

Brief Communication: A Cranial Morphometric Assessment of the Taxonomic Affinities of *Trachypithecus auratus* (E. Geoffroy, 1812 Primates: Colobinae) With a Reassessment of the *T. auratus* Type Specimen

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ABSTRACT The debate over the taxonomic position and affinities of *Trachypithecus auratus* has been ongoing since its identification by E. Geoffroy Saint-Hilaire in 1812. The type specimen of this species is housed in Muséum national d'Histoire naturelle in Paris (MNHN-ZM 2005-912). This point is debated due to the complex and fluctuating taxonomy of Southeast Asian Colobinae (Brandon-Jones et al.: *Int J Primatol* 25 (2004) 97-164) and to the fact that this individual is represented by a mounted skeleton. By means of 3D medical imaging methodologies we describe for the first time the cranial anatomy of the specimen MNHN-ZM 2005-912 and compare it with other *Trachypithecus* species, in order to test the molecular systematic hypotheses for affinities among the *T. auratus*-*T. cristatus* group. We ascertain the taxonomic

attribution of this individual to the species *Trachypithecus auratus* species. The most diagnostic characters shared by the type specimen and *Trachypithecus auratus* compared to other species of *Trachypithecus* are the rounded orbits and the straight facial profile. We then try to clarify the inconsistencies concerning the geographical provenance of the type. The island of Java appears to be the most probable locality from a cluster analysis based on linear morphometry. After this approach and a discriminant analysis, a northeastern Javanese provenance of this specimen, as proposed by Brandon-Jones et al. (*Int J Primatol* 25 (2004) 97-164) is dubious. Finally we provide 3D models of the skull and the endocast, and a list of cranial landmark coordinates of the holotype for future research. *Am J Phys Anthropol* 146:306–312, 2011. © 2011 Wiley-Liss, Inc.

The history of the taxonomy of Southeast Asian langurs and particularly that of the Javanese langur *Trachypithecus auratus* is long and complex (Brandon-Jones, 1993, 1995, 1996; Groves, 2001; Brandon-Jones, 2006). In 1812, E. Geoffroy Saint-Hilaire briefly described as *Trachypithecus auratus* a monkey said to have been collected from the Maluku Islands (Southeast Asia) which was given to him by C.J. Temminck (Geoffroy Saint-Hilaire, 1812). But this species does not exist on this group of islands. Müller (1839) mentioned “Samarang, Java” as the geographic provenance. Considering the pelage color, Brandon-Jones (1995) proposed East Java as the locality where this individual was collected. Rode (1938) mentioned that the skull is preserved under the skin. The accession number of this mounted specimen is MNHN-ZM 2005-912. Elliot (1912: p.77) reassessed the holotype and identified the specimen MNHN-ZM 2005-912 as a typical Javanese langur on the basis of the color of the fur and cranial and body measurements taken through the skin.

Many species have been named after E. Geoffroy's work (such as *T. maurus* and *T. pyrrhus*) and which are now considered as synonymous with *T. auratus* and reassessed at the subspecies level (Horsfield, 1824; Fischer, 1829; Lesson, 1838; Martin, 1838; Müller, 1839; Syb- randi, 1864; Pocock, 1934; Elliot, 1912; Weitzel and Groves, 1985).

In 1822, Raffles described the species *Trachypithecus cristata* that he renamed *T. cristatus* in 1830. The type specimen was collected with other mammals on Sumatra. Today the type specimen of *T. cristatus* is lost and thus cannot be studied (Thomas, 1906; Pocock, 1934). In 1934, Pocock demoted *T. cristatus* as a subspecies of *T. auratus* (the close affinities between these two species had already been mentioned by Müller, 1839), and this taxonomy was followed by Chasen (1940), Ellerman (1955) and Hooijer (1962). In 1977, Rosenblum and coauthors published the first DNA study of the species, focusing on nucleotides and haplotype diversity of mtDNA. In their conclusions, they challenge the occurrence of two species *T. auratus* and *T. cristatus*.

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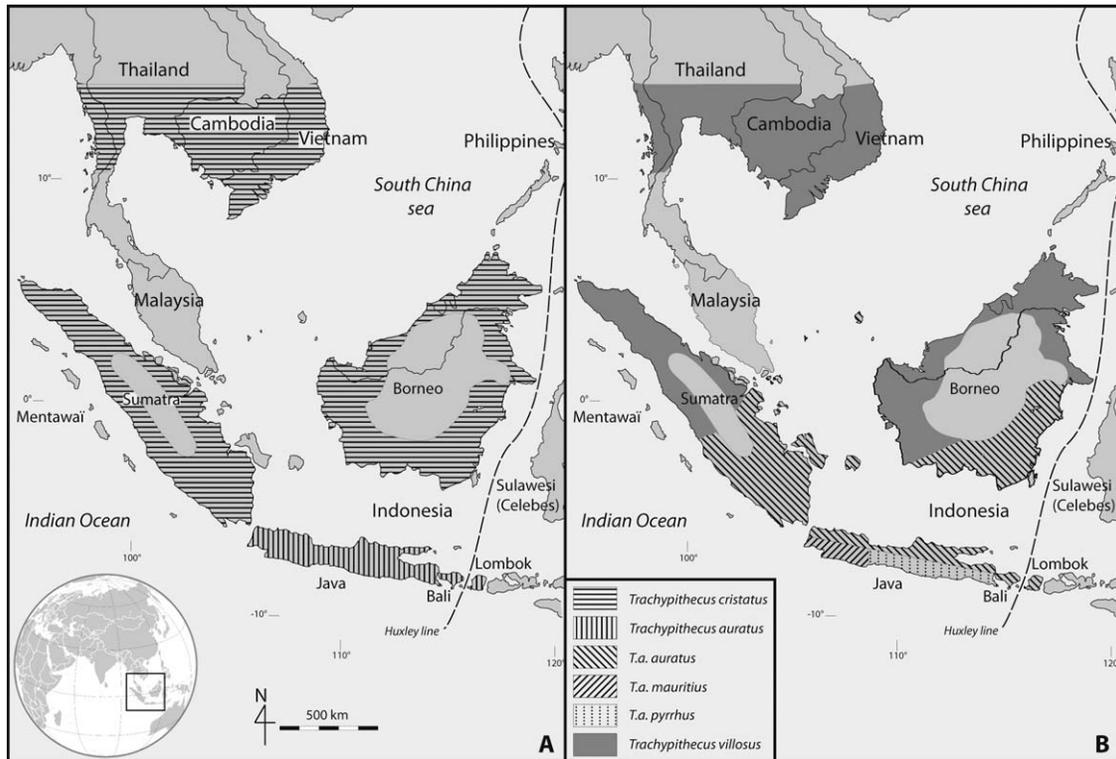


Fig. 1. Two maps showing: **A.** the ancient geographical distribution of *T. auratus* and *T. cristatus* before 2004 consensus and **B.** present day distribution of *T. auratus* through its recognized subspecies.

In 2004, Brandon-Jones et al. (p. 136 and 146) divide the species *T. cristatus* in two taxa *T. auratus* and *T. villosus*. The latter species is present in Sumatra, Borneo, and the north of Java Island (see Fig. 1). On the basis of fur color, three subspecies for the Javanese langur are recognized: *T. a. auratus* in the north of the island, *T. a. mauritius* in the southwest and *T. a. pyrhus* in the southeast. It is also on the basis of fur color that Brandon-Jones et al., (2004, p.137) suggested that the type of *T. auratus* probably comes from the northeast of Java: “specimens from SE. Java are paler than elsewhere in this species range and that the east Java orange morphs [...] appear to divide into a northern darker and southern paler population whose geographic boundary coincides with that of pelage colour variation in the melanic morph. The holotype of *C. auratus* probably derives from the northern section”.

Although Brandon-Jones et al. (2004) provided a detailed and comprehensive review of the taxonomy of *Trachypithecus*, many scholars (Nadler et al., 2005; Roos et al., 2007, 2008; Osterholz et al., 2008; Karanth et al., 2008) do not follow this classification for *Trachypithecus*, especially the name *T. cristatus* for the individuals from Sumatra and Borneo. This seems justified by important differences in specimens as Osterholz et al. (2008) show in their study of the variability of cytochrome b in Asian Colobinae. After studying the haplotype of the *T. cristatus* group, Roos et al. (2007) proposed keeping the specific name of *T. cristatus* and Roos et al. (2008) proposed raising *T. a. mauritius* to species rank for West Java. But the species concept used by these authors when proposing new species was not clear enough for Denise et al. (2008) who contested the classification proposed based on their own nuclear diversity analyses and the reference to a case of hybridization between *T. a. auratus* and *T. cristatus*.

Metrical analysis of the *Trachypithecus* clade is limited to the work of Maryanto et al. (1997) and the unpublished Master’s Thesis of Weitzel (1983). Moreover all the published measurements of the type have been taken on the mounted skeleton through the skin (length and width of the cranium and of the body) taken by Elliot (1912), then Hooijer (1962), and finally Weitzel and Groves (1985). There is no description of the skeletal anatomy of this type specimen despite the fact that *T. auratus* is often mentioned in the fossil record of Southeast Asia (Watanabe et al., 1985; Harrison, 1996; Jablonski and Tyler, 1999; Sémah et al., 2004; Setiagama Fadjjar, 2006; Bouteaux et al., 2006; Morwood et al., 2008; Piper et al., 2008).

In this context, morphological and morphometric analyses of the skull are conducted to attempt to assess the taxonomic affinities of the *Trachypithecus auratus* clade through a reassessment of its type specimen, by means of 3D medical imaging methods. Finally we attempt to clarify the geographical provenance of this holotype.

MATERIALS AND METHODS

As noted by Weitzel and Groves (1985), MNHN-ZM 2005-912 is a female. X-rays reveal that the specimen’s posture is supported by metal bars placed within the skin (see Fig. 2). While the cranium is fairly complete, the sphenoid and ethmoids are absent, as is the basicranium, and a portion of the palatine is missing.

We CT scanned the type in the Service neurologique, Hôpital de La Pitié-Salpêtrière, Paris to access the bony anatomy through the skin. Orientation of the specimen and resolution of the data (pixel matrix of 512×512 and voxel size of $0.299 \times 0.299 \times 0.5 \text{ mm}^3$) were chosen

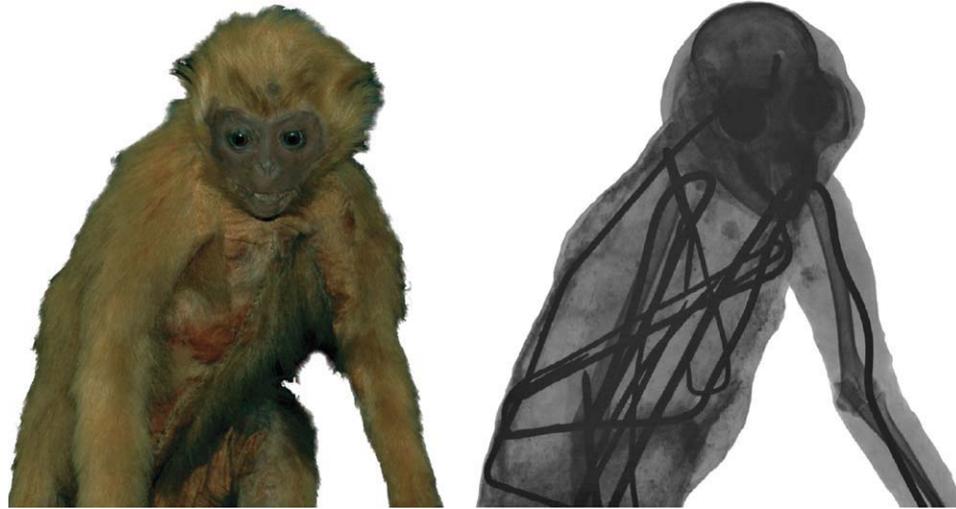


Fig. 2. Photograph and radiograph of the type showing metallic bars. MNHN-Dir. des collections ©. A color version of this figure can be found in the on-line version of this paper. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 1. List of species used in this study with their geographic provenance

Species	Sub-species	Locality	Number
<i>T. auratus</i>	<i>T. a. auratus</i>	North Java	28
	<i>T. a. auratus</i>	Bali	6
	<i>T. a. pyrrhus</i>	South-east Java	4
	<i>T. a. mauritius</i>	South-west Java	9
	Unknown	Java	12
<i>T. cristatus</i>		Sumatra	4
		Borneo	4
		Unknown	8
<i>T. johnii</i>			2
<i>T. obscurus</i>			6
<i>T. vetulus</i>			8

to minimize artifacts due to the presence of metal. CT acquisition of the postcranial elements was not possible.

The densities of bones and skin overlap and we had to perform a manual segmentation (with Avizo 6.0 software). Multiple threshold values were required in order to obtain precise 3D models of the different analyzed structures (Balzeau et al., 2005).

Finally we printed 3D prototypes of the cranium, the mandible and the endocast to permit preservation of the unique type specimen and to allow future studies of its hidden cranial morphology.

We compared the specimen MNHN-ZM 2005-912 with the collections of extant Southeast Asian langurs curated at the Muséum national d'Histoire naturelle (Paris, France) and the Nationaal Natuurhistorische Museum (Leiden, The Netherlands). We only considered adult females in order to prevent intraspecific variability due to sexual dimorphism. Individual specimens were allocated to subspecies based on geographical provenance information when available. Our total sample used in this study is composed of 91 females of the genus *Trachypithecus* from five species and three subspecies (Table 1).

Six linear measurements were taken with digital calipers on the face as it is the most diagnostic part of the cranium in Colobinae (Olivier, 1955) and especially in *Trachypithecus* (Weitzel, 1983). These measurements are rhinion-nasospinal length (Rh-Ns), nasion-nasospinal

length (Na-Ns), nasion-prosthion length (Na-Pr), ecto-chonchion-lacrimal width (Ect-La), bi-ectochonchion width (Ect-Ect), bizygofrontal width (ZyFo-ZyFo), and molar row length. Some of these measurements were not possible for three *T. cristatus* individuals, and we then did not use them in our metrical analyses.

Our first step was to compare molar row length among *Trachypithecus* species and *T. auratus* subspecies. Weitzel (1983) mentioned prognathism and relative length of the face as distinctive features of the Sumatran-Bornean and Javanese specimens. Measuring prognathism on the type is not possible as the basicranium is missing, so we compared molar row length variability of the different groups with a boxplot analysis (see Fig. 4). We grouped the specimens from Sumatra and Borneo to increase the confidence interval for the median and then make our comparisons on equi-weighted groups. We then apply the Log-shape ratio method as described by Darroch and Mosimann (1985). We performed a hierarchical clustering dendrogram on log-shape ratios in order to predict the position of the type-specimen among the geographical groups.

DESCRIPTION OF THE TYPE

Cranial anatomy

We focus here on the characteristics of the type that we found to be diagnostic among *Trachypithecus* species.

Norma facialis. The supra-orbital torus is V-shape, well-marked all along the eyebrow ridge as in *T. auratus* and *T. cristatus* while in the other species of the genus there is no glabellar depression (Fig. 3A). The orbits are extremely rounded and the interorbital width is narrow. In *T. obscurus* the orbits are quadrangular; they are oval in *T. johnii*, and intermediate in *T. vetulus*. The *incisura frontalis* does not extend onto the superciliary arch. Under the orbits, three infraorbital canals are present on the maxilla following the zygomatico-maxilla suture in parallel as in *T. auratus* and *T. cristatus*. Whereas this character is variable, most of the specimens of the other species of *Trachypithecus* only exhibit two canals. The canine jugum is weakly pronounced and there is no canine fossa. The nasal aperture is oval in shape and

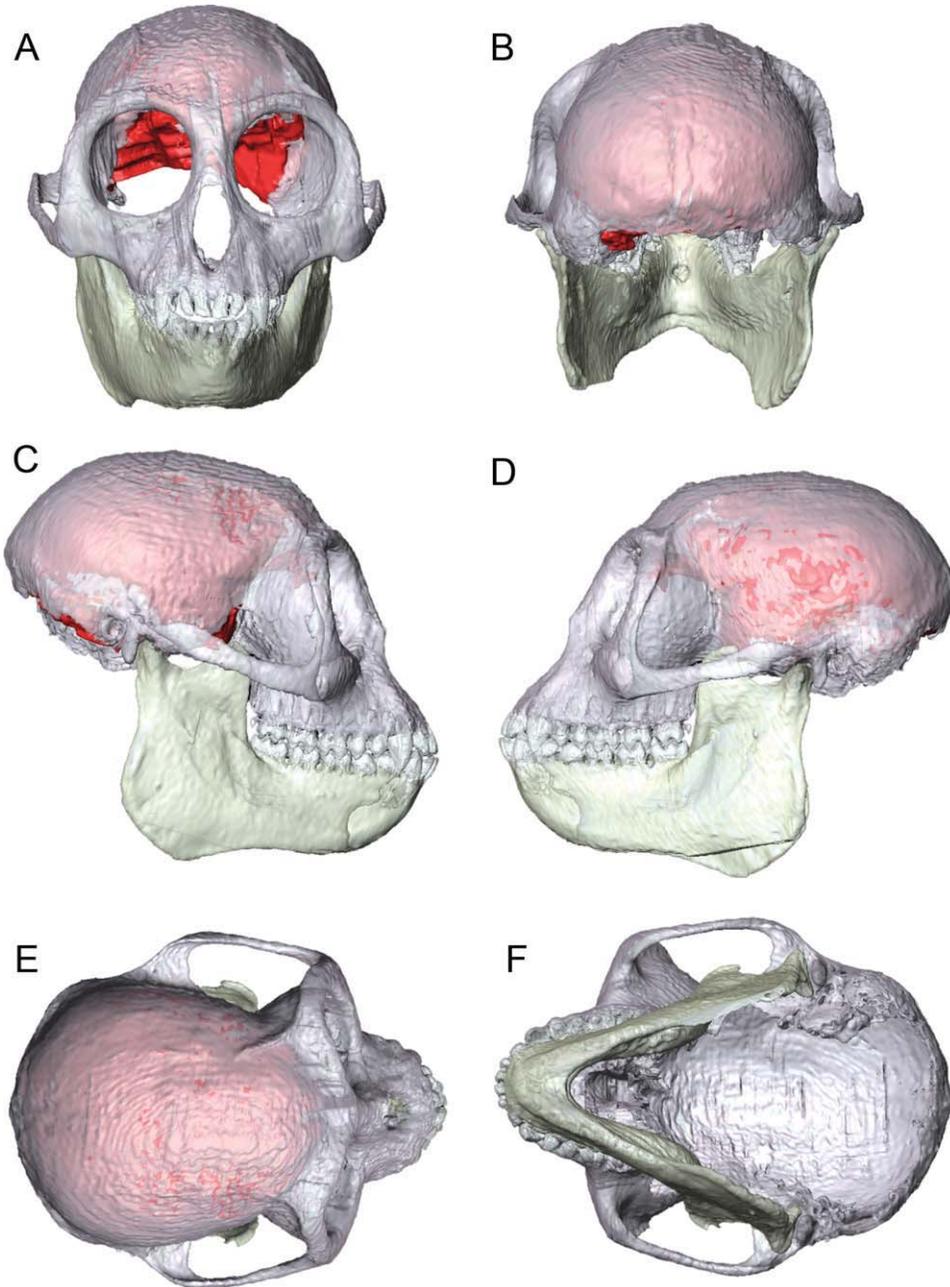


Fig. 3. CT scan of *T. auratus* skull with mandible and endocrania in **A.** *norma facialis*, **B.** *norma occipitalis*, **C.** *norma lateralis* right, **D.** *norma lateralis* left, **E.** *norma verticalis* and **F.** *norma basalis*. A color version of this figure can be found in the on-line version of this paper. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

the distal border is pointed. On the frontal bone squama the temporal lines are prominent near the eyebrow and decrease rapidly posteriorly.

Norma occipitalis. The maximum width of the braincase is low (Fig. 3B). It corresponds to the mastoid area on the temporal bone.

Norma lateralis. The supraorbital torus is strongly prominent and a postorbital depression can be seen as in *T. auratus* and *T. cristatus*, and compared to other *Trachypithecus* species (Fig. 3C and 3D). The forehead is upright in all the species of *Trachypithecus* except *T.*

vetulus where the forehead is receding. The maxilla is slightly convex under the orbit. Bregma is the highest point of the cranium as in *T. auratus* and *T. cristatus*, while it is posterior to the highest point in the other species. The braincase is ovoid with a strong angle between parietal and occipital planes as in *T. auratus* and *T. cristatus*. This angle is stronger in the other species of the genus. The profile of the face is straight as in *T. auratus* and *T. cristatus*, while there is an infranasal prognathism in the other species. In the Frankfort plane, the zygomatic arch is oriented superiorly and posteriorly. This arch is horizontal in *T. obscurus*.

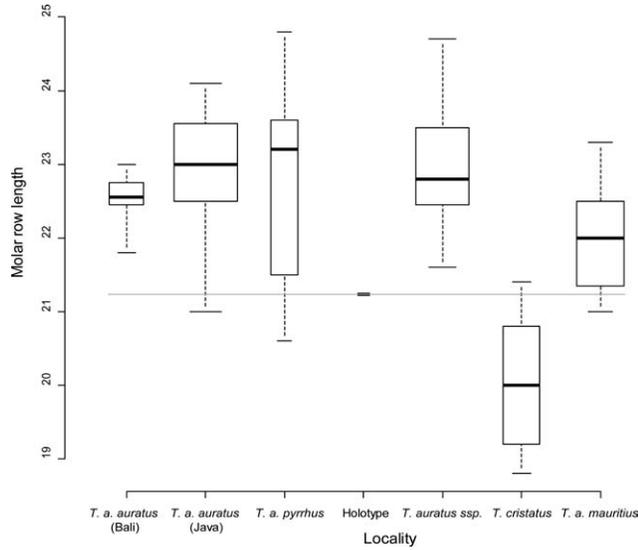


Fig. 4. Boxplot of molar row length. We regrouped Sumatra and Borneo specimens to increase confidence interval for the median. Boxes widths are proportional to the square roots of sample sizes.

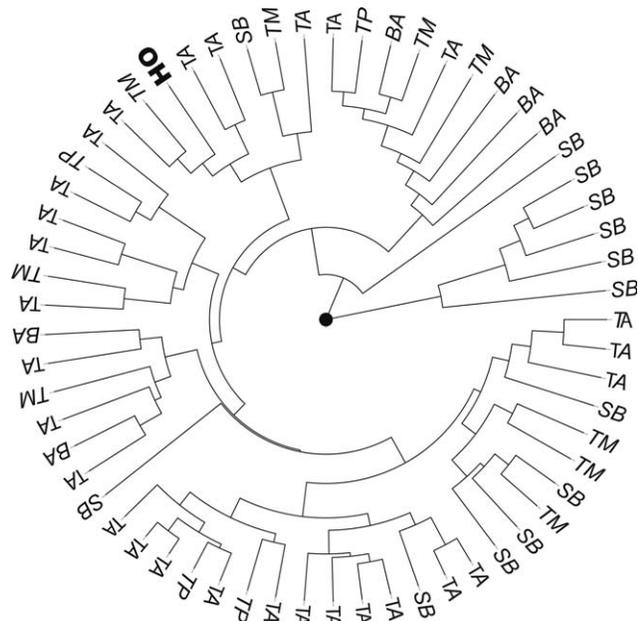


Fig. 5. UPGMA clustering dendrogram on log-shape ratios of Rh-Ns, Na-Ns, Na-Pr lengths and Ect-La, ZyFo-ZyFo and Ect-Ect widths for geographical *T. auratus* groups. **BA:** *T. a. auratus* from Bali, **TM:** *T. a. mauritius* from Java, **TA:** *T. a. auratus* from Java, **TP:** *T. a. pyrrhus* from Java, **SB:** *T. a. auratus* from Sumatra and Borneo, **Ho:** Type specimen.

Norma verticalis. In this view, there are no diagnostic characters for the different species of the clade (Fig. 3E).

Morphometric analysis

The maximum length of the cranium (Prosthion-Opisthocranium length) is 97.2 mm. The maximum width (Bizygomatic width) is 77 mm. The maximum width of the palate (33 mm) is located between the first and second

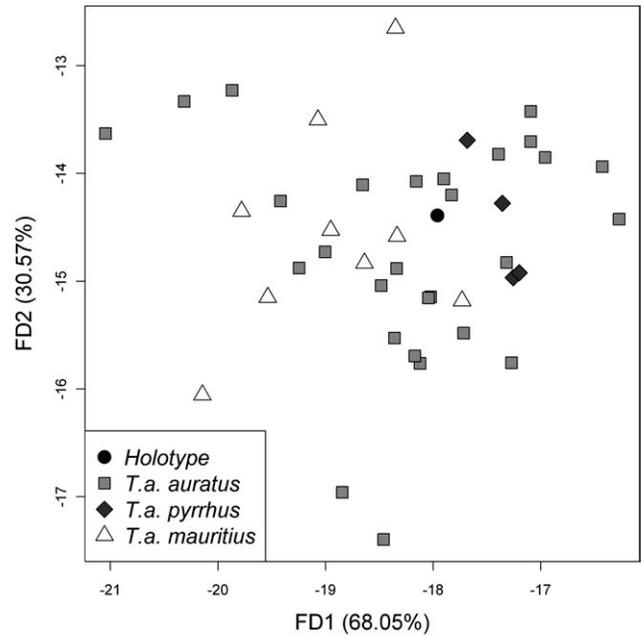


Fig. 6. Linear discriminant analysis on log-shape ratios of Rh-Ns, Na-Ns, Na-Pr lengths and Ect-La, ZyFo-ZyFo and Ect-Ect widths for geographical *T. auratus* groups.

molars. The cranial measurements through skin of the type found by Weitzel and Groves (1985) was 98 mm for the maximum length and 75.4 for the maximum width. We found respectively 97.2 mm and 77 mm.

Apart from these few linear measurements of the skull, we also provide 3D coordinates for numerous landmarks on both mandible and calvaria (exocranial and endocranial) to complete future studies of this specimen (Supporting Information).

We compare here cranial measurements of the type specimen with different species of the genus *Trachypithecus*.

From the boxplot analysis (see Fig. 4), the specimens from Sumatra and Borneo have a shorter molar row than the specimens from Java. Although the Sumatran, Bornean, and Javanese specimens are well separated, the type falls between the third and fourth quartiles of the two groups, so it is difficult to make inferences on its geographic provenance.

As size does not permit us to classify the type into one or other group, we focus the analysis on shape variation.

Isometry was tested by analyzing the variance between geometric sizes and log-shape ratios. We thus performed an ANOVA. The *F*-value is highly significant ($F = 5.7567$, $df = 5/68$, $P^{***} = 2.001 \cdot 10^{-4}$) suggesting that isometry is not the only factor explaining the variance.

The type specimen clusters with skulls from Java, but the subspecies do not sort out on the basis of this analysis (see Fig. 5). Thus, it is likely that the type specimen is from Java but craniometrics do not allow a more specific suggestion. This conclusion is supported by the linear discriminate analysis (see Fig. 6). Predefined cluster number analysis ($N = 5$) as K-means or partitioning around medoids methods gave similar results.

DISCUSSION AND CONCLUSION

We summarize here the diagnostic osseous features of the individual MNHN-ZM 2005-912 and we clarify its

taxonomic position as the type specimen of *Trachypithecus auratus*.

Here we present new information that provides support to Martin (1841), Elliot (1912), and Weitzel and Groves (1985) concerning the attribution of MNHN-ZM 2005-912 to *Trachypithecus auratus*. For example the circular orbit, the strong post-orbital constriction, the low cranial vault, the acute angle of the posterior braincase, the straight profile of the face, the middle position of the alare-alar on nasal aperture and the posterior position of the maximum zygomatic width are features that are diagnostic of *T. auratus* found on MNHN-ZM 2005-912 (Ingicco, 2010).

Size is considered to be a good criterion to differentiate *T. cristatus* from *T. auratus* (Martin, 1841; Elliot, 1912; Weitzel, 1983; Weitzel and Groves, 1985; Weitzel et al., 1988). The size of the type specimen of *T. auratus* falls just between the *T. cristatus* and the *T. auratus* clades (see Fig. 4). In our clustering analyses, most of the Bornean and Sumatran specimens ($N = 8$) plot among the Javanese cluster (see Fig. 5). Thus, the intermediate size of the type specimen and the weak morphological distinction between Javanese and Bornean-Sumatran groups do not support their separation into two different species. In this sense, *T. cristatus* does not appear as a valid species. Therefore, our results are consistent with the classification proposed by Brandon-Jones (2004) and do not agree with Nadler et al. (2005), Roos et al. (2007, 2008), Osterholz et al. (2008) and Karanth (2008).

Our clustering analyses support the argument that the type specimen is from Java, a conclusion that contradicts the information that is attributed to C.J. Temminck by Geoffroy Saint-Hilaire (1812). It is not possible to offer a more precise geographical provenance based on our osteometric analysis (see Fig. 6). Thus, we are unable to support or refute the suggestion of the north-east Java provenance offered by Brandon-Jones et al. (2004).

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