Original Article

Anatomical Study of the Main Sulci and Gyri of the Cebus Libidinosus *Brain (Rylands, 2000)*

Estudo Anatômico dos Principais Sulcos e Giros do Cérebro de *Cebus Libidinosus* (Rylands, 2000)

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ABSTRACT

The purpose of this work was to study the brain of the *Cebus* genus in morphological terms to evidence the main gyri and sulci, the gyrenchepaly degree, the encephalization index and the measure of the main structures, to compare the results with literature data in humans, chimpanzees, baboons and others nonhuman primates. Four specimens of adult and healthy *Cebus libidinosus* were used. All animals, donated by IBAMA-GO, were sacrificed by lethal injection of sodium pentobarbital. The animals were conserved on 10% formaldehyde in closed opaque box and deposited in the anatomical collection from the Federal University of Goiás. Brains were removed from the skull, weighed and measured with a caliper and documented with digital camera. The gyri, sulci and other structures denomination were described according to descriptions from humans and other primates. In general, the results indicate that the morphology of the gyri and sulci of the *C.l.* brain is closer to baboons than to chimpanzees and humans.

KEYWORDS: anatomy, *Cebus*, brain, gyri and sulci

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RESUMO

O objetivo deste trabalho foi estudar a morfologia do cérebro de *Cebus* a fim de evidenciar os principais giros e sulcos, o grau de girencefalia, o índice de encefalização e as medidas das principais estruturas, para compararar os resultados com os dados na literatura para humanos, chimpanzes, babuínos e outros primatas não humanos. Quatro espécimes de *Cebus libidinosus* adultos e saudáveis foram utilizados. Todos os animais, doados pelo IBAMA-GO, foram eutanasiados por injeção letal de pentobarbital sódico. Os animais foram conservados em formaldeído 10% e mantidos em caixa opaca e depositados na coleção anatômica da Universidade Federal de Goiás. Os cérebros foram removidos do crânio, pesados e medidos com um paquímetro e documentados com câmera digital. A denominação dos giros, sulcos e outras estruras foram feitas de acordo com as descrições para humanos e outros primatas. Em termos gerais, os resultados indicam que a morfologia dos sulcos e giros do cérebro de *C.l.* é mais próxima dos babuínos do que em chimpanzes e humanos.

PALAVRAS CHAVE: anatomia, *Cebus*, cérebro, giros e sulcos

INTRODUCTION

Biological sciences have as an important basis the morphological knowledge. Macroscopic anatomy serves as a tool for the description of species and/or for the comparison between species with morphological likenesses[3].

The *Cebus libidinosus* (*C.l.*)[41] is a genus featuring the largest geographical distribution among neotropical primate species, and according to Lopes (2004), it is observed from Colombia and Venezuela all the way to northern Argentina; inhabits tropical, subtropical and riverside forests, as well as savannah and semi-arid regions of Brazil. Cognitive and very skillful, they display an immense capacity to handle tools for obtaining food and amusement, and such activities are observed in both captivity and in the wild[11, 37, 50].

Anatomical studies on *C.l.* have been performed in anatomy[3, 4, 5, 6, 7, 8, 9, 18, 29, 32, 33, 42, 44, 45], cortical physiology[23], behavior and use of tools[1, 2, 11, 15, 19, 25, 37, 50, 53], encephalic index[36] and memory[48]. The high cognition capacity and biological aspects of *C.l.* make them similar to Old World primates in relation to the use of tool[14, 31, 35, 50], social organization capacity based on information transmission and learning[37].

The behavioral comparative analysis of recent primates, associated with the philogenetic trunks derived from cladism, generate important knowledge of recent human cognitive evolution[13], associated with nonhuman primates from the Old World. According to Resende et al. (2003), *Cebus,* human and Old World primates have the same basic neural substrate for memory, and learning tests indicate a long term convergence of the development of these species.

Studies[24] have associated asymmetry in *Cebus* brain using MRI to the Sylvian fissure, microscopic connections in prearcuate cortex[22], and cerebral, cerebral trunk and cerebellum morphological description in general terms was conducted[51, 52]. However, Oliveira and colleagues (2007) studied the cerebellum of *Cebus* and found no differences in relation to the description of Watanabe (1982). In addition, Marques and colleagues (2005) conducted a cerebral trunk morphological study in *Cebus* and also found no differences in relation to findings of Watanabe & Madeira (1982), and stressed the need for further studies on the same topic.

However, no accurate study on the *C.l.* brain has been performed so far, considering data on gyrencephaly and gyrus, their relative lengths and curvature levels, which are important aspects to characterize the complexity of species[49].

The knowledge on the macroscopic internal structure of *C.l.* would provide data for histological and biochemical studies and contribute in ethological studies and the preservation of the species[10, 52].

Additionally, the description of *Cebus* brain is aimed at offering support for future architecture studies of cortex and physiological areas and also to verify whether or not the sulci and gyri forms are similar to chimpanzees and/or to humans or baboons.

The purpose of this work was to study the brain of the *Cebus* genus in morphological terms to evidence the main gyri and sulci, the gyrenchepaly degree, the encephalization index and the measure of the main structures.

MATERIAL AND METHODS

Samples

Four specimens (three males and one female) of adult (1 to 3 kg) and healthy *Cebus libidinosus* were used. The animals were donated by the Brazilian Institute of the Environment (IBAMA-GO). The animals were deposited in the anatomical collection from the Federal University of Goiás, Campus of Catalão. This work was previously approved by the Institutional Ethical Committee from the Federal University of Goiás (CoEP-UFG 81/2008, authorization from the IBAMA No. 15275).

Preparation of animals to dissection

All animals were weighed and sacrificed by lethal injection of sodium pentobarbital, and perfused via abdominal aorta with latex 601-A (Dupot) mixed with red colorant diluted in ammonium hydroxide solution; included in water at room temperature for 10-12 hours and 10% formaldehyde mixed with 5% glycerin through femoral vein perfusion for fixation. The animals were conserved on 10% formaldehyde in closed opaque box.

Dissection and documentation

Brains were removed from the skull, weighed and measured with a caliper and documented with digital camera (7.1 megapixels). The gyri, sulci and other structures denomination were based on descriptions from humans and other primates[47]. The measure of the major gyrus in straight line and with sinuosity was performed to verify the curvature degree and the results were compared with humans. The major encephalon measure was performed in length and transversally. The gyrencephaly degree was observed to lobes and the major sulci description. The encephalization index was measured by the following relation: [body weight / brain weight] x100. Statistical analysis of frequency for the presence of structures and central tendency measures (mean and standard deviation) for measurements of the brain were carried out.

RESULTS

The anatomical analysis of the *C.l.* brain in the convex side shows that the frontal lobe is almost lissencephaly, the occipital lobe is lissencephaly, the insula is lissencephaly, the parietal lobe and the temporal lobe are gyrencephalon (see Figure 1).

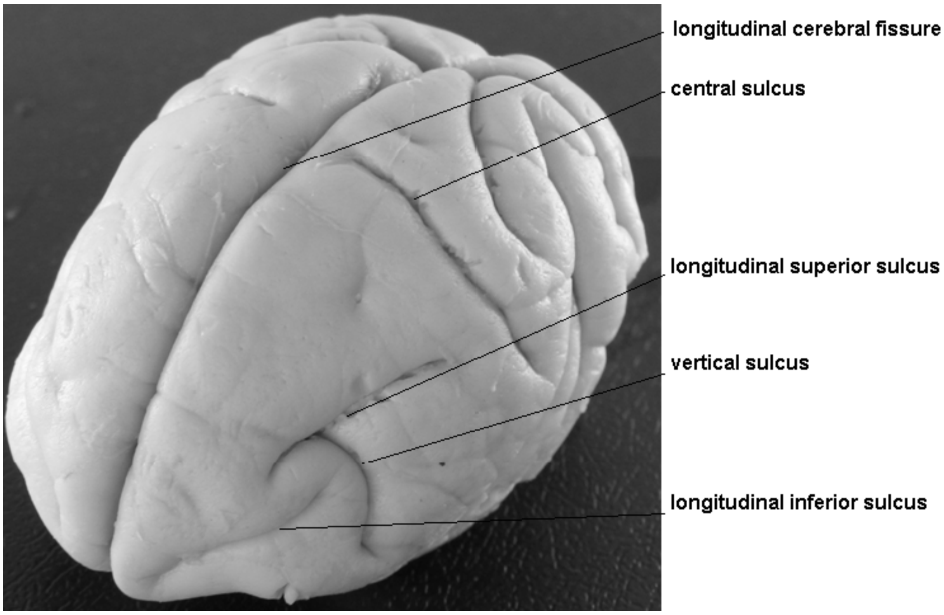

Figure 1: Anterolateral overview of *C.l.* brain showing the main sulcus.

The frontal lobe is bounded on the inferior portion by the lateral sulcus and on the posterior portion by the central sulcus. This is the largest lobes in *Cebus*, with three sulci , two longitudinal sulci, one superior and one inferior, but both located in the inferior half of the lobe, and a vertical sulcus. These sulci are nearly straight, with few bends, but deep (Table 1 and Table 2). The superior longitudinal sulcus is caudal in relation to the inferior longitudinal sulcus, which is rostral. There is a small vertical sulcus situated in the middle lobe, forming an angle of 90 °s with the longitudinal sulcus from which it emerges, about the midpoint. The vertical sulcus, only the frontal lobe is caudal to the inferior longitudinal sulcus and is located approximately in the middle line on the vertical sulcus. Since the parietal lobe does not have a pre-central sulcus, the pre-central gyrus is not bounded in *Cebus* (Figure 1). If one considers the imaginary continuation of superior and inferior longitudinal sulcus, it is possible to define the superior, middle and inferior frontal gyri.

The frontal lobe is separated from the parietal lobe by the central sulcus (Figure 1), present in 100% of the brains, and starts on convex side of the brain, being almost vertical, with smooth bends and does not meet the lateral sulcus at the lower portion; its vertical tilt is -0,10, once it was done by the difference between the average distances between the upper extremity of the central sulcus in relation to the anterior and posterior extremities of the brain, to the average of the inferior extremity of the central sulcus in relation to the extremities of the brain. The absolute measurements of these values were divided by the length of the brain in order to determine the relative size of the distances compared to men (Table 1). The sinuosity degree was obtained by the ratio between the average of the measures on the vertical axis of the sulcus with the average of the sinuous measures, and for *Cebus*, this value was 0,97 indicating a slightly sinuous sulcus.

In the parietal lobe (Figure 2), parieto-occipital sulcus are obvious (lunate or ape sulcus) separating the parietal occipital lobe in both convex and medial sides, and the post-central sulcus that is the caudal limit of the post-central gyrus, limited in the rostral portion by the central sulcus. The caudal portion of the lateral sulcus is superior, enters the parietal lobe and divides it into two parts, a larger rostral part and a smaller caudal part. The inferior caudal portion of the parietal lobe is continuous with the temporal lobe.

Figure 2: Right side view of *C.l.* brain with the main sulci highlighted.

The temporal lobe has a superior prominent sulcus, and a short inferior sulcus, restricted to the rostral portion of the lobe. It is possible to define the superior temporal gyrus, bounded on the superior portion by the lateral sulcus and on the inferior portion by the superior temporal sulcus. A small inferior temporal sulcus is not long enough to define a gyrus, then we can consider that there is an inferior temporal gyrus delimited by the superior portion of the superior temporal sulcus and the inferior part of the brain bounded by a side sulcus, which is the lateral limit of the parahippocampal gyrus, at the anterior portion of this lobe. The uncus is observed at the anterior medial portion to the parahippocampal gyrus.

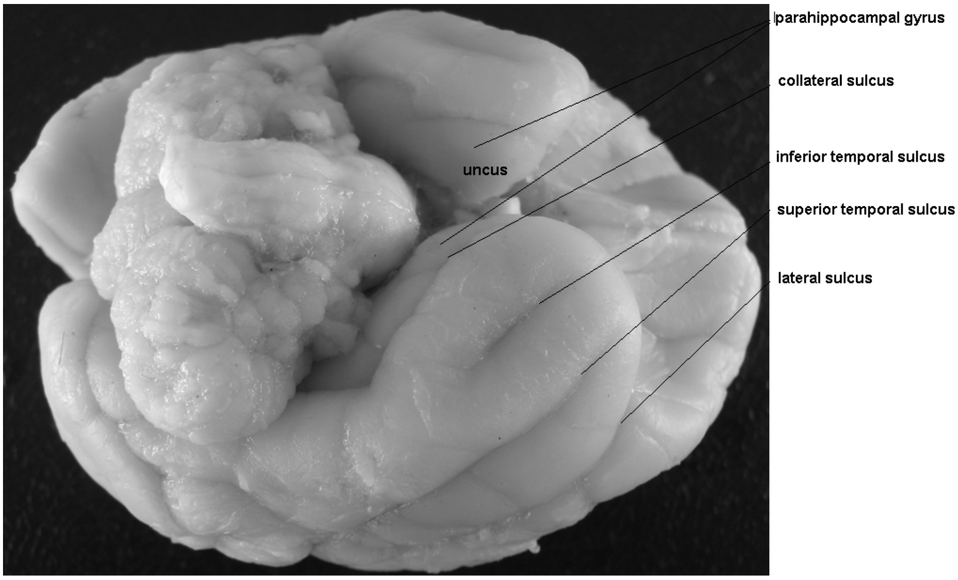

Figure 3: Overview of the base of *C.L.* brain with the main sulci and gyri indicated.

On the underside of the brain, at the temporal lobe (Figure 3 and Figure 4), it is possible to verify the existence of the cingulate and lingual gyrus, and the calcarine sulcus.

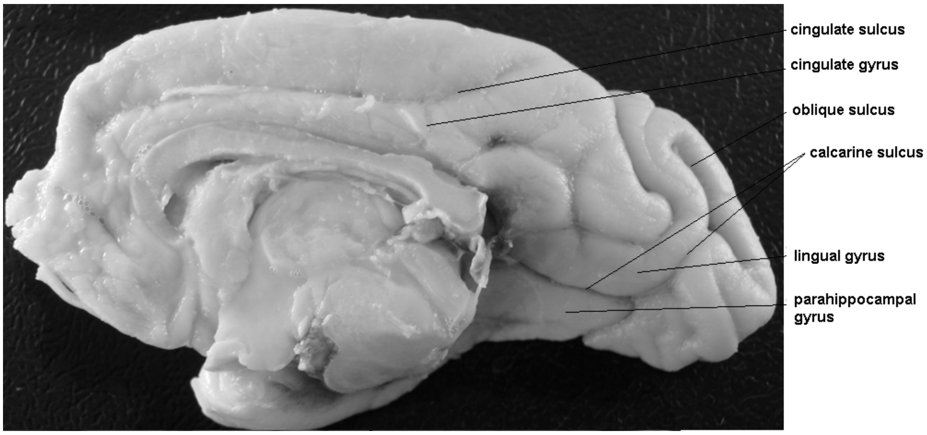

Figure 4: Medial overview of the *C.l.* right brain with the main sulci and gyri indicated.

The calcarine sulcus (Figure 4) defines medially the lingual gyrus and lateral-inferiorly the parahippocampal gyrus. The cingulate sulcus (Figure 4) is evident on the medial side of the brain and ends with an ascending branch at the post-central gyrus level, and this sulcus delimits the cingulate gyrus, which is bounded below by the sulcus of the corpus callosum and posterior, the cingulate gyrus is continuous, in *Cebus*, with the lingual gyrus (Figure 4).

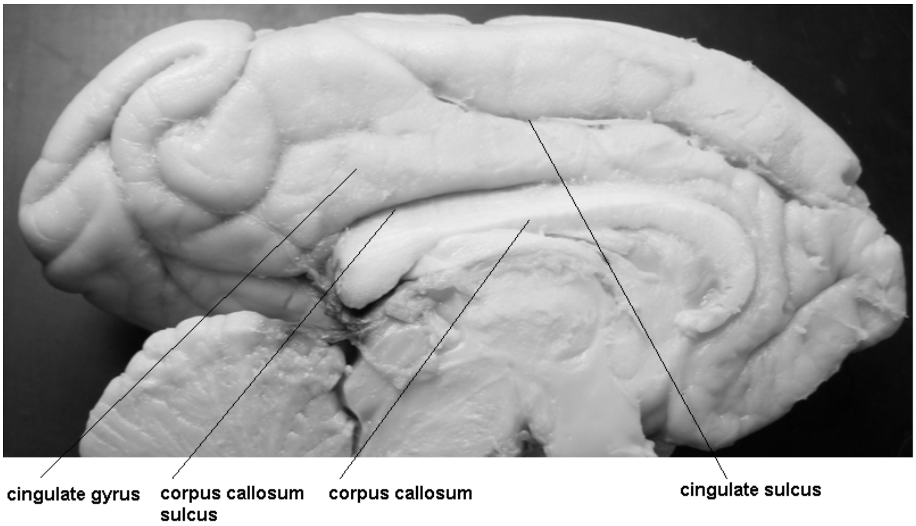

Figure 5: Medial overview of the right hemisphere of *C.l.* with the main sulci and gyri indicated and the corpus callosum.

The occipital lobe (Figure 4 and Figure 6) is lissencephaly in the convex portion and has a deep oblique sulcus on the medial side that seems to be formed by a fold of neural tissue. The calcarine sulcus, in *Cebus*, continues up to the superior middle portion of the occipital lobe communicates with the oblique sulcus in its middle portion.

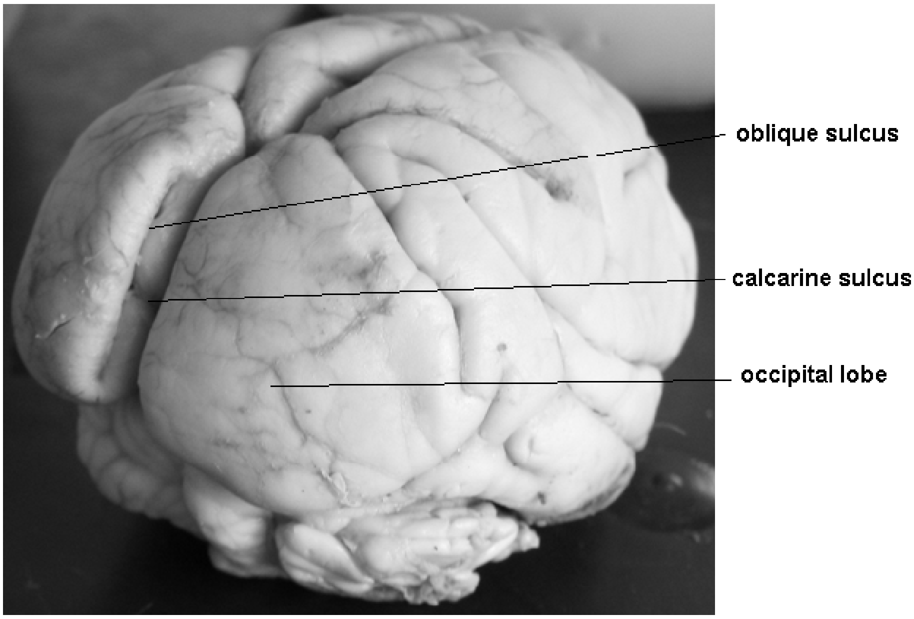

Figure 6: Posterolateral overview of *C.l.* brain indicating the occipital lobe and its sulci.

The insula lobe (Figure 7) is smooth and formed by only one longitudinal gyrus that can be observed in the removal of the superior and inferior edges of the lateral sulcus.

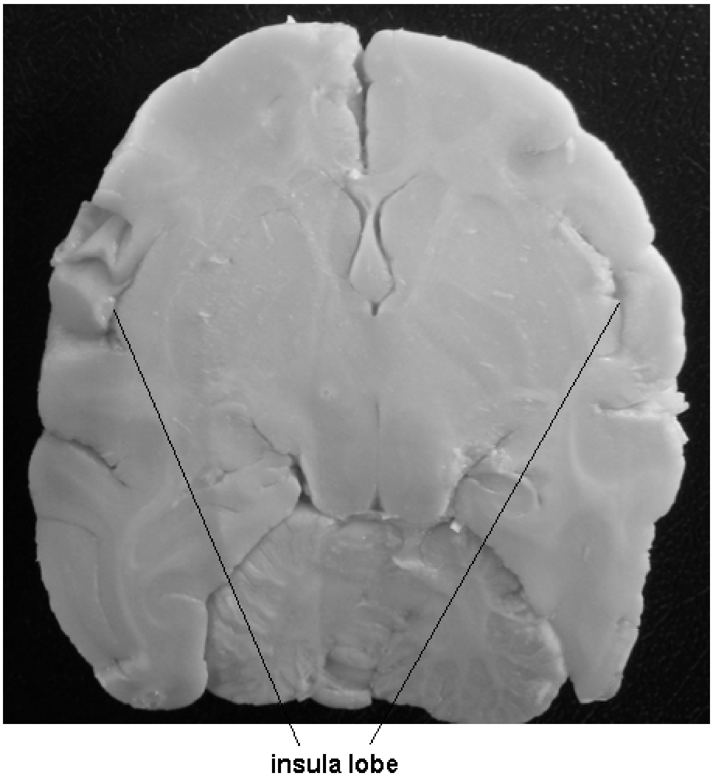

Figure 7: Front section of the *C.l.* brain at the anterior portion level of the lateral sulcus, with the insula lobe indicated.

The lateral sulcus (Figure 2) separates the temporal and parietal lobes, starts in the cranial portion, has ascendant path up to the central sulcus level, from which a strong inflexion can be observed, becoming oblique in the parietal lobe and ends at the superior side of the parietal lobe.

The measurements of the lobes were taken in absolute and relative terms so that the comparison between *Cebus* and man could be performed in terms of size and tilt of the main sulci (Table 1 and Table 2).

The calculation of the encephalization index indicated the value of 2.12 ± 0.31 for *Cebus libidinosus*.

Table 1 - Absolute and relative measures and inclination of the central sulcus.

Measures of the central sulcus extremities		**Average of absolute measures (cm)**		**Average of relative measures (cm)**	
		Cebus	**Human***	***Cebus***	**Human**
Superior extremity	**to the anterior edge**	3,06	11,10	0,48	0,69
	to the posterior edge	3,30	4,90	0.52	0,30
Inferior extremity	**to the anterior edge**	3,20	7,10	0,50	0,44
	to the posterior edge	3,20	8,90	0,50	0,56
Distance in horizontal projection (inclination)		(3,20-3,30) = -0,10	(8,90-4,90) = 4,00		

* data from Testut & Latarjet (1958).

Table 2 – Straight and sinuous measures of the main sulci.

Structures	**Straight measures (cm)[1]**				**Sinuous measures (cm) [2]**				**[1]/[2]**	
	RH		**LH**		**RH**		**LH**		***Cebus***	**Human***
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**		
Lateral sulcus	3,5	±0,3	3,6	±0,3	4,6	±0,2	4,7	±0,2	0,76	
Central sulcus	2,2	±0,3	2,2	±0,2	2,2	±0,4	2,3	±0,1	0,97	[9/11,8]=0,76
Parieto-occipital sulcus	2,0	±0,2	2,3	±0,4	2,6	±0,2	2,3	±0,6	0,87	

RH = right hemisphere; LH = left hemisphere
* data from Testut & Latarjet (1958).

DISCUSSION

Convex face lissencephaly of the occipital lobe and insula, the few sulci and gyri of the frontal lobe of *C.l.* have no similarity to baboon, chimpanzee and man, according to descriptions of Swindler & Wood (1973). However, the convex faces of the parietal and temporal lobes are similar to descriptions for baboon (Figure 8), with few sulci and gyri, but well defined. Compared with the marmoset and man, Watanabe & Madeira (1982) conclude that the brain of *Cebus* is closer to humans than marmosets, considering that the marmoset has lissencephaly brain, while *Cebus* have the main sulci that delimit the main lobes.

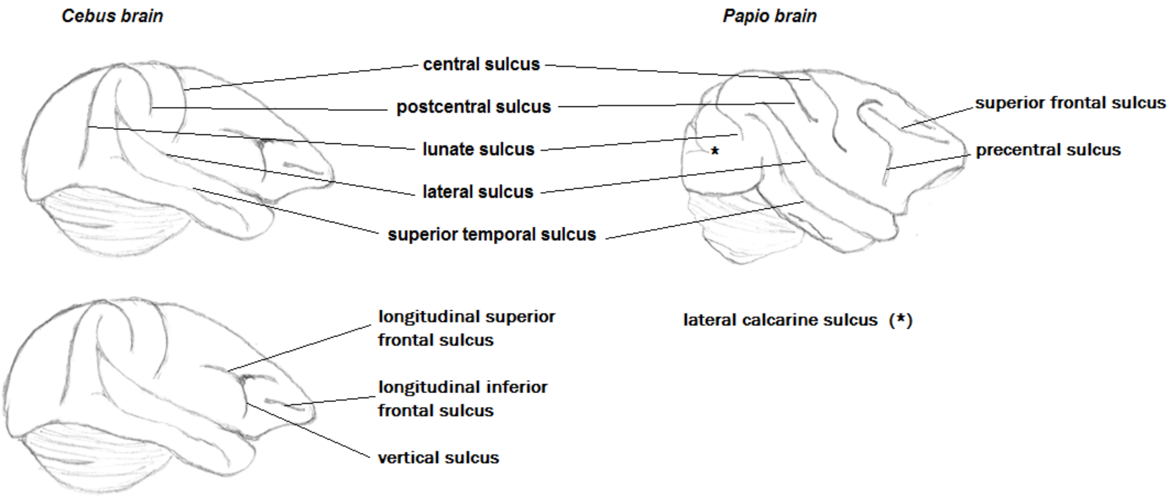

Figure 8: Comparative scheme of the main sulci of *Cebus* and Baboons brains (baboon brain scheme modified from Swindler & Wood, 1973).

The central sulcus is well developed in baboons, chimpanzees and humans, the same can be said about *C.l.*, however, it is more inclined and sinuous in humans, chimpanzees and baboons, increasingly in that order (Figure 9).

In relation to the sinuosity degree, *C. l.* was 0.97, while in humans, according to Testut & Latarjet (1958), the value is 0.76. The inclination of the central sulcus in *C. l.* was -0.10, whereas in humans, it is 4.0. Together, these data indicate that the central sulcus in *C. l.* has inclination with the superior edge slightly ahead of the inferior edge, while in humans the superior end is posterior to the inferior end, which is also observed in baboons and chimpanzees[47].

Measures on the edges of the central sulcus in relation to the anterior and posterior edges of the brain show that the central sulcus is located at the middle portion of the brain hemispheres in *C.l.*, while the values in humans suggest that the central sulcus is relatively posterior, indicating that the human frontal lobe is larger than that of *Cebus*.

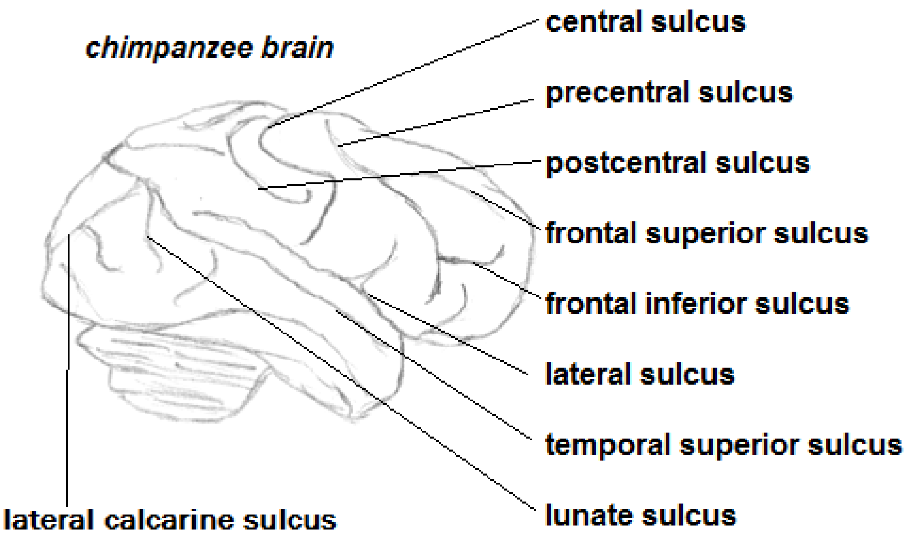

Figure 9: Diagram of the chimpanzee brain with the main sulci shown in the convex side (scheme modified from Swindler & Wood, 1973).

Watanabe & Madeira (1982) consider the existence of superior and inferior frontal sulcus in the frontal lobe of *Cebus*, but in this study, they were not considered as such, since the sulcus, here called as superior and inferior longitudinal sulcus, not precisely delimit the gyri in the frontal lobe and are so well marked as the vertical sulcus, which is not reported to exist in primates[47].

However, data from Swindler & Wood (1973) show that the vertical sulcus can be a continuation of the inferior frontal sulcus, at least in baboons. The vertical sulcus in the frontal lobe of humans, chimpanzees and baboons, is the pre-central sulcus, but this consideration is inappropriate in *Cebus*, as the vertical sulcus is located in a much anterior position.

The parieto-occipital sulcus (lunate or ape sulcus) separates the parietal from occipital lobe in both the medial and convex faces in *C.l.,* baboons and chimpanzees[47], but in humans, it occurs only in the medial face[20, 27].

The post-central sulcus is reported for all species compared in this study. It is relatively short in baboons and *C.l.* and more extensive in humans and chimpanzees[47].

The lateral sulcus in *C.l.* also features description similar to that of Swindler & Wood (1973) for baboons due to aspects of the inclination in the posterior portion for not joining to the central sulcus and for dividing the parietal lobe into anterior and posterior halves. In chimpanzees and humans, it is shorter and the central sulcus often finds it[49].

According to Sontag (1924), the lateral sulcus is complete only in humans, and its side opening shows the insula. This fact was observed in *Cebus* and described for baboons and chimpanzees[47], but in *C.l.*, the insula has a smooth surface, which is in accordance with the description of Watanabe & Madeira (1982).

In baboons, the lateral fissure does not meet the superior temporal sulcus, nor in Cebus, but in chimpanzees and humans, it does meet the sulcus[20, 49]. In *C.l.*, the lateral sulcus has the highest sinuosity degree of the sulcus analyzed (0.78), however, it shows no separation in branches as in humans.

The temporal lobe in *C.l.* and baboons are similar, especially due to the presence of a short and right inferior temporal sulcus, has sulci and gyri well-defined in both, and as for the other lobes, it has morphology closer to that of chimpanzees and humans.

On the inferior face of the brain, in the temporal lobe, it is possible to verify the existence of the cingulate gyrus and lingual gyrus, besides the calcarine sulcus that continues to the occipital lobe and meets the oblique sulcus. The oblique sulcus, despite being schematized for baboons and chimpanzees, is not described by Swindler & Wood (1973), or with another name in *Cebus* by Watanabe & Madeira (1978).

The lateral calcarine sulcus is described in baboons and chimpanzees, rarely found in humans and was not observed in *Cebus*, since its presence is seen on the convex side of the occipital lobe of these primates, being smooth in *Cl.*

The absence of the lateral calcarine and lunatus sulcus in humans is referred to as a consequence of displacement of the parietal and occipital lobes for increased visual area[47].

The calcarine sulcus, cingulate sulcus and the sulcus of the corpus callosum and the lingual gyrus have elements similar to baboons, which was similar to descriptions for chimpanzees and humans[47], however, these grooves are shorter in *C.l.* than in other primates. The cingulate sulcus is smaller, proportionately, than in other primates studied and does not end surrounding the cingulate gyrus in the posterior portion, but in an ascending branch. In baboons, these gyri are also short, but lack the ascending branch, and in chimpanzees and humans, the cingulate sulcus ends in the postero-inferior position[20, 27, 47, 49].

The measures carried out of sulci in *C.l.* allow a comparison on the size of this sulcus with the sulci of other species, which allows a more objective analysis for comparison. In the literature, only data obtained in humans were found[49], allowing the comparison between *C.l.* and humans in this respect. The data obtained for *C.l.* are in accordance with the findings of Swindler & Wood (1973), who report that there is an increasing complexity of sulci and gyri from the prosimians up to great apes and from these to humans, also indicating the existence of a frontal lobe much larger in humans due to the measures of distances from the central sulcus in relation to the extremity of the brain.

Unlike other groups of animals, primates are characterized by greater brain size, by the improvement of cognitive and manipulative skills and increasing of the complex social behavior. These traits influence the way in which individuals encode and use information in decision-making and developed mainly with the combination of changes in the visual system and expansion of the cerebral cortex[30].

When comparing the relationship between the size of the frontal cortex and total cortex in carnivores, humans and nonhuman primates, Bush & Allman (2004) found no significant differences between the second and third group, and accordingly, Hill (1970) shows that the brain hemispheres of baboon are large and the encephalon competes in mass proportionally, with humans. According to Paiva (1998), *Cebus* has a larger encephalization index than gorillas and orangutans, primates of the Old World, but identical to those traits in chimpanzees.

The encephalization phenomenon can be objectively measured by the so-called " encephalization coefficient or index", which is calculated by the ratio between the brain weight and the body weight. This can be calculated for any two individuals, what weight the brain would have if their body weights were identical[16]. Data from this study demonstrate that the explanation for the cognitive abilities are qualitative, since the encephalization degree of *C.l.* cited in literature about their behavior put them next to chimpanzees. However, the brain of *Cebus*, even less gyrencephaly in anatomical descriptive terms, is closer to the baboons.

The increase in body size, on the evolutionary scale, is accompanied by increase exponentially smaller than the increase of the brain, the order of an exponent of 0.6-0.8. In this study, the data indicate an encephalization coefficient of 2.12 ± 0.31 for *C.l.,* while Roth & Dicke (2005) indicate a value between 2.4-4.8 for *Cebus* and 2.2-2.4 for chimpanzees. The difference for the data for *Cebus* is probably due to the fact that there are many species of *Cebus*[17] and some of them are confused by researchers[41].

Fragaszy and colleagues (2004), considered that differences between encephalization index in literature is because did not occur adequate selection of largest male from each species to analysis, but Testut and Latarjet (1958) indicate that the differences in a same species is due to differences in body mass. In other words, bigger body mass indicate a big brain mass with little convolutions, and reciprocally, small body mass indicate small brain mass with more superficial area, sulci more deep and very tortuous gyrus.

Therefore, despite the anatomical cortical characteristics, one explanation for the higher cognitive abilities of primates would be differences in the microscopic morpho-physiological factors of the cortical architecture. This has been suggested by other authors indicating that the anatomical differences between the brains of Great Apes and hominids appear to be qualitative and not quantitative, such as cell density[47].

Another possibility would be the largest amount of white substance of the prefrontal region of humans in relation to other primates[39]. The white substance is formed by the axons of neurons whose cell bodies are located in the cerebral cortex, and the greater volume of white substance indicates increasing connectivity in this area[43].

Other possibility is a higher growth of the frontal lobe compared with other lobes in primates, whose cognitive function is more significant in relation to other brain structures[26, 27].

CONCLUSION

In general, the morphology of the gyri and sulci of the *C.l.* brain is closer to baboons than to chimpanzees and humans. However, work on cognitive aspects put *C.l.* close to chimpanzees, considered the primates closest to humans in cognitive terms. This would indicates that the hypothesis of cognition is directly correlated to anatomical aspects of the brain needs to be revised. It is likely that this would be more related to histological and architectural structural aspects. However, other studies are necessary to explore all these possibilities.

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