

A new Abelisauroid from the Upper Cretaceous of Brazil

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ABSTRACT

Although important dinosaur specimens have been recently described from Brazil, the theropod record in this county is still rather scarce, particularly from Cretaceous strata. Here we describe a complete right tibia (MCT 1783-R) from the Marília Formation (Maastrichtian, Bauru Basin) near Peirópolis (Uberaba, Minas Gerais). This is the best theropod specimen recovered from this unit after five decades of collecting. MCT 1783-R shows a well developed cnemial crest with a lobular distal end, that projects significantly above the proximal articular surface, features that are characteristic of the Abelisauroidea. It further shows unique characters such as a marked asymmetry of lateral and medial condyles in posterior view, and a very deep triangular articular face for the astragalus, suggesting that it represents a new taxon.

Key words: tibia, theropod, Abelisauroidea, Cretaceous, Bauru Basin, Brazil.

RESUMEN

A pesar de que importantes especímenes de dinosaurios de Brasil se han descrito recientemente, el registro de terópodos en este país es todavía bastante escaso, especialmente en los estratos del Cretácico. Aquí reportamos una tibia derecha completa (MCT 1783-R) de la Formación Marília (Maastrichtiano, Cuenca Bauru) en el área de Peirópolis (Uberaba, Minas Gerais). Este es el mejor material de terópodo recuperado de esta unidad en cinco décadas de recolección. MCT 1783-R muestra una cresta cnemial bien desarrollada con un extremo distal lobular; proyectado significativamente por encima de la superficie articular proximal, los cuales son rasgos característicos de Abelisauroidea. Muestra, además, algunas características únicas, como una marcada asimetría de los cóndilos medial y lateral en el lado posterior y una cara triangular articular muy profunda por el astrágalo, sugiriendo que representa un nuevo taxón.

Palabras claves: tibia, terópodo, Abelisauroidea, Cretácico, Cuenca Bauru, Brasil.

INTRODUCTION

The Bauru Group crops out in several states of Brazil (Paraná, São Paulo, Minas Gerais, Goiás and Mato Grosso

do Sul) and also in Paraguay (Fernandes and Coimbra, 1996). The stratigraphy of the Bauru Group has changed over the years (Soares *et al.*, 1980; Souza, 1984, Fernandes and Coimbra, 2000), and since the work of Fernandes and

Coimbra (1996) these deposits have been considered part of an independent depositional area known as the Bauru Basin, which filled with sediment accumulated over the basalts of the Serra Geral Formation.

Except for teeth (Bertini *et al.*, 1993; Kellner, 1996; Franco-Rosas, 2002; Candeiro *et al.*, 2004), the record of theropod dinosaurs in the Bauru Basin is considerably scarce, as elsewhere in Brazil (Kellner and Campos, 1999; 2000; Bittencourt and Langer, 2011). The only named taxon is the abelisaurid *Pycnonemosaurus nevesi* Kellner and Campos 2002. This species is known from an incomplete skeleton collected in Cretaceous deposits of Mato Grosso State that has been tentatively correlated with the Bauru Group (Kellner and Campos, 2002). However, these deposits most likely are a distinct stratigraphic unit, the Quilombinho Formation (Weska, 2006). Some isolated non-avian theropod bones were also reported from the Late Cretaceous Adamantina Formation (Bertini, 1996), but most remains come from outcrops of the overlying Maastrichtian Marília Formation (Dias-Brito *et al.*, 2001).

The region known as Veadinho Hill (“Serra do Veadinho”, see Campos and Kellner, 1999), in the area of Peirópolis (Uberaba, Minas Gerais State), has yielded several isolated specimens. These include one manual ungual (Novas *et al.*, 2005) and one scapula (Machado *et al.*, 2008) assigned to an unidentified maniraptoran theropod, as well as one incomplete femur and one pedal phalanx attributed to *Abelisauridae* (Novas *et al.*, 2008). To date these specimens indicate the presence of, at least, two distinct theropod taxa in these strata. However, none of the specimens show any autapomorphy or unique combination of characters that would allow the proposal of a new taxon.

Herein we describe another isolated element, a tibia that was collected at the Veadinho Hill locality by Lewellyn Ivor Price and his team in 1969. The specimen is housed at the Museu de Ciências da Terra of the Departamento Nacional de Produção Mineral (MCT 1783-R; cast at Setor de Paleovertebrados of the Departamento de Geologia e Paleontologia - Museu Nacional/UFRJ - MN 7370-V). It can be referred to the clade *Abelisauroida*, and is the most representative theropod dinosaur material thus far known from the Marília Formation (Maastrichtian; Dias-Brito *et al.*, 2001). It most likely represents a new species. However, due to the incompleteness of this specimen we refrain of giving the taxon a formal designation until more theropod material from this site becomes available.

MCT 1783-R, is herein referred to as the “Cambará theropod” (in allusion to the former name of the area of Peirópolis) and compared with all abelisauroid taxa for which a tibia is known, as follows: *Aucasaurus garridoi* Coria *et al.*, 2002; *Berberosaurus liassicus* Allain *et al.*, 2007; *Ekrixinatosaurus novasi* Calvo *et al.*, 2004; *Eoabelisaurus mefi* Pol and Rauhut, 2012; *Majungasaurus crenatissimus* Lavocat, 1955; *Masiakasaurus knopfleri* Sampson *et al.*, 2001; *Pycnonemosaurus nevesi* Kellner and Campos, 2002; *Quilmesaurus curriei* Coria, 2001; *Rahiolisaurus gujaratensis*

Novas *et al.*, 2010; *Rajasaurus narmadensis* Wilson *et al.*, 2003; *Skorpiovenator bustingorryi* Canale *et al.*, 2009; *Xenotarsosaurus bonapartei* Martínez *et al.*, 1986 (Allain *et al.*, 2007; Calvo *et al.*, 2004; Canale *et al.*, 2009; Coria, 2001; Coria *et al.*, 2002; Kellner and Campos, 2002; Martínez *et al.*, 1986; Novas *et al.*, 2010; Pol and Rauhut, 2012; Sampson *et al.*, 2001; Wilson *et al.*, 2003). Most comparisons are based on the original descriptions, complemented with additional published information for some of the taxa (Carrano *et al.*, 2002; Carrano, 2007; Carrano and Sampson, 2008; Novas *et al.*, 2004; Juárez-Valvieri *et al.*, 2007).

DESCRIPTION AND COMPARISON

The tibia MCT 1783-R belongs to the right side and is well preserved, showing no apparent distortion (Figure 1a). The cortical bone is fractured in some parts and the tibio-fibular crest is slightly abraded. The maximum length, including the dorsally projected cnemial crest, is 395 mm while the length of the shaft is 380 mm. The shaft is compressed anteroposteriorly, and has an oval transverse section (middle shaft dimensions: 44.7 mm × 31.5 mm; circumference: 123 mm).

The proximal articulation is 55.8 mm wide and 119.5 mm long, including the tip of the cnemial crest. Both proximal condyles project posteriorly and are separated by a well-marked intercondylar groove, followed by an irregular surface, the latter likely for muscle attachment (Figure 1b). The intercondylar groove is more developed than in *Majungasaurus crenatissimus*, *Quilmesaurus curriei*, *Pycnonemosaurus nevesi*, but less conspicuous than in *Skorpiovenator bustingorryi* and *Ekrixinatosaurus novasi*. In posterior view, the lateral condyle is larger and square, while the medial one is more triangular, having a straight medial margin. The accentuated asymmetry in shape of the condyles is more marked in this specimen than in other abelisauroids where this portion is preserved. The most noticeable difference between the Cambará theropod and *Eoabelisaurus mefi* is in the position of the lateral condyle, which is placed more posteriorly in the former, but more laterally in the latter. It differs from *Majungasaurus crenatissimus*, in that the posterior edge is not angled obliquely relative to the mediolateral axis.

In medial view, the proximal portion shows numerous muscle scars, especially near the cnemial crest. There is a shallow and elongate depression (= lateral fossa) located on the medial surface close to the posterior margin (Figure 1c). The cnemial crest is very well developed, curves laterally and is directed anterodorsally, a typical feature of abelisauroids (Kellner and Campos, 2002; Carrano, 2007; Carrano and Sampson, 2008). In lateral view, the main axis of the cnemial crest forms an angle of about 115° relative to the shaft, rising well above the proximal articulation surface (Figure 1d). This condition is similar to *Majungasaurus crenatissimus* and *Eoabelisaurus mefi* and differs from

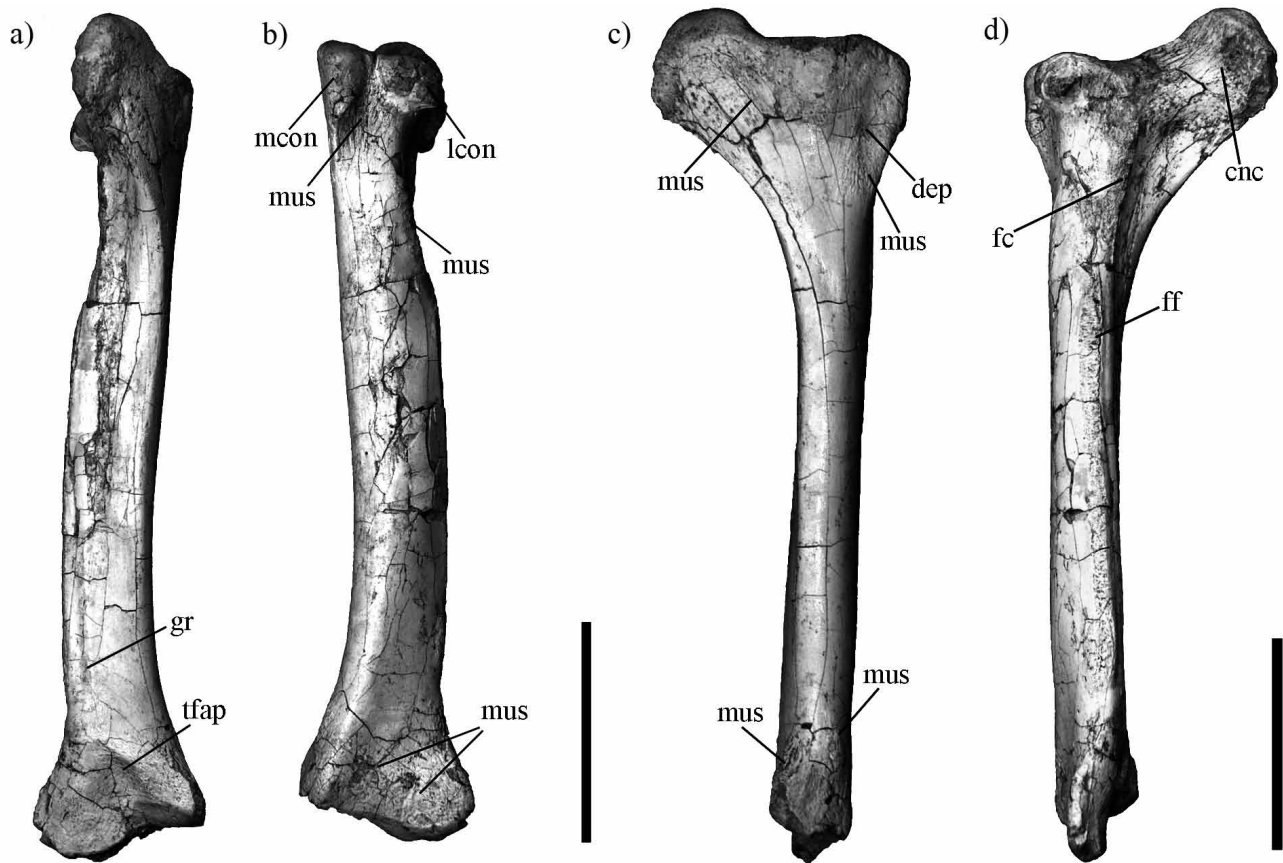


Figure 1. Right tibia (MCT 1783-R). a) Anterior view showing the torsion presented in relation to the proximal and distal condyles; b) posterior view showing the two asymmetrical condyles and the surrounding muscle attachment scars; c) medial view, showing muscle scars on the proximal epiphysis, and muscle scars in proximal and distal portions; and d) lateral view; note the cnemial crest is elevated above the proximal articulation. Abbreviations: cnc - cnemial crest, dep - depression, gr - groove, tfap - tibial facet for ascending process of astragalus, tfas - tibial facet for astragalus, fc - fibular crest, ff - fibular facet, lcon - lateral condyle, lm - lateral malleolus, mcon - medial condyle, mm - medial malleolus, mus - muscle scar. Scale bar equals 100 mm.

Masiakasaurus knopfleri and *Xenotarsosaurus bonapartei* where it projects less relative the dorsal margin of the proximal articulation. In proximal view, this structure is strongly curved laterally, more than in other abelisauroids except for *Masiakasaurus knopfleri* and *Ekrixinatosaurus novasi* (Figure 2). In medial view, the dorsal margin of the cnemial crest is concave, in contrast with the straight ventral border. At the anterior end of the cnemial crest, there is a longitudinal groove on the lateral surface for the knee extensor tendon. A well-developed lateral fossa is located between the cnemial crest and the shaft.

Despite being abraded, the fibular crest is clearly broad, and begins near the cnemial crest, ending dorsal to the fibular facet. A shallow and triangular depression is present posterior to this crest. Several anteroposteriorly oriented blunt ridges can be delineated on the lateral surface, dorsal to the beginning of the fibular crest, and partially extending over the posterior surface of the shaft. These are interpreted as muscle scars.

The fibular facet is well developed (180 mm) and extends for about half the total length of the shaft, suggesting an almost total lack of mobility between the tibia and

fibula. The extent of this facet is similar in *Masiakasaurus knopfleri* and *Xenotarsosaurus bonapartei*, but much larger than in *Majungasaurus crenatissimus* and *Rahiolisaurus gujaratensis*. *Ekrixinatosaurus novasi* also has an extended fibular facet that is broader than in MCT 1783-R.

The shaft is curved, with the medial margin concave and the lateral margin convex, differing from the relatively straight condition observed in *Pycnonemosaurus nevesi*, *Quilmesaurus curriei*, *Ekrixinatosaurus novasi* and *Rahiolisaurus gujaratensis*. As in *Masiakasaurus knopfleri*, the anterior surface bears a blunt ridge that according to Carrano *et al.* (2002) acts as a limit for musculature. Between this ridge and the fibular facet is a shallow elongate groove not reported in other abelisauroids.

The distal portion of the shaft is expanded mediolaterally (88.3 mm × 17 mm), and forming in anterior view, two asymmetric malleoli. The lateral (fibular) malleolus is broader and projects farther distally than the medial one. It differs from *Majungasaurus crenatissimus*, *Pycnonemosaurus nevesi*, *Quilmesaurus curriei* and *Rajasaurus narmadensis* in that the fibular malleolus projects less distally, and in having a more rounded end.

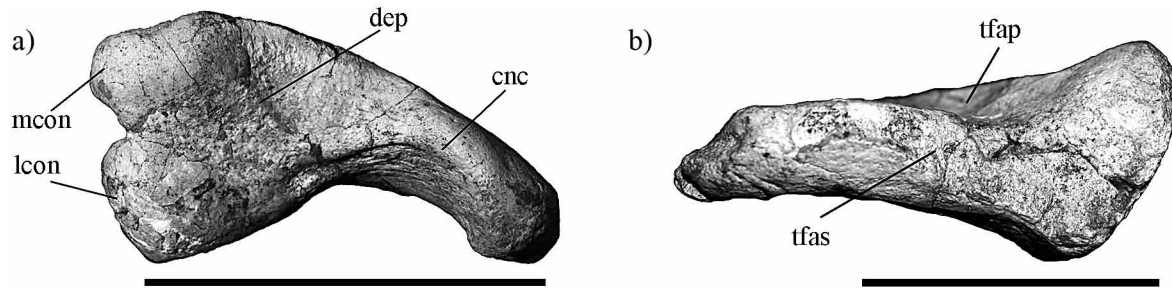


Figure 2. Right tibia (MCT 1783-R). a) Proximal view, showing asymmetrical medial and lateral condyles; note the hook-shaped curvature of the cnemial crest, and b) distal view, showing the astragalus and calcaneum articulation surface. Scale bar equals 100 mm.

The anterior articular facet for the astragalus is triangular and deeper than in other abelisauroids. Based on the articulation facet and the muscle scars above it, the astragalus ascending process was apparently of moderate height. The distal end of the tibia is complete, and neither the astragalus nor the calcaneum are preserved. This suggests that those elements were not fused in this specimen (Figure 3).

DISCUSSION

The Cambará theropod shows a well-developed cnemial crest with a lobular distal end which projects considerably above the proximal articular surface. These features are characteristic of the Abelisauroidea (Rauhut, 2003; Carrano *et al.*, 2002; Novas *et al.*, 2004), and allow the assignment of the specimen to this clade.

Among abelisauroids there are about twenty-nine taxa, most based on incomplete material (Carrano and Sampson, 2008; Canale *et al.*, 2009; Ezcurra *et al.*, 2010; Novas *et al.*, 2010). Only twelve of these have the tibia, at least, partially preserved, allowing for comparison with the Cambará theropod (Figure 4). The least complete is the tibia in the holotype of *Berberosaurus liasicus*. Based on published information, this african species comes from Early Jurassic deposits (Allain *et al.*, 2007), and apparently has a cnemial crest smaller than in the Cambará theropod.

Among other african abelisauroids, the Cambará specimen differs from *Majungasaurus crenatissimus* in lacking the marked angle of the posterior end of the tibia relative to the main axis, which can be better observed in proximal view (Carrano, 2007). Furthermore, the brazilian species has a fibular malleolus that projects less distally, with a more rounded end, and a much larger fibular facet.

Similarities between the Cambará theropod and *Masiakasaurus knopfleri* are noticeable, and include the curvature of the shaft and the extension of the lateral fossa. Among the main differences is the less developed and projected cnemial crest in *Masiakasaurus knopfleri*, which also has the tarsal elements fused to the tibia (Carrano *et*

al., 2002). Furthermore, the Cambará specimen is almost two times larger.

There are two abelisauroids from India with the tibia preserved. *Rahiolisaurus gujaratensis* differs from the Cambará theropod in having a more elongate cnemial crest, an almost straight shaft in anterior view, and a smaller fibular facet. *Rajasaurus narmadensis* only preserves the distal portion of the tibia, which differs from the brazilian species in having the lateral malleolus more projected distally.

Among the remaining Cretaceous abelisauroids where the tibia is known, five are from Argentina: *Aucasaurus garridoi*, *Ekrixinatosaurus novasi*, *Quilmesaurus curriei*, *Xenotarsosaurus bonapartei* and *Scorpiovenator bustingorryi*. Recently a new species, *Eoabelisaurus mefi*, was found in the Upper Jurassic of Patagonia, which is considered the oldest record of the clade.

The Cambará specimen differs from *Aucasaurus*

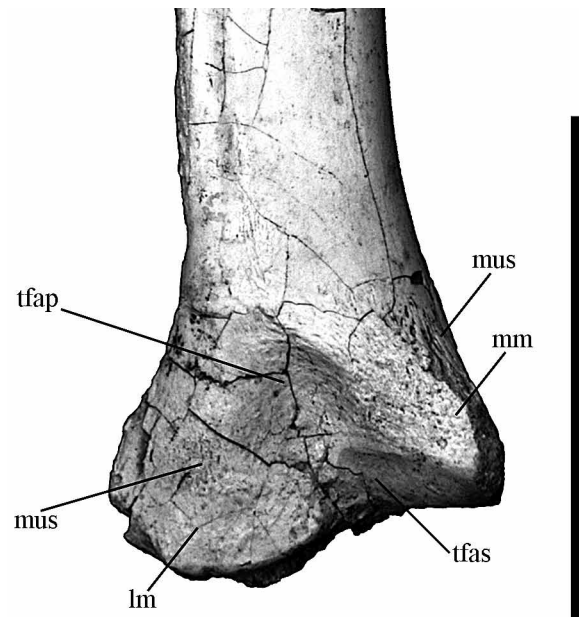


Figure 3. Detailed view of distal portion of the right tibia (MCT 1783-R) in anterior view; note the deep but short depression for the ascending process of astragalus. Scale bar equals 100 mm.

garridoi in having the distal end of the cnemial crest blunt and rounded, and in lacking the lateral process present in the latter. The argentinean species further has the tip of the distal margin of the cnemial crest ventrally projected, giving it a 'hatchet' shape. In *Aucasaurus garridoi* the astragalus and calcaneum are fused to the tibia (Coria et al., 2002), which is not the case in the brazilian specimen. Lastly, in *Eoabelisaurus mefi* the condyles differ not only in shape, but in position compared to the brazilian specimen. The Jurassic specimen is not only from a larger and more robust animal, but it also differs by having a fused distal end of the tibia.

Compared to *Ekrixinatosaurus novasi*, the Cambará specimen possesses a less developed intercondylar groove and a comparatively narrower fibular facet. The fibular facet in *Ekrixinatosaurus novasi* is also straight in anterior view, and the tarsal elements are fused to the tibia (Calvo et al., 2004). *Quilmesaurus curriei*, a species based on the distal

articulation of a femur and a complete tibia (Coria, 2001), has a straight shaft and a slightly expanded distal end of the cnemial crest, features not present in the Cambará theropod. The argentinean species also has a more projected fibular malleolus, a less developed intercondylar groove, and belongs to a much larger animal.

Size is also a difference between the new brazilian specimen and *Xenotarsosaurus bonapartei* and *Scorpiovenator bustingorryi*; both are much larger. *Xenotarsosaurus* further has a cnemial crest more triangular and less projected, and a straighter shaft (Martínez et al., 1986). *Scorpiovenator bustingorryi* displays a wider intercondylar groove between the proximal condyles (Canale et al., 2009). Both also have the tarsal elements fused with the tibia.

The tibia in the only named abelisaurid from Brazil, *Pycnonemosaurus nevesi*, is more robust, has a straight shaft and is about double the size of the Cambará speci-

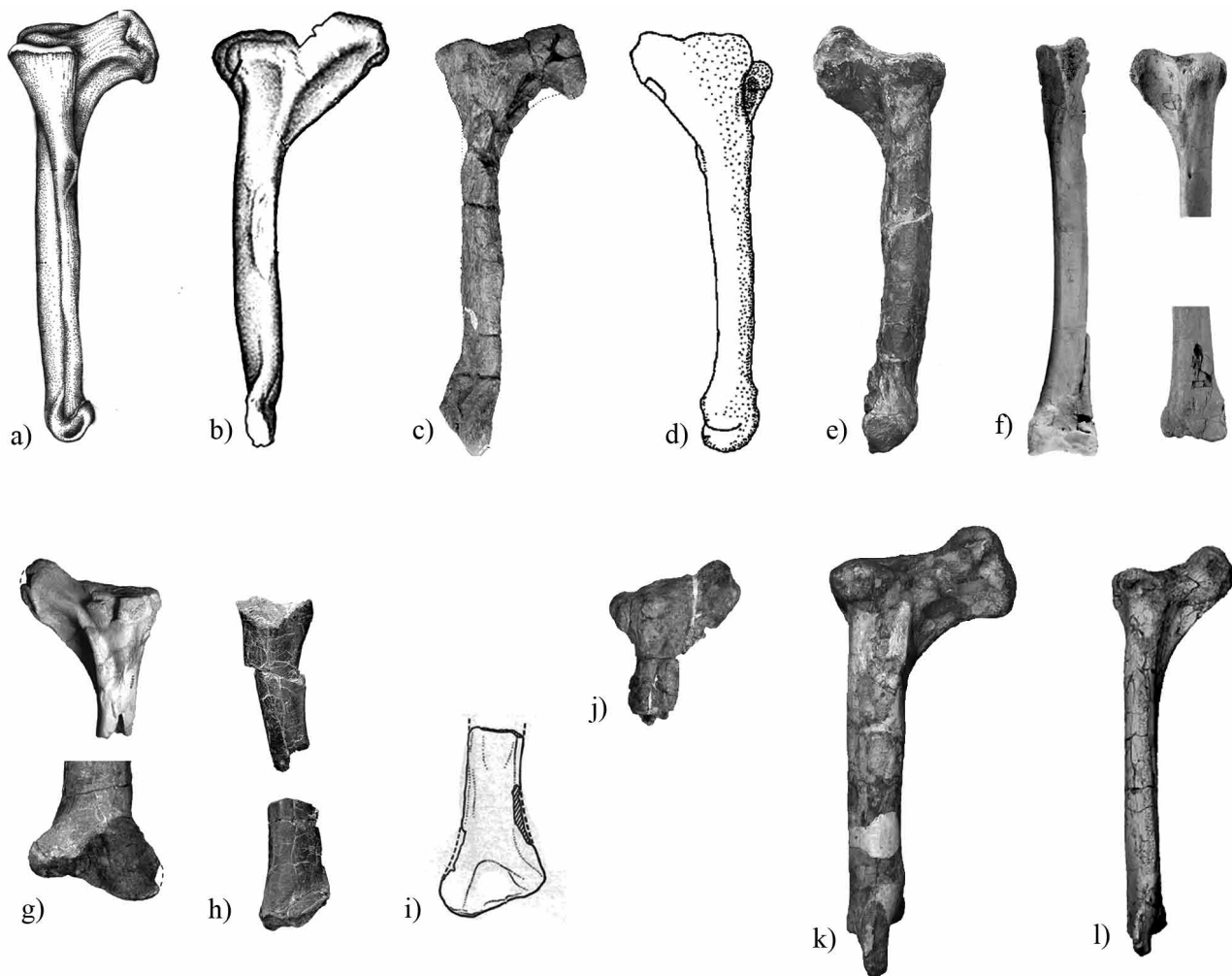


Figure 4. Comparison of tibiae in different abelisauroids. a) *Aucasaurus garridoi* in lateral view; b) *Rahiolisaurus gujaratensis* in lateral view; c) *Quilmesaurus curriei* in lateral view; d) *Xenotarsosaurus bonapartei* in medial view; e) *Ekrixinatosaurus novasi* in lateral view; f) *Masiakasaurus knopfleri* (left FMNH PR 2122 in anterior view; upper right FMNH PR 2118 in lateral view and bottom FMNH PR 2119 in anterior view); g) *Majungasaurus crenatissimus* (upper FMNH PR 2424 in lateral view, bottom FMNH PR 2278 in anterior view); h) *Berberosaurus liassicus* (upper MHNM Pt 21 in medial view, MHNM Pt 16 in posterior view); i) *Rajasaurus narmadensis* in anterior view; j) *Eoabelisaurus mefi* in lateral view; k) *Pycnonemosaurus nevesi* in lateral view; l) Cambará specimen (MCT 1783-R) in lateral view. Not to scale.

men. Another difference is the hatchet-shaped condition of the cnemial crest, diagnostic of *Pycnonemosaurus nevesi*. Furthermore, the lateral malleolus is more lobular in MCT 1783-R, while in *Pycnonemosaurus nevesi* this structure is more elongate, projecting laterally and downward (Kellner and Campos, 2002). Based on those differences, and on the fact that the new material comes from a different stratigraphic unit, it is unlikely that the Cambará theropod represents a juvenile or immature individual of *Pycnonemosaurus nevesi*.

Besides those differences, there are two potentially unique features in the Cambará theropod: 1) the condyles at the posterior margin of the proximal articulation are strongly asymmetric, with the lateral condyle square and the medial condyle triangular, and 2) the articular facet for the astragalus on the anterior surface is triangular and very deep. There is also a shallow elongate groove on the anterior surface, lateral to the fibular facet, which is not present in *Pycnonemosaurus nevesi* and has not been reported in any other abelisauroid. This may also be a unique feature of the Cambará theropod.

After five decades of excavation in the Peirópolis area (Campos and Kellner, 1999), only a handful of theropod specimens have been recovered. Two were assigned to maniraptoran theropods, one ungual (Novas *et al.*, 2005), and one scapula (Machado *et al.*, 2008). Three others were regarded as abelisauroids, and due to their large size (from individuals over 5 m in estimated body length) tentatively attributed to the Abelisauridae (Novas *et al.*, 2008). Of those, two came from the same deposit as the tibia described here: a pedal phalanx and the distal end of a femur. According to Novas *et al.* (2008), the distal articulation surface of the femur has a transverse section of 102 mm, which is almost double the transverse dimension of the proximal articulation of the tibia described here (MCT 1783-R; 55.8 mm). This clearly shows that the Cambará theropod tibia is from a much smaller individual.

Although difficult to determine accurately, MCT 1783-R is a little larger than half the size of *Masiakasaurus knopfleri* (see Carrano *et al.*, 2002, table 1) and about half the size of *Pycnonemosaurus nevesi*, suggesting that the Cambará theropod represents an individual with a body length of around 3.5 meters.

Although relationships among abelisauroids remain to be resolved, several authors recognize at least two distinct clades: the Abelisauridae and the Noosauridae, (Novas *et al.*, 2004; Carrano *et al.*, 2002; Carrano and Sampson, 2008). Among the main differences between them is size, with noosaurids and abelisaurids represented by comparatively small (less than 2.5 meters) and large (over 5 meters) species, respectively. Unfortunately, there is no synapomorphic feature present in the tibia that would allow a confident assignment of the Cambará specimen to one or the other abelisauroid clade. At the present level of knowledge, this species falls between the typical sizes of Noosauridae and Abelisauridae. It could potentially either be the largest

known noosaurid or the smallest known abelisaurid. In any case, the occurrence of the Cambará theropod clearly indicates the presence of at least three distinct theropods at the Veadinho Hill site: one maniraptoran (Machado *et al.*, 2008; Novas *et al.*, 2008) and two abelisauroid taxa of distinctly different sizes.

CONCLUSIONS

An isolated abelisauroid tibia (MCT 1783-R) from the Veadinho Hill locality in Peirópolis, Minas Gerais, was recovered from the Maastrichtian Marília Formation. After more than four decades of excavation there (Campos and Kellner, 1999), this is the first theropod specimen recovered that shows diagnostic features and a unique combination of characters, which along with its stratigraphic position and geographical location, suggest that it is a new species (Kellner, 2010). Nonetheless, due to the incompleteness of this material we refrain from erecting a new species until more theropod specimens from this unit may become available.

Based on the morphological features of the cnemial crest, the Cambará specimen represents a member of Abelisauroidea. This group has been subdivided into two clades with different typical body lengths, the smaller Noosauridae (less than 2.5 m) and larger Abelisauridae (more than 5 m). The estimated body length for the Cambará theropod falls between those typical sizes, and it could represent either a large noosaurid or a small abelisaurid. The new specimen demonstrates the presence of two abelisauroid species in the Peirópolis region of Brazil, and indicates that theropods were more diverse here during Late Cretaceous time than previously recognized.

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