1895" may fit to this hypothesis, but a corresponding record is missing. In fact, the available museum's catalogues list only very few specimens of Australian marsupials in general and none of Peramelemorphia in particular. The latest entry in the catalogue of mounted mammals (N-VV 29/2005 No. 71) dates from 1877 and in the catalogue of skeletons and skull (N-VV 29/2005 No. 80) from 1901, though it is evident that the museum received further specimens at least until the 1930s, notably the vast ethnological, palaeontological and zoological collections of Gabriel von Max (1840–1915) in 1917 (von Gagern 1967). Thus, how the specimen became part of the zoological collections in Mannheim and who misidentified it as *Chaeropus ecaudatus* remains obscure.

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Archival materials

Archival materials Marchivum (Mannheim city archive)

N-VV 29/2005 No. 71 – Catalogue of [mounted] mammals in the fifth hall of the Grand Duke Natural History Museum Mannheim [latest entry in 1877]

N-VV 29/2005 No. 80 – Catalogue of skeletons [and skulls] in hall no. 37 of the Grand Duke Natural History Museum Mannheim [latest entry in 1901]

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
Regarding the use of AI in the preparation of this manuscript, the authors declare the following: GPT.
Used for: Language, style and writing, Software and automation.
Large language models like ChatGPT were used to correct grammar and spelling errors in the chapter "Material and methods" as well as for instructions when confronted with problems while using BLENDER.

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Author contributions

Johanna Specht performed and processed the 3D-Scans as well as the virtual 3D-reconstruction. She also wrote the methodology section. Kenny J. Travouillon identified the species on the basis of the virtual reconstruction and wrote the section on species identification. Albrecht Manegold was responsible for the study conception as well as for the research regarding the provenance of the specimen and wrote the first draft of the manuscript. All authors commented on previous versions, and they read and approved the final manuscript.

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Data availability

The virtual 3D-reconstruction of the skull is available at Morphosource (DOI: https://doi.org/10.17602/M2/M860778).