Artículo

IT TAKES MORE THAN LARGE CANINES TO BE A SABRETOOTH PREDATOR

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ABSTRACT. *Monodelphis dimidiata* is a small marsupial from southern South America. It is a true semelparous species that develops an extreme sexual dimorphism associated to the attaining of sexual maturity, both on the size, weight and skull morphology, including the development of sabre-like canines in males. A recent paper considered *M. dimidiata* males to be pigmy sabretooth predators, based mainly on morphometric analyses. Here we study the skull morphometry (including canine size) of *M. dimidiata* in comparison with other marsupials, living felids and extinct sabretooth predators, looking for convergences with the latter. We also put the hypothesis of *M. dimidiata* as a sabretooth predator in the context of its life history, reinterpreting the origin of its sabre-like canine and its suitability as a living analogue of primitive sabretooth predators. We found that the skull pattern of *M. dimidiata* is not different from other didelphid marsupials, and even *Didelphis albiventris* has canines of the same relative length. We consider that the large canines of *M. dimidiata* are a byproduct of the exacerbated growth of males, caused by their delayed eruption, as well as by their late apexification. Large canines are related to the particular reproductive cycle of this species instead of being an adaptation to hunt large preys, as was proposed for sabretooth cats.

RESUMEN. **Se precisa más que caninos grandes para ser un predador dientes de sable**. *Monodelphis dimidiata* es un pequeño marsupial del sur de América del Sur. Es una especie con semelparía verdadera, que desarrolla un dimorfismo sexual extremo asociado a la madurez sexual, tanto en el tamaño, el peso y la morfología craneana, incluyendo el desarrollo de caninos tipo sable en los machos. Un trabajo reciente considera a los machos de *M. dimidiata* como depredadores dientes de sable pigmeos, sobre la base de análisis morfométricos. Aquí se estudia la morfometría del cráneo (incluyendo el tamaño de los caninos) de *M. dimidiata* en comparación con otros marsupiales, félidos vivientes y especies extintas de depredadores dientes de sable, en busca de convergencias con el último grupo. También se pone a prueba la hipótesis de *M. dimidiata* como depredador dientes de sable en el contexto de su historia de vida, reinterpretando el origen de su canino tipo sable y si es apropiado como un análogo viviente de los depredadores dientes de sable primitivos. Se encontró que la morfología general del cráneo de *M. dimidiata* no es diferente de otros marsupiales didélfidos, e incluso *Didelphis albiventris* tiene caninos del mismo largo relativo. Consideramos que los grandes caninos de *M. dimidiata* son un subproducto del crecimiento exacerbado de los machos, causado por su erupción retrasada, así como por su apexificación tardía. Los caninos grandes parecen estar relacionados con el ciclo reproductivo particular de esta especie en lugar de ser una adaptación a cazar presas grandes, como se propuso para los tigres dientes de sable.

Key words: Canine growth. *Didelphis albiventris*. Marsupials. *Monodelphis dimidiata*.

Palabras clave: Crecimiento de los caninos. *Didelphis albiventris*. Marsupiales. *Monodelphis dimidiata*.

INTRODUCTION

Monodelphis dimidiata (Wagner, 1847) is a small didelphid marsupial from the Pampas and Atlantic Forest domains of Argentina, Brazil, Uruguay, and Paraguay (as *M. sorex*; Pine and Handley, 2007; Smith, 2008; Vilela et al., 2010). This small mammal has the peculiarity of being semelparous, meaning that its life cycle is reduced to one reproductive event (1 year in this case), where males die after reproduction and females after the weaning of the offspring (Pine et al., 1985; Baladrón et al., 2012). Associated with the attaining of sexual maturity, both sexes increase the growth rate, being this rate more accentuated in males, which are significantly larger than females (Pine et al., 1985). This extreme sexual dimorphism is not only evident in the size and weight of males, but also in the skull morphology, where males have larger cranial crests than females, enlarged postorbital processes on the frontals, wider zygomatic arches and sabre-like canines (Pine et al., 1985:217).

In a recent paper, Blanco et al. (2013) "rediscovered" the sabre-like canines of *M. dimidiata* and considered the species (particularly males) as a pigmy sabretooth predator, based on a morphometric analysis and the comparison with measurements of sabretooth predators published by Emerson and Radinsky (1980), and the observations of animals held in captivity published by González and Claramunt (2000). Blanco et al. (2013) stated, using indices previously defined by Emerson and Radinsky (1980), that *M. dimidiata* have canines relatively larger than the other marsupials analyzed, and even the indices calculated by Blanco and coworkers were similar to those of sabretooth predators. Also, the authors found, in a principal component analysis of several species of marsupials, that males of *M. dimidiata* could be separated in the fifth principal component mainly by the loadings of several variables that could be related to a sabretooth condition: large upper canine height and anteroposterior length, short masseteric fossa length and lever arm of temporalis, long distance from the mandibular condyle to the M3, and short jaw (Blanco et al., 2013). The authors also found that the humerus of males of *M. dimidiata* is very robust, analogue to what happens in some sabretooth cats (e.g., Meachen-Samuels and Van Valkenburgh, 2010). This combination of characters led the authors to conclude that *M. dimidiata* might be a living analogue of the primitive sabretooth condition, with hyperthrophied canines, a wider gape, lower bite force, and a strong humerus.

The conclusion of Blanco et al. (2013) is intriguing, because the morphological skull pattern, diet (mostly insectivorous), and size of *M. dimidiata* differ greatly from sabretooth cats (Pine et al., 1985; Busch and Kravetz, 1991; Pine and Handley, 2007). These differences make it difficult to see how further evolutionary, behavioral and ecological studies of *M. dimidiata* would provide a better understanding of the origin and behavior of sabretooths in the past (Blanco et al., 2013:9), and leave the possibility that the similarities found by the authors are only convergences related to other causal factors.

In this paper we study the morphometry of the skull (including canine size) of *M. dimidiata* in comparison to other marsupials, living felids and extinct sabretooth predators (Felidae, Nimravidae, Sparassodonta), looking for convergences with the last group. We also put the findings of Blanco et al. (2013) in the context of the life history of *M. dimidiata*, reinterpreting the origin of its sabre-like canine and reassessing its suitability as a living analogue of primitive sabretooth predators.

MATERIALS AND METHODS

We reanalyzed the data of Blanco et al. (2013) adding two large males and one large female of *M. dimidiata* (ages 6/7 following Gardner, 1973), five *Didelphis albiventris* of ages 6 and 7, and two adults of each of the following living felids: *Neofelis nebulosa*, *Panthera leo*, *Puma concolor* and *Leopardus tigrinus* (**Appendix 1, supplementary material**). We also included in the analyses the sample of sabretooth predators (SP, hereafter) of the clades Felidae, Nimravidae, and Sparassodonta from Emerson and Radinsky (1980). Measurements C1W (upper canine mediolateral width) and OCPH (occipital height) were excluded since we did not have data for the SP and *Neofelis*, respectively. It is important to mention that both measurements

were also excluded by Blanco et al. (2013) to obtain a level of variation above the Jolliffe cut-off point and consequently are not relevant to the discussion. Since the taxonomic sample we are analyzing is a mixture of felids and marsupials, we consider that the length from the condyle to the third lower molar (COM3) in marsupials is analogue to the length from the condyle to the first lower molar (COM1) in Feliformia (see Jones, 2003).

We performed a principal component analysis (PCA) using indices obtained from the 12 measurements (dividing the measurements by the skull length or the jaw length in order to standardize them), and one using the final 6 indices selected by Blanco et al. (2013). Since these indices are ratios, we log-transformed the data prior to performing the PCA (James and McCulloch, 1990). The variance-covariance matrix was used to obtain the eigenvalues and eigenvectors.

Blanco et al. (2013) also used allometric equations based on their sample to estimate an expected value for each measurement. Then, they obtained an index as the ratio between the measured value and the expected value obtained from the equations, and compared those indices with the data from Emerson and Radinsky (1980). The problem with that approach is that Blanco et al. (2013) compared indices obtained using different allometric equations (since they did not include the data from Emerson and Radinsky in their estimations), which is incorrect and can lead to wrong conclusions. Other problem with this approach is that it does not take into account the phylogenetic signal of the data, biasing the allometric pattern obtained (e.g., Harvey and Pagel, 1991). To avoid these problems we prefer to estimate the relative sizes of the canines and other measurements, dividing each measurement by the geometric mean of all the measurements used in this study (Jungers et al., 1995).

Finally, as another way of analyzing overall similarity, we performed a cluster analysis using the measurements above mentioned divided by their geometric mean (log-transformed). For the cluster analysis we used the unweighted pair-group average algorithm (UPGMA), computing the distance matrix using the Euclidean matrix. All the statistical analyses were performed using the software PAST vers. 2.10 (Hammer et al., 2001).

RESULTS

In the PCA where we used the 11 indices, the first principal component (PC1) explained 71.6% of total variance, while the second

principal component (PC2) explained 9.8% of total variance. PC1 separated the SP from the remaining taxa (**Fig. 1**). Except for *Dinictis,* SP were placed on the negative end of PC2, while living felids were placed on its positive end (**Fig. 1**). *M. dimidiata* was mostly placed on the negative side of PC2, in the same morphospace of *Didelphis albiventris* and other species of *Didelphis* (**Fig. 1**). Regarding its position in PC1, *M. dimidiata* and *D. albiventris* were at the same coordinates than living felids (except *Neofelis*) and *Sarcophilus harrisii* (**Fig. 1**). The remaining marsupials were placed on the negative side of PC1. Canine height and length (C1H and C1L) and jaw height (JH) were the most influential variables for PC1, the three increasing towards its positive end (**Table 1**). For PC2 the variables that contributed the most were: zygomatic arch width (ZAW), occipital width (OCPW), temporal fossa length (TFL), jaw height (JH), masseteric fossa length (MFL) and the moment arm of the temporalis (MAT) towards the positive end, while tooth row length (TRL) and C1L increased towards the negative end of PC2 (**Table 1**). None of the remaining 9 PCs placed *M. dimidiata* close to the sabretooth predators. Using the 6 indices selected by Blanco et al. (C1L, C1H, JL, COM3, MFL, and MAT) the pattern was similar, except that some specimens of *M. dimidiata*, *D. albiventris* and the two specimens of *S. harrisii* were placed in the same morphospace that some living felids (not shown). Again, none of the PCs placed *M. dimidiata* close to the sabretooth predators.

The relative height of canines of *M. dimidiata* (as shown by dividing C1H by the geometric mean) did not escape the morphospace of other marsupials, widely overlapping with the relative height of canines of *D. albiventris* (**Fig. 2a**). Among marsupials, the highest value belonged to a *M. dimidiata* female (MACN [Museo Argentino de Ciencias Naturales] 24458). There was no overlap between SP and any of the other taxa, being *N. nebulosa* the closest species to the sabretooth predators (**Fig. 2a**). The same pattern was observed for the relative length of canines, where *M. dimidiata* did not differ from other marsupials and SP did not overlap with any other taxa (**Fig. 2b**). Finally, the relative distance from the mandibular condyle to the
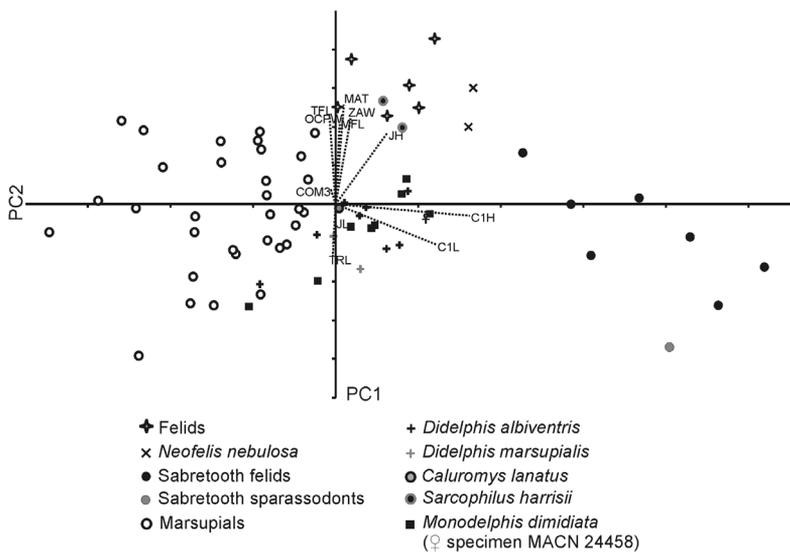
Fig. 1. Plots of PC1 versus PC2 from principal component analysis of the 11 indices, for marsupials, felids and sabretooth predators from the sample of Emerson and Radisnky (1980).

The cluster analysis (cophenetic correlation coefficient = 0.8409) was consistent with the other analyses, and showed no relation between *M. dimidiata* and the SP. Most sabretooth predators (except *Dinictis*) were placed in a cluster distant from the remaining taxa. *M. dimidiata* grouped with *D. albiventris*, *D. marsupialis*, *Caluromys lanatus* and one specimen of *Lutreolina crassicaudata*. *S. harrisii* grouped with some of the living felids, while *N. nebulosa* was clustered with *Dinictis* (**Fig. 3 supplementary material**).
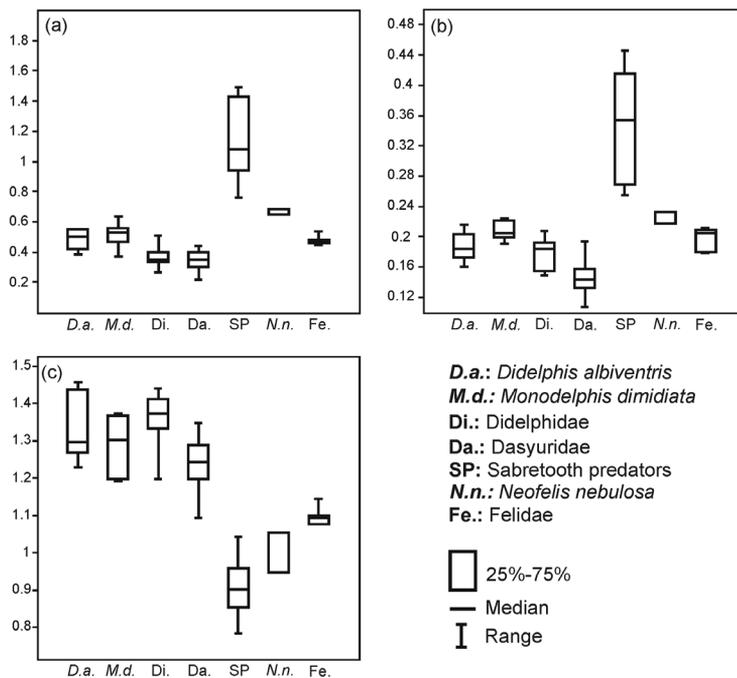
DISCUSSION

Our results clearly show that in a morphological context, *M. dimidiata* does not escape from the morphometric space of other didelphids (**Figs. 1** and **3** [**supplementary material**]), and is far from the sabretooth predator morphotype (**Fig. 1**). The PCA including all the variables separated the SP along PC1 mainly by the size of the canines, and placed them on the positive end of PC1 and towards the negative side of PC2. In this analysis, *M. dimidiata* was the extant marsupial with higher PC1 scores, but was widely overlapped with *D. albiventris* and only one female (MACN 24458) had a slightly higher score. *N. nebulosa*, a felid considered by some authors to be a living analogue of sabretooth cats (Christiansen, 2006, 2008a, 2008b) was placed on the positive end of PC1, being the closest living taxa to SP. However, like other living felids, *N. nebulosa* was also on the positive end of PC2, mainly due to a wider zygomatic arch, larger temporal and masseteric

Table 1

PC loadings (eigenvectors) obtained from the principal component analysis (PCA) of the 11 indices. Acronyms: C1H = upper canine height; C1L = upper canine anteroposterior length; COM3 = condyle to M3; JL = jaw length; OCPW = occipital width; SL = skull length; TFL = temporal fossa length; TRL = tooth row length; ZAW = zygomatic arch width; JH = jaw height; MFL = masseteric fossa length; MAT = moment arm of temporalis; PC, principal component.

Indices	PC1	PC2	PC3
	71.56%	9.76%	7.12%
C1H/SL	0.7608	-0.0522	0.0773
C1L/SL	0.5687	-0.1830	0.0216
JL/SL	-0.0049	-0.0777	0.0036
OCPW/SL	0.0016	0.3720	0.7532
TFL/SL	-0.0368	0.4047	0.0383
TRL/SL	-0.0160	-0.2323	0.1284
ZAW/SL	0.0841	0.3915	0.2977
COM3/JL	-0.0285	0.0693	-0.1431
JH/JL	0.2926	0.3226	-0.2533
MFL/JL	0.0227	0.3705	-0.3086
MAT/JL	0.0450	0.4497	-0.3740

M3 was highly overlapped among marsupials, being *D. albiventris* the species with the highest distance (**Fig. 2c**). The complete set of measurements and their indices are available on **Appendix 2 (supplementary material)**.

Fig. 2. Boxplots summarizing the information from the analyses of three indices (a) upper canine height/geometric mean, (b) upper canine anteroposterior length/geometric mean, and (c) condyle to M3 or M1/geometric mean.

D.a.: *Didelphis albiventris*
M.d.: *Monodelphis dimidiata*
Di.: Didelphidae
Da.: Dasyuridae
SP: Sabretooth predators
N.n.: *Neofelis nebulosa*
Fe.: Felidae

☐ 25%-75%
— Median
I Range

muscle advantage, longer temporal fossa and wider braincase.

SP were placed on the positive end of PC1, with more specialized taxa (e.g., *Thylacosmilus*, *Barbourofelis*) having higher PC1 scores, and negative PC2 scores, while less specialized species (e.g., *Dinictis*) showed positive PC2 scores and were placed forming a continuum between living felids and the highly specialized SP (**Fig. 1**). This pattern of continuum variation between felids and SP (though with derived SP occupying a different portion of the morphospace), and even the superposition between less specialized SP and felids, was found previously, using different taxonomic samples and geometric morphometric analyses (e.g., Slater and Van Valkenburgh, 2008; Christiansen, 2008; Prevosti et al.*,* 2010). With the variables used here we can state that specialized SP have longer and larger upper canines, narrower skulls, longer dental series and lower mandible, and smaller fossae for temporal and masseteric muscles and shorter coronoid process, while less modified taxa are more similar to felids (specially to *Neofelis*), presenting the opposite pattern (**Fig. 1**). In this analysis is also clear that living marsupials do not invade the morphospace of SP, and that *Monodelphis* and *Didelphis* are in the periphery of the marsupial sample. Though *Monodelphis* and *Didelphis* showed PC1 scores similar to living felids, because of their relatively longer and larger canines, their skull anatomy is not different from other marsupials, and is strik-ingly different from living felids and SP (**Figs. 1** and **4**). The living marsupial that showed a more divergent anatomy in the PCA analysis was *S. harrisii*, which also has relatively larger canines, and a skull proportion similar to living felids (at least with the variables used here; **Fig. 1**). This agrees with the more predatory and scavenger habits reported for the Tasmanian devil (e.g., Strahan, 1998; Nowak, 2005).

The PCA arrangement described in this paper contrasts with the analyses published by Blanco et al. (2013), which could be related to the inclusion of more didelphid specimens, but mainly to the inclusion of felids and sabretooth predators. However, the principal component analyses performed by Blanco et al. (2013) deserve two important criticisms. First, we think that the procedure followed by the authors to reduce the number of variables in the PCA is highly questionable, since they manipulated the data until they obtained the results they expected (i.e., *M. dimidiata* in a different morphospace than the remaining marsupials). Moreover, the reduced PCA has a limited representation of variables (i.e., different morphometric aspects of the skull), and reduces the entire skull shape

to six measurements, none of which refers to the cranium. Second, the authors used ratios as variables, but they did not log-transformed the data. Log-transforming the data is important not only because it helps normalizing the data and achieving homoscedasticity (Legendre and Legendre, 1998), but in the case of ratios, when one has a product of variances, the transformation helps making the relationship between variables linear, which is a requirement for PCA (James and McCulloch, 1990). We performed the same PCAs conducted by Blanco et al. (2013) (i.e., without adding specimens) but log-transforming the variables, and found that the pattern they described disappears, both for the complete and the reduced analysis (**Fig. 5 supplementary material**). Consequently, the authors should reconsider their findings, not only based on the discussion presented here, but also based on a more accurate statistical analysis of their data.

The same tendency found in the PCA was observed when analyzing the relative size of *M. dimidiata* canines, which were not different from the relative size of *D. albiventris* canines, even overlapping with the canine size of the other marsupials analyzed. Also, the distance between the mandibular condyle and the third lower molar was no different in *M. dimidiata* versus other marsupials, and even the largest values belonged to a specimen of *D. albiventris*.

Consequently, there is nothing on the morphological features analyzed here that indicates that *M. dimidiata* is a pigmy sabretooth predator (see **Fig. 4** for a comparison among species). Even the size of the canines is discarded as a distinctive feature, since there is a wide overlap with *D. albiventris*. A lateral view of the skull of the specimen MACN 36.731 (**Fig. 4c**) clearly resembles the sabre-like canines of *M. dimidiata* males (**Fig. 4b**). We believe that Blanco et al. (2013) failed to see that overlap not only due to the indices they used (see above), but also because the three specimens of *D. albiventris* that they selected were small, while we included the largest specimens of *D. albiventris* available (as well as we did with *M. dimidiata*). A striking result was the position of the *M. dimidiata* female MACN 24458 (**Fig. 4a**), which had the highest canines among marsupials and was the

only specimen that escaped from the morphometric space of the marsupials in the reduced PCA. This suggests that some females also have the potential of developing a large body size and large canines, probably in cases where there are available good food sources, or in cases of reduced fecundity, as suggested by Gardner (1973) for *Didelphis virginiana*. Consequently, the issue of *M. dimidiata* as a pigmy sabretooth predator is not only associated with males, as stated by Blanco et al. (2013), but also with some females.

If the 'sabretooth predator' morph in *M. dimidiata* is mainly restricted to adult males, we should expect to find differences between sexes in diet, behavior and ecology, which is not the case. The diet analysis of *M. dimidiata* performed by Goin et al. (1992) supports the idea that females are not that different from males, since they found no differences in the stomach contents of both sexes, not even in adults of over 60 g (i.e., after attaining sexual maturity). In fact, up to date, there is no published evidence of differences in the diet between males and females. There are speculations that males would be more carnivorous than females (e.g. Pine et al., 1985), but in captivity females killed mice as avidly as males did (González and Claramunt, 2000). The fact that females kill and consume mice in the same way males do, goes against the behavioral explanation proposed by Blanco et al. (2013) for the convergence between *M. dimidiata* and sabretooth predators, since the average adult female has much shorter canines than males, as well as a shorter distance from the mandibular condyle to the m3. As previously suggested, it is clear that the large canines of males are not related (or at least not strongly related) to the feeding habits of *M. dimidiata* (Goin et al., 1992; González and Claramunt, 2000). In addition, contrary to other carnivorous didelphid marsupials such as *L. crassicaudata* (Mares et al., 1989), *M. dimidiata* is not considered to be an effective mammalian predator, and there are even some reports that, when put on the same cage, they coexisted with mice (Pine et al., 1985, and references therein). The majority of possible rodent preys described for *M. dimidiata* are smaller than this marsupial (Busch and Kravetz,

Fig. 4. Lateral view of the skull of (a) *Monodelphis dimidiata* ♀ MACN 24458, (b) *M. dimidiata* ♂ MACN 24440, (c) *Didelphis albiventris* ♂ MACN 36.731, (d) *Smilodon fatalis* YPM 11532, (e) *Hophlophoneus oreodontis* YPMPU 13628, (f) *Neofelis nebulosa* FMNH 75831. Scale = 10 mm.
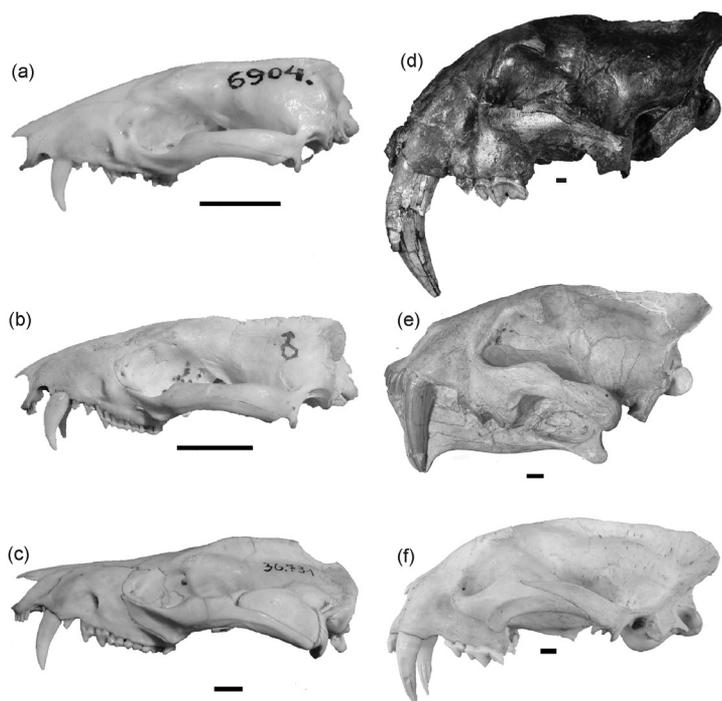
1991), only *Oxymycterus rufus* (= *O. rutilans*) and *Necromys obscurus* (= *Bolomys obscurus*) could be considered to be similar in size to an adult *M. dimidiata* (52 g and 86 g respectively; Fornes and Massoia, 1965). Additionally, laboratory mice (*Mus musculus*) weight less than half the weight of a grown adult male (González and Martínez Lanfranco, 2010), so *M. dimidiata* rarely kills rodents larger than themselves.

We believe that the morphological convergences between *M. dimidiata* and SP described by Blanco et al. (2013) are a byproduct of the ontogenetic development of *M. dimidiata* males, and have little to do with ecological or trophic factors. Once males attain sexual maturity, they start to grow faster than females, ending up being larger (Pine et al., 1985). Since males have this exacerbated growth once they have the complete dentition, it is expected that they will develop a large distance between the coronoid process and the last molar, since molars had already erupted in their definite size when males were much smaller and had smaller mandibles to accommodate the dentition. This increases the COM3 measurement, but merely as a consequence of the enlargement of the mandible, and not as a biomechanical requirement for a wider gape. Moreover, large females that did not develop large canines have a relative COM3 value similar to males with larger canines (**Fig. 6 supplementary mate-**

rial), meaning that the long distance from the mandibular condyle to the third lower molar is not a modification to maintain mandible functionality with hypertrophied canines, as was suggested by Blanco et al. (2013), and is merely a consequence of the enlargement of the mandible after the eruption of the molars.

Something similar happens with canines; Jones (2003) mentioned that canine teeth of marsupial carnivores never cease to erupt. A radiographic analysis of the canines of *M. dimidiata* showed that individuals that completed their adult dentition have a wide pulp cavity, with an open apex with thin walls on the root canal (**Fig. 7a**), meaning that the canines still have the potentiality of growing. Even in large sexually mature males and females the apex remains open, and apexification (i.e., tapering of the root apex) is not complete (**Figs. 7b** and **7c**). This means that the long canines are also a byproduct of the exacerbated growth of males, and evidently the same factors that cause the development of the cranial crests, the enlargement of the postorbital processes on the frontals and the widening of the zygomatic
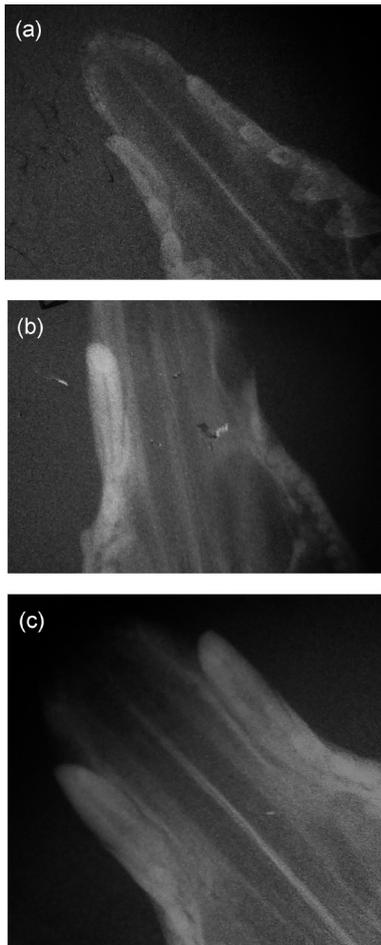
Fig. 7. Radiographs showing the canine pulp cavity and the open apex in *Monodelphis Dimidiata*: (a) ♀ MACN 22474, (b) ♂ MACN 22458, and (c) ♂ MACN 24440.

arches also affect canine growth (and humerus robustness). Consequently, this delay in canine eruption and the late apexification causes that species such as *D. albiventris* that continue to grow throughout their life (Gardner, 1973) develop large canines, as well as *M. dimidiata* males, which have an accelerated growth in the reproductive season (Pine et al., 1985). In the case of the large females of *M. dimidiata*, the situation is similar to the one in *D. albiventris*, where the canine enlargement is caused by the body growth. The acquisition of these long canines in *M. dimidiata* is clearly not related to predatory habits as it is in sabretooth predators (Akersten, 1985; Anton and Galobart, 1999).

Finally, finding a living analogue for the extinct sabretooth cats is an appealing idea, and surely *M. dimidiata* could be somehow considered one. But similarly, it is possible to find analogues to different aspects of the sabertooth cat mechanics in different vertebrates. For example, snakes were used as a model for the sabretooth stabbing (Simpson, 1935; Scott, 1937), while varanid lizards were considered to be a good analogue based not only on tooth morphology, but also on ecological features (Akersten, 1985). There are many other examples of mammals which have long canines, such as many species of primates, the water deer (*Hydropotes inermis*), and the walrus (*Odobenus rosmarus*); all of them might be sharing some similarities with SP of the past. Even the hippos (*Hippopotamus amphibius*), with their wide gape and reduced coronoid process could be considered a living analogue of sabretooth predators. However, we feel that long canines and a wide gape are not enough to be considered a sabretooth predator, particularly in the case of *M. dimidiata*, which can hardly be considered a predator of large preys. We believe that evolutionary, behavioral and ecological studies of *M. dimidiata* will be as useful for understanding the origin and behavior of SP of the past as the same studies in *D. albiventris*, especially when taking into account the broad differences between the morphology, behavior and life history of *M. dimidiata* and any member of Felidae, Nimravidae or Sparassodonta. *N. nebulosa*, due to morphological similarities (see above) and phylogenetic relationships is clearly the best living analogue that we have for these extinct predators.

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ONLINE SUPPLEMENTARY MATERIAL

Fig. 3. Dendrogram obtained from the UPGMA analysis of the 11 measurements (divided by their geometric mean): upper canine height, upper canine anteroposterior length, condyle to M3, jaw length, occipital width, temporal fossa length, tooth row length, zygomatic arch width, masseteric fossa length, and moment arm of temporalis.
http://www.sarem.org.ar/wp-content/uploads/2014/06/SAREM_MastNeotrop_21-1_Chemisquy-sup1.pdf

Fig. 5. Repetition of the principal component analyses presented by Blanco et al. (2013) as evidence for the sabretooth condition of *M. dimidiata*, but log-transforming the variables; (a) PC1 vs. PC5 from the analysis using 14 indices; (b) PC1 vs. PC3 from the analysis using 6 indices.
http://www.sarem.org.ar/wp-content/uploads/2014/06/SAREM_MastNeotrop_21-1_Chemisquy-sup2.pdf

Fig. 6. Lateral view of the mandible of *Monodelphis dimidiata*: (a) ♂ MACN 24440, and (b) ♀ MMP-Ma88077. Scale = 10 mm.
http://www.sarem.org.ar/wp-content/uploads/2014/06/SAREM_MastNeotrop_21-1_Chemisquy-sup3.pdf

Appendix 1. Measurements (in mm) of the specimens included in the analysis.
http://www.sarem.org.ar/wp-content/uploads/2014/06/SAREM_MastNeotrop_21-1_Chemisquy-sup4.doc

Appendix 2. Cranial and mandibular indices of the species included in the analyses.
http://www.sarem.org.ar/wp-content/uploads/2014/06/SAREM_MastNeotrop_21-1_Chemisquy-sup5.doc