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Morphometry of the Femur, Tibia and Fibula of *Plecturocebus caquetensis*

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ABSTRACT

Background: Osteology is the study of the structure and function of bones, aimed at understanding how an individual's activity influences their size. While this branch of anatomy has been extensively explored in domestic animals, there have been limited investigations into Neotropical primates. This lack of research has resulted in a shortage of essential information for veterinarians and professionals working with wild populations, hindering efforts to ensure the health and protection of these species.

Methods: A study was conducted on the large structures of the left and right hind limbs of the Colombian Amazonian primate *Plecturocebus caquetensis*. This study obtained morphometric data, validated in previous investigations, based on ten variables of the proximal region, eleven of the distal region five general variables of the femur, five of the tibia and four of the fibula. The investigation used structures from legal biological collections in Colombia to avoid unnecessary and unethical captures, as the species is critically endangered.

Result: Significant differences were found between the right and left sides of the femur, tibia and fibula. Variables such as diaphysis length, axis, morphological lengthand biomechanical length of the tibia, maximum tibia and maximum fibula, present higher standard deviation values. These differences are due to the traction generated by the muscles inserted in these areas, which is influenced by external stimuli from the environment or physical surroundings.

Key words: Animal anatomy, Femur, Fibula, Primates, Tibia.

INTRODUCTION

The Colombian Amazon primate, *Plecturocebus caquetensis,* is a species that belongs to the Pitheciidae family (Carneiro *et al*., 2016). This family is from Cauca and Caquetá departments in Colombia (Villota *et al*., 2021). Besides, it has limited space distribution (Suárez Ramírez *et al*., 2021) in municipalities such as Piamonte, Solano, Solita, Valparaíso, Curillo, San José del Fragua, Milánand Albania (Defler *et al*., 2016). Following this idea, this species was only reported until 2010 (Defler, 2014) because, during the early years, public order difficulties in the region did not allow investigators' entrance (Defler and Garcia, 2016). However, this species has been studied recently considering some aspects of its natural history (Van Roosmalen *et al*., 2002) in which travel habits are mentioned to define the species as a jumping primate (Rocha *et al*., 2019) considering the species' size (Byrne *et al*., 2016) and anatomical design (Isidro, 1994) that define the species as qualified for its habitat (Osbahr *et al*., 2009). Nonetheless, this information is general. That is why the investigations' developments are required to recognize the anatomical, morphometrics and functional conditions that define the species'ecology (García and Defler, 2011).

The aforementioned aspects are considered by other authors from areas such as biology (Garcia and Defler, 2013), trophic ecology (Defler *et al*., 2016), conservation (Defler and Garcia, 2016) and phylogenetics (Boubli *et al*., 2019), but thorough findings related to size and function of a specimen's anatomical structures, as input to understand populations' necessities (García *et al*., 2010) that define handling and health conditions (Lucy *et al*., 2018).

The *Plecturocebus caquetensis* anatomy has been only tackled from the descriptive point of view of its osteology (Montilla-Rodríguez *et al*., 2023), but morphometrics or functional data are unknown because in 2010 the principal studies focused on distribution (Villota *et al*., 2021), endemism (Defler *et al*., 2016) and population size (Acero-

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Murcia *et al*., 2018) affected by deforestation for cattle raising (Lacetera, 2019), illegal mining, illicit cropsand oil exploitation (Lizcano *et al*., 2021).

Thus, this study externalizes morphometric data that contribute to this type of knowledge, selecting appendicular skeleton structures such as the femur, fibula and tibia, that are important for locomotion in the habitat (Ariana *et al*., 2020). In this sense, relating obtained values to functional aspects (LLeó, 2015) works as a contribution to veterinarian knowledge (Bharti *et al*., 2022) of the species to understand related conditionals to the locomotion, the jump (Fleagle *et al*., 2016) and mechanical loads (Morimoto, 2012) that the species has to endure in its habitat.

MATERIALS AND METHODS

It utilized bone structures from primates of the *Plecturocebus caquetensis* species, preserved at the Instituto de Ciencias Naturales of Universidad de Colombia and the Museo de Historia Natural of Universidad de la Amazonia. These bone structures were used to study their anatomy (Sepkoski, 2009) by using essentially existent corpses, without attacking specimens that still exist in the natural environment. Besides, striving to prevent its extinction (Monsalve-Buriticá, 2019) was important because the species population does not exceed 250 individuals (García and Defler, 2011). The code of ethics for Veterinary Medicine, Veterinary Medicine Zootechnics and Zootechnics in Colombia (Ley 576, 2000) as well as the Sentence C-666 (2010) from the Corte Constitucional, the Ley 84 (1989), Ley 1774 (2016) and the articles 8 and 79 from the Constitucion Política de Colombia (1991) establish the ban on ending wildlife in honor of science.

Therefore, from the existent bone structures in the biological collections the femur, tibia and fibula were considered. In this sense, these bones were measured by using a digital vernier (Gualda-Barros *et al*., 2012) with 0.01 mm precision (Kohn and Lubach, 2018) considering different studies on this topic (Ciochon and Corruccini, 1975). In this order of ideas, to carry out the morphometric registration, variables corresponding to articular surfaces were mainly registered, providing information about the primate's mechanics of movement in other parts of the bone (Ruff, 2002). This is because there is a close congruence between neighboring structures and the interdependence of all the functional components of the joints (Vancata, 1991). In the same line of thought, bone structure images were taken by using the digital camera CANON® EOS Rebel T3 to locate the points of reference of the obtained variables (Fig 1 and 2).

Initially, the femur was addressed considering the proposed variables by (Ciochon and Corruccini, 1975), Fleagle and Meldrum (1988); Elissamburu (2004) and Blanco-Rodríguez *et al*. (2015) to register the following data (Table 1).

Subsequently, it was obtained data about the variables in the structures corresponding to the tibia and fibula according to Fleagle and Meldrum (1988); Aiello and Dean (1996) and Blanco-Rodríguez *et al.* (2015) are registered below (Table 2).

In this sense, the obtained values were useful to generate summary measures such as mean and standard deviation. This was carried out by using the Infostat® software considering the obtained data about the structures of the right and left pelvic limbs of the specimens. Moreover,

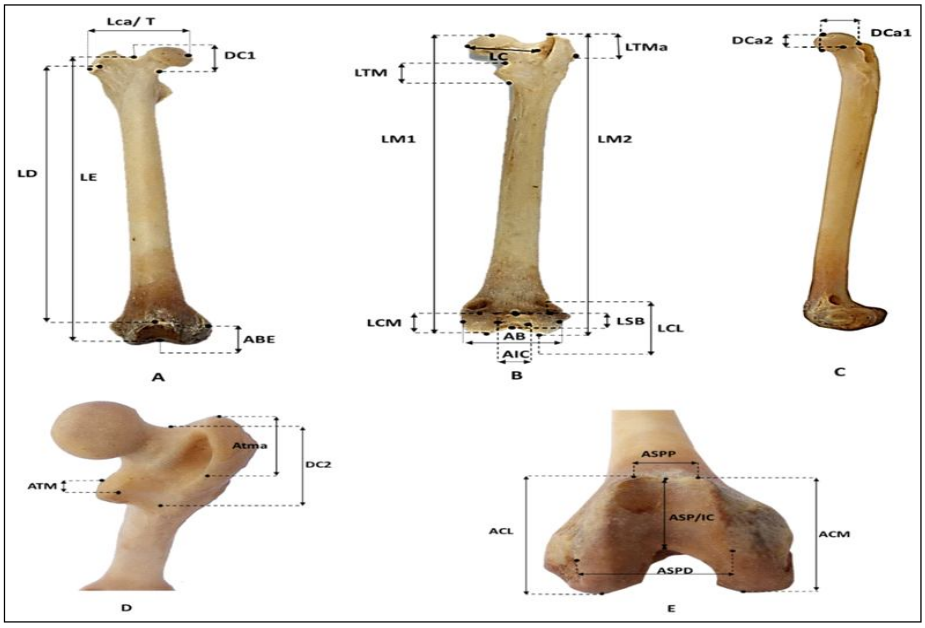


Fig 1: Studies variables in the femur of *Plecturocebus caquetensis*: Cranial (A), Caudal (B), Medial (C), Proximal extremity (D), Distal extremity (E).

it was sought to demonstrate the general distribution of the data for each of the variables to locate those that present greater variance.

RESULTS AND DISCUSSION

In Table 3, significant differences are apparent in all variables between the left and right Femur, Tibia and Fibula, with the right side showing greater development in all cases. Additionally, LT exhibits a higher standard deviation compared to the other variables, followed by LBT, LE, LF, LM1, LM2 and LD, in that order (Table 3).

In Fig 3, it can be observed that LT and LBT are the variables that present the highest coefficients of variation and both are related to the tibia, given that the biceps femoris, semitendinosus, vastus lateralis, gastrocnemius and popliteus muscles have their origin or insertion in spaces determined by these variables (Polly, 2007) and their joint functioning determines the close relationship that exists between them. On the other hand, the variables LE, LF, LM2, LM1 and LD, are associated with the femur and the fibula, presenting a certain relationship between them, based on their variations in size and function (Ankel-Simons, 2007), since the adaptation of the axis (Fig 1) allows bending in multiple directions in order to reduce the harmful consequences of a new mechanics and this determines the locomotor behaviors of primates and the positional behaviors (Carlson, 2005).

Likewise, the muscles that are inserted in the proximal end of the femur allow to extension of the limb by turning it around the head (Polly, 2007), in such a way that the muscles that are related to the body of the femur and the axis, indistinctly determine the conditions of the variables. The diaphysis, for its part, functions as an engineering beam, providing limb stiffness, particularly against bending and torsional loads (Argot, 2002), allowing the femur to resist bending loads in the caudolateral/craniomedial direction and allowing the bone to act as an energy absorber when running or jumping in a pronograde position. This makes the geometric construction of the femur ideally suited to resist high bending loads below the femoral diaphysis, particularly in the mediolateral plane (Sargis, 2002).

The LBT and LF variables, along with their standard deviations, should be highlighted as they meet the two previous conditions between the tibia and fibula. The length of the tibia depends on the activity carried out by the muscles, with only a small percentage of this load being

Table 1: Femur morphometrics variables of the *P. caquetensis*.

Abbreviation	Variable
DF	Diameter of the diaphysis of the femur
LM1	Morphological length 1
LMF	Morphological length 2
LE	Shaft length
LD	Diaphyseal length
	Proximal region
DCA1	Diameter of the femur's head 1
DCA2	Diameter of the femur's head 2
LCA/T	Head length / trochanter
ATMA	Width of the greater trochanter
LTMA	Length of the greater trochanter
ATM	Ancho del trocánter menor
LTM	Width of the lesser trochanter
DC1	Neck diameter 1
DC2	Neck diameter 2
LC	Neck length
	Distal region
AB	Bicondylar width
ABE	Biepicondylar width
ASPP	Width of proximal patellar surface
ASPD	Width of distal patellar surface
AIC	Intercondylar width
ASP/IC	Width of patellar surface/intercondyloid
LSB	Length of intercondyloid surface
LCM	Medial condyle length
LCL	Lateral condyle length
ACM	Width of medial condyle
ACL	Width of lateral condyle

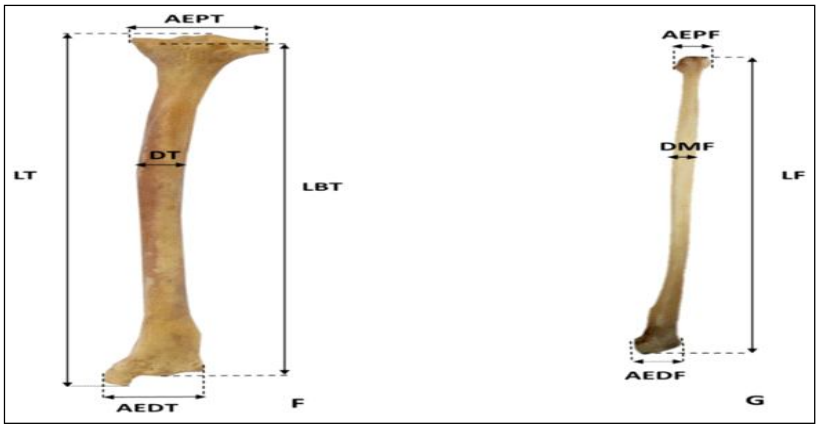


Fig 2: Studied variables of the Tibia (F) and Fibula (G) of *P. caquetensis,* caudal view.

supported by the fibula (Funk *et al*., 2004). This explainswhy the fibula's length and diameter are always smaller. As the longest and widest bone in the leg region, the tibia is responsible for weight bearing in primates such as *Plecturocebus caquetensis*. It is connected by two slightly mobile joints (synovial joints) at the proximal and distal ends (Ankel-Simons, 2007). In arboreal primates where jumping is part of locomotion, the proximal end of the tibial shaft is more mediolaterally compressed (Fleagle and Meldrum, 1988). The insertion of the quadriceps femoris muscle determines speed and agility by allowing rapid extension of the knee (Salton and Sargis, 2009; Ruff and Runestad, 1992; Szalay and Sargis, 2001).

The length of the fibula affects the agility and range of movement of the lower limb required for quadrupedal arboreal locomotion (Marchi, 2007). It is mobile due to the characteristics of the proximal and distal tibiofibular joints, which have adapted to perform rapid and sudden movements (Barnett and Napier, 1953; Salton and Sargis, 2009). However, the fibula's low robustness in comparison to the tibia is because of its position and its relatively minor role in bearing mechanical loads (Marchi, 2007).

The other variables obtained from the femur, tibia and fibula of *P. caquetensis*, with coefficients of variation less than one, do not show significant differences between them. This is because there is a total synergy between structures and joints for the transmission of force (Marchi, 2007) associated with all these variables. For example, the variable LC reflects a mechanical adaptation to resist flexion forces during jumping (Ford, 1990) and the variables LTM, LTMa, Lca/T, ATM and ATMa are related to the vastus lateralis and quadriceps femoris muscles, which are also linked to knee extension associated with jumping (Salton and Sargis, 2009).

It is important to note that the differences between the right and left bone structures in all cases determine specific aspects of movement asymmetry. While there are no recognized references to this in primates, it is indicated in humans that high impacts and constant bone tension can lead to size gain (Nikander *et al*., 2010). Given that *Plecturocebus caquetensis* is a primate that jumps and moves on small tree branches, its posture may reflect this.

Table 2: Tibia and Fibula morphometrics variables of the *Plecturocebus caquetensis*.

Abbreviation	Variable
	Tibia
LT	Maximum length of tibia
LBT	Biomechanical length of the tibia
AEPT	Maximum width of the proximal epiphysis of the tibia
AEDT	Maximum width of the distal epiphysis of the tibia
DT	Mediolateral diameter of the shaft
	Fibula
LF	Maximum fibula length
DMF	Maximum diameter of the middle axis of the fibula
AEPF	Maximum width of the proximal epiphysis of the fibula
AEDF	Maximum width of the distal epiphysis of the fibula

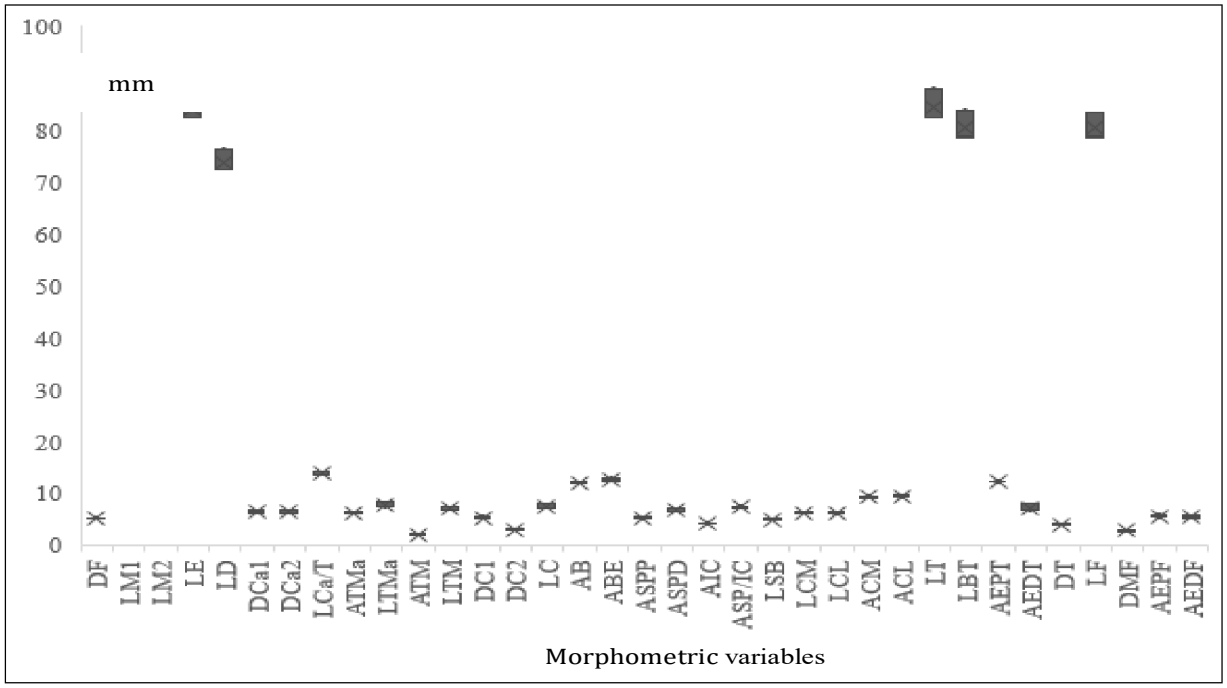


Fig 3: Distribution of measurements of the variables in the femur, tibia and fibula of *Plecturocebus caquetensis*.

Table 3: Average and standard deviation in mm of variables of the femur, Tibia and fibula in *Plecturocebus caquetensis*.

Variable	Left	Right
AB	12.03±0.17	12.12±0.18
ABE	12.54±0.35	12.65±0.40
ACL	9.37±0.23	9.44±0.23
ACM	9.20±0.26	9.28±0.22
AEDF	5.37±0.31	5.48±0.33
AEDT	7.08±0.75	7.18±0.75
AEPF	5.52±0.34	5.64±0.31
AEPT	12.22±0.14	12.34±0.11
AIC	4.12±0.16	4.20±0.15
ASP/IC	7.27±0.22	7.38±0.22
ASPD	6.54±0.33	6.65±0.33
ASPP	5.13±0.21	5.24±0.29
ATM	1.93±0.13	1.99±0.12
ATMa	6.16±0.20	6.24±0.19
DC1	5.24±0.29	5.31±0.28
DC2	2.95±0.16	3.03±0.19
DCa1	6.39±0.31	6.48±0.31
DCa2	6.23±0.31	6.30±0.28
DF	5.17±0.05	5.26±0.07
DMF	2.74±0.14	2.80±0.13
DT	3.95±0.19	4.00±0.19
LBT	80.33±2.97	80.46±2.93
LC	7.33±0.51	7.42±0.49
LCa/T	13.68±0.44	13.78±0.46
LCL	6.10±0.20	6.17±0.20
LCM	6.15±0.21	6.23±0.17
LD	73.60±2.20	73.79±2.33
LE	83.93±2.85	84.18±2.91
LF	80.23±2.77	80.33±2.75
LM1	88.12±2.74	88.29±2.72
LM2	88.05±2.71	88.15±2.74
LSB	4.92±0.15	5.01±0.12
LT	84.12±3.24	84.27±3.35
LTM	6.92±0.29	6.99±0.28
LTMa	7.61±0.54	7.68±0.55

However, detailed studies in its natural habitat, similar to those carried out by Cubí and Llorente (2021) or in the past by Colell (1992) focusing on the hind limbs, are necessary to identify the reason for this preferred posture.

CONCLUSION

The longitudinal variables of the femur, Tibia and fibula show a greater variation due to the effect of the muscles that are inserted in them, an aspect that may be associated with physical factors of the environment related to the architecture of the forest and particularities of the primate such as age, sexand hierarchical level.

Understanding morphometry provides information on some functional aspects that determine the well-being of primates, facilitating the discernment of characteristics necessary for confinement areas or habitat conservation conditions.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Permits related to animal handling were not required for this study, since the work involved anatomical structures stored in biological collections.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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