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Macroscopic Anatomic Study of Gastrocnemius, Superficial Flexor Digitorum and Soleus Muscles of Coati (*Nasua nasua*)

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***Abstract*— Coati (Nasua nasua) taxon is poorly described, since the contribution to knowledge and development of biological system from this specie, so this paper aimed analyzes and describes the anatomy of the gastrocnemius, superficial flexor digitorum, and soleus muscles in Coati. The present study demonstrate that racoon gastrocnemius of Coati, located within caudal part of leg, is a robust muscle in relation to physical size of the animal. One head of muscle is medial and other relatively larger than medial, medial head originates from the plantar surface of distal end of femur and lateral head epicondyle incorporate by a common tendon with soleus muscle at distal aspect of calcaneus. Superficial flexor digitorum muscle is a long muscle, whose womb is surrounded by heads of gastrocnemius muscle. Its origin is common with lateral head of gastrocnemius muscle and its insertion is in plantar aponeurosis, after it crosses calcaneus distally. Soleus muscle is a long, flat muscle, deep to gastrocnemius and superficial flexor digitorum muscles, whose origin is the head of fibula and surrounding areas. The common insertion of the soleus muscle with the gastrocnemius muscle forms the Achilles tendon.*

***Keywords*— Coati, Raccon, Comparative Anatomy, Descriptive Anatomy and Muscles.**

I. INTRODUCTION

Comparative anatomy of wild animals has taken center stage in laboratory studies and research as well as specialized journals, probably due the importance of comparative anatomy in phylogeny understanding and following evolutionary lines of taxonomic groups. Anatomic structure of wild species can be helpful in understanding the biology of these groups and establishing relationships between form and function of similar structures present in different groups **[1]**.

All anatomical systems that make up the body of an animal have importance in integrity and survival; however, the locomotor system is particularly critical because it supports body movement. The muscular system alone can produce movement, a fundamental function in defense, feeding, and reproduction **[1]**. Providing body contour, muscles undergo adaptation providing information on dietary habits, reproductive behavior, and body posture **[2]**. In many instances, macroscopic anatomy studies have been displaced by microscopic studies; however, macroscopic studies are necessary for complete physiological understanding of organisms.

Cerrado biome is highly complex, ranking second in size among Neotropical biomes. Its habitats range from open fields of grasslands to gallery forests, dry forests and semi-deciduous **[3]**. This great variety supports the development and hosting of a large number of native species **[4]**. Mammalian fauna of Cerrado biome is comprised of a large number of species, including several large carnivorous from the coati group (*Nasua nasua*), which is the object of investigation in the present research.

The evolutions of species in Neotropics determine the emergence of different phyletic lines occupying different areas. Thus, those ocuppying open areas have developed different characteristics from those that inhabit dense forests; in addition, anatomical structures have been adapted according to the environment, food and reproduction. Among the mammals of cerrado, there are walkers, runners, jumpers, and those that adopt a combination of these

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characteristics, in accordance with the requirement of the moment. The muscles are the main protagonists in this process and are therefore, well adapted to specific motions even though the basic structure is maintained. Raccoon is a Procionídeo that is well adapted to Cerrado biome. The racoon can live and breed in small forests, sometimes in communion with human beings. It is a semi-arboreal animal with plantigrade locomotion habits. The habit of stepping using the entire foot has resulted in consistent muscle adaptations. **[5-6]**.

Based on anatomical comparative observations to the development of anatomic studies and considering that the anatomy of gastrocnemius, superficial flexor digitorum and soleus muscles Coati (*Nasua nasua*), were not until described and will contributes to the knowledge of the biological system and, whenever possible, to infer the necessary adjustments to their "modus vivendis", the present study was designed to dissected and describe these muscles of this specie distributed almost every South American.

II. MATERIAL AND METHODS

The present work is a descriptive anatomical study with two specimens of Coati (*Nasua nasua*) a male and a female,of unknow age, obtained from accidental death on the roadsides of Brazilian Southeast of Goiás, donated from "Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA", under authorization of SISBIO nº 37072-2. Considering the descriptive approach of this work, statistical analysis is not necessary. All procedures were conducted in accordance with ethical principles and were approved by the Institutional Ethics in Research Committee at the Federal University of Uberlândia (CEUA/UFU nº 067/12).

The study was made in the research laboratory of human and comparative anatomy from the Federal University of Goiás – RC, were the specimens were submitted to fixation with aqueous 10% formaldehyde solution to conservation.The preparation of anatomical pieces was performed under consecrated techniques in Macroscopic Anatomy.

The Sony Cyber® digital camera was used to the photographical documentation and the description nomenclature adopted is the standard of *Nomina Anatomica Veterinaria* (2017) **[7]**, elaborated by the International Committee on Veterinary Gross Anatomical Nomenclature. Morphometric measurements were performed as follows with a ZAAS precison 25 cm caliper. 1) The length of the muscle belly was obtained in the long axis of the womb. 2) The width was the average of three values: one proximal a distance of 1 cm from the origin (MP), another at the widest part of the belly (MM) and the third, at a distance of 1 cm from the distal end of the belly (MD). The values corresponding to the thickness of the stomach were obtained using the same protocol used for the width. To obtain the approximate volume of the muscle belly, average values of width and thickness were calculated, then values were multiplied using the following formula: length X width X thickness, with approximate results reported in cm^3.

III. RESULTS

Gastrocnemius: The description of Coati (*Nasua nasua*) gastrocnemius muscle was performed in conjunction with superficial flexor digitorum muscle description, due the latter is located between the two heads of the gastrocnemius and partially adhered to the lateral head, forming a mass continues only separable by scalpel. The gastrocnemius muscle, along with the superficial flexor digitorum muscle, is robust structure of the leg with respect to the physical size of the animal. The average length of the tibias were left tibia (TE) 8.5 cm and right tibia (TD) 8.6 cm, consistent with a medium-sized animal (2.0 to 3.0 kg). The volume of the right muscle mass, including two heads of the gastrocnemius and the superficial flexor, is approximately 13.42 cm^3 and left around 12.84 cm^3. The gastrocnemius muscle of coati (*Nasua nasua*) consisted of two parts: the medial head and lateral head, with the lateral head partially adhered to the flexor digitorum superficialis muscle throughout its length and sharing a common origin. Thus, the lateral muscle mass, comprising the sum of the belly side volume with the volume of the flexor digitorum superficialis, was greater than the medial mass. The right side belly of the gastrocnemius (VLDG) = 4.89 cm^3; belly superficial flexor of the right fingers (VFSDD) = 3.73 cm^3, totaling 8.62 cm^3 against a volume of the belly of the right medial head (VCMD) = 4.80 cm^3. To the left antimere, there was a left lateral belly volume of the gastrocnemius (VLEG) = 4.80 cm^3; belly superficial flexor digitorum (VFSDE) = 3.62 cm^3, totaling 8.42 cm^3 against the left medial belly of the gastrocnemius volume = 4.42 cm^3 (Figure 1 and 2)(table 1-2).

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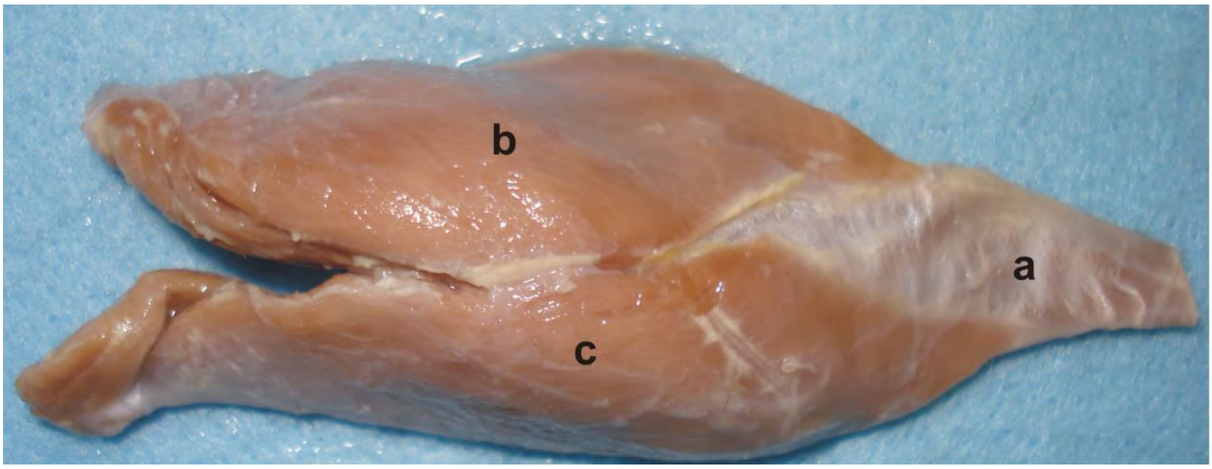

Fig.1: Photomacrograph of the coati leg, view - a- aponeurosis common insertion, b- lateral head of m. gastrocemius, c medial head of m. gastrocnemius.


Fig.2: Photomacrograph of the coati leg: cranial view - a- lateral head of m. gastrocnemius, b- m. superficial flexor digitorum, c medial head of m. gastrocnemius.

Table 1: Morphometric measurements (cm) of medial belly right gastrocnemius muscle of raccoon.

VENTRE	LARGURA				ESPESSURA				VOLUME
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm³**
6,4	1,1	2,1	1,2	**1,5**	0,6	0,5	0,4	**0,5**	**4,80**

Table 2: Morphometric measurements (cm) of left belly of the medial gastrocnemius in Coati.

VENTRE	LARGURA				ESPESSURA				VOLUME
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm³**
5,9	1,3	2,1	1,1	**1,5**	0,6	0,6	0,3	**0,5**	**4,42**

The medial head was longer: VMD = 6.4 and = 5.9 cm VME; closer: VMD = 1.5 and = 1.5 cm VME, and thinner: VMD = 0.5 and = 0.5 cm VME, than the lateral head, whose length was: VLD = 5.1 and VLE = 5.0 cm; width: VLD = 1.6 and VLE: 1.6 cm and thickness: VLD = 0.6 and = 0.6 cm VLE, making a total gastrocnemius muscle volume of right side

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(MGD) = 9.69 cm^3 and left side (MGE) = 9.22 cm^3. Thus, the right gastrocnemius is relatively larger than the left gastrocnemius. Its origin was small and fleshy, located medial to the medial condyle above-crest and a major origin, tendon, also in the above-medial condylar crest; however, the distal fixation fleshy. The proximal third of medial head was roughly cylindrical and narrow, while the middle third was flat and wide. Within the distal third and continuing to its insertion, the aponeurosis was fused with the aponeurosis of the lateral head. The medial head is completely independent of the lateral head and superficial flexor digitorum muscle (Figures 3)(tables 3-4).

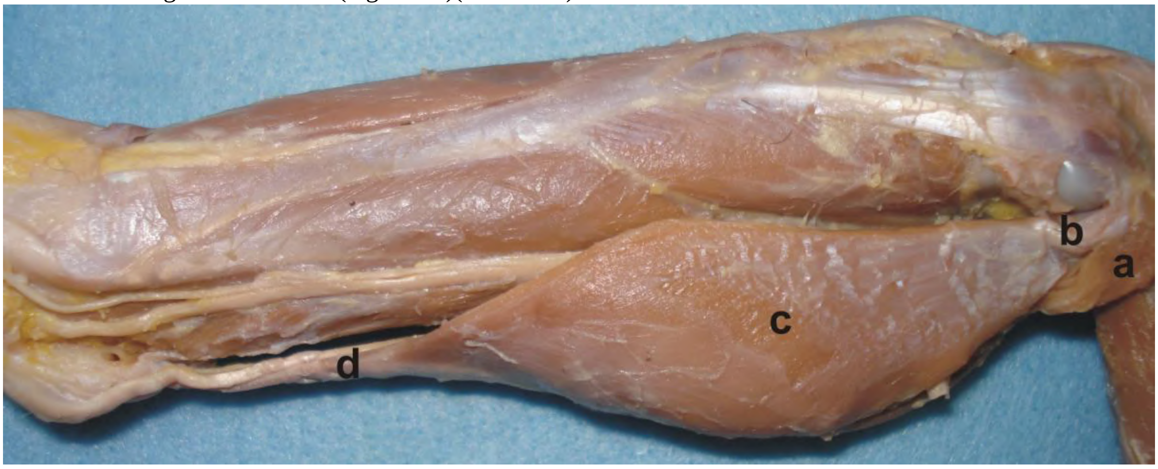

Fig.3: Photomacrograph of the coati leg: medial view - a- fleshy origin of the medial head of m. gastrocnemius; b- tendon origin of the medial head of m. gastrocemius, c belly of the medial head of m. gastrocnemius, d - Achilles tendon.

Table 3: Morphometric measurements (cm) of right belly of gastrocnemius muscle in raccoon.

VENTRE	LARGURA				ESPESSURA				VOLUME
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm³**
5,1	1,2	2,1	1,5	**1,6**	0,6	0,7	0,5	**0,6**	**4,89**

Table 4: Morphometric measurements (cm) of left belly of the gastrocnemius muscle in Coati.

VENTRE	LARGURA				ESPESSURA				VOLUME
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm³**
5,0	1,2	2,0	1,6	**1,6**	0,6	0,7	0,5	**0,6**	**4,80**

Lateral head was shorter than medial closer, with a nearly cylindrical shape near its origin, widening in distal direction. Its origin was in supra-condylar side crest and caudolateral capsule of the knee adjacent to superficial flexor digitorum muscle. The belly of lateral head was separated from the belly of superficial flexor digitorum muscle throughout its length by a thin aponeurosis, visible superficially as a small groove (Figure 4).

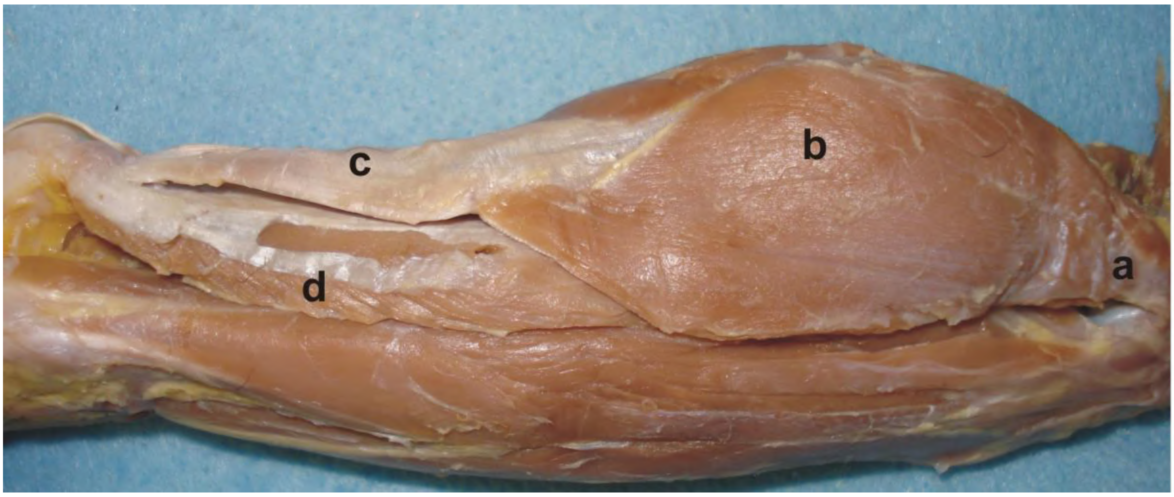

Fig.4: Photomacrograph of the coati leg: Lateral view - a- origin of the lateral head of m. gastrocnemius; b- belly of the lateral head of m. gastrocnemius, c Achilles tendon, d-m.soleus.

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In cranial view, the side of head and superficial flexor digitorum muscle was identified by a groove, while in caudal view, two grooves separate the flexor of both heads of the gastrocnemius (Figure 5).

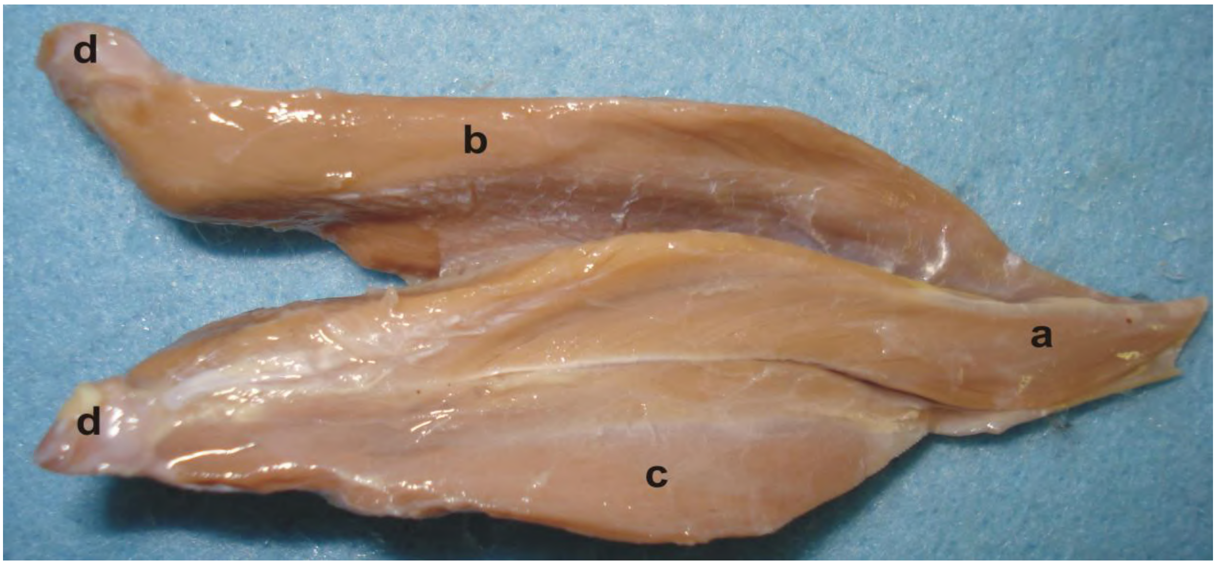

Fig.5: Photomacrograph of the coati leg: cranial view - a- superficial flexor digitorum, b, medial head of m. gastrocnemius, lateral head of the c m. gastrocnemius, d- sesamoid bones.

The aponeurosis of two lateral and medial heads fuses distally and then converges to form the single Achilles tendon that inserts at the end of the calcaneus. Superficial flexor muscle of fingers (MFSD) -The superficial flexor digitorum muscle was a long muscle, whose womb was surrounded by the heads of the gastrocnemius muscle. Proximal, medial and distal measurements were nearly identical: MFSD: Length = 6.9; Width = 0.9 and thickness = 0.6 cm and MFSE: Length = 6.8, Width = 0.9 and thickness = 0.6 cm. The superficial flexor digitorum muscle had a common origin with the lateral head of the gastrocnemius muscle and its insertion was in the plantar aponeurosis, after crossing the calcaneus distally. It was surrounded by the gastrocnemius muscle bellies, except on the cranial aspect, when in contact with the m. soleus muscle (Figures 4 and 6).

Table 5: Morphometric measurements (cm) of superficial flexor muscle of the right fingers in Coati.

VENTRE	**LARGURA**				**ESPESSURA**				**VOLUME**
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm^3**
6,9	0,9	0,9	0,9	**0,9**	0,5	0,7	0,6	**0,6**	**3,73**

Table 6: Morphometric measurements (cm) of flexor surface of the left fingers in coati.

VENTRE	**LARGURA**				**ESPESSURA**				**VOLUME**
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm^3**
6,8	0,9	0,9	0,9	**0,9**	0,5	0,7	0,6	**0,6**	**3,62**

Soleus muscle: The raccoon had a relatively robust soleus muscle, whose approximate volume was around MSD = 4.2 cm^3 and MSE = 3.41cm^3. The lateral side was elongated and slightly flattened in appearance (Figures 4 and 6).

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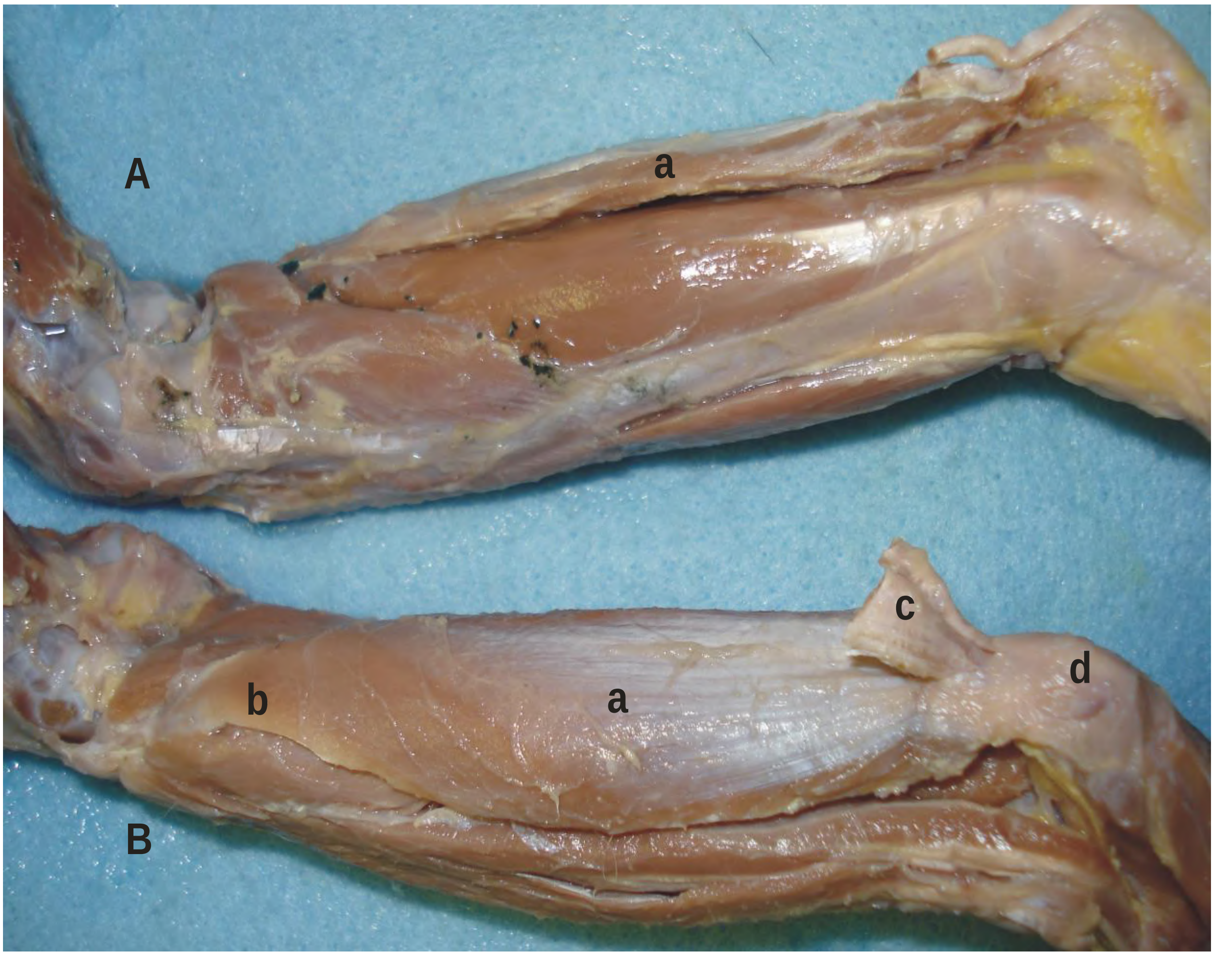

Fig.6: Photomacrograph of the coati leg: A- medial view, B- Side view: a- belly soleus, b- proximal fixation of the soleus, gastrocnemius tendon c-, d- calcaneus.

Table 7: Morphometric measurements of right soleus muscle in Coati.

VENTRE	**LARGURA**				**ESPESSURA**				**VOLUME**
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm^3**
6,0	1,2	1,7	1,2	**1,4**	0,4	0,4	0,6	**0,5**	**4,20**

Table 8: Morphometric measurements (cm) of left soleus muscle of Coati.

VENTRE	**LARGURA**				**ESPESSURA**				**VOLUME**
CV	**PR**	**MM**	**DI**	**MD**	**PR**	**MM**	**DI**	**MD**	**VOL/cm^3**
6,1	1,1	1,8	1,2	**1,4**	0,2	0,3	0,7	0,4	**3,41**

Soleus muscle is located in the leg, deep to gastrocnemius muscle. Its origin was in lateral aspect of fibular head, through a plan tendon and slender and intermuscular fascia. In the two proximal thirds, it was located in the intermuscular septum between it and superficial to the deep flexor digitorum longus muscle. Moving away from its origin in the distal direction, it became increasingly independent, with only fascial attachment to the flexor. The superficial surface was in contact with the gastrocnemius and tensor of plantar aponeurosis (superficial finger flexor) muscles, though was completely separate from them. The distally insertion was at the end of the calcaneus, deep to the insertion of the gastrocnemius.

The volumetric values of each target muscle showed that the right muscles are relatively larger than the left ones, being more pronounced in the soleus muscle. The right muscle group had a relatively larger volume than the left one, showing asymmetry between the sides (Figure 7).

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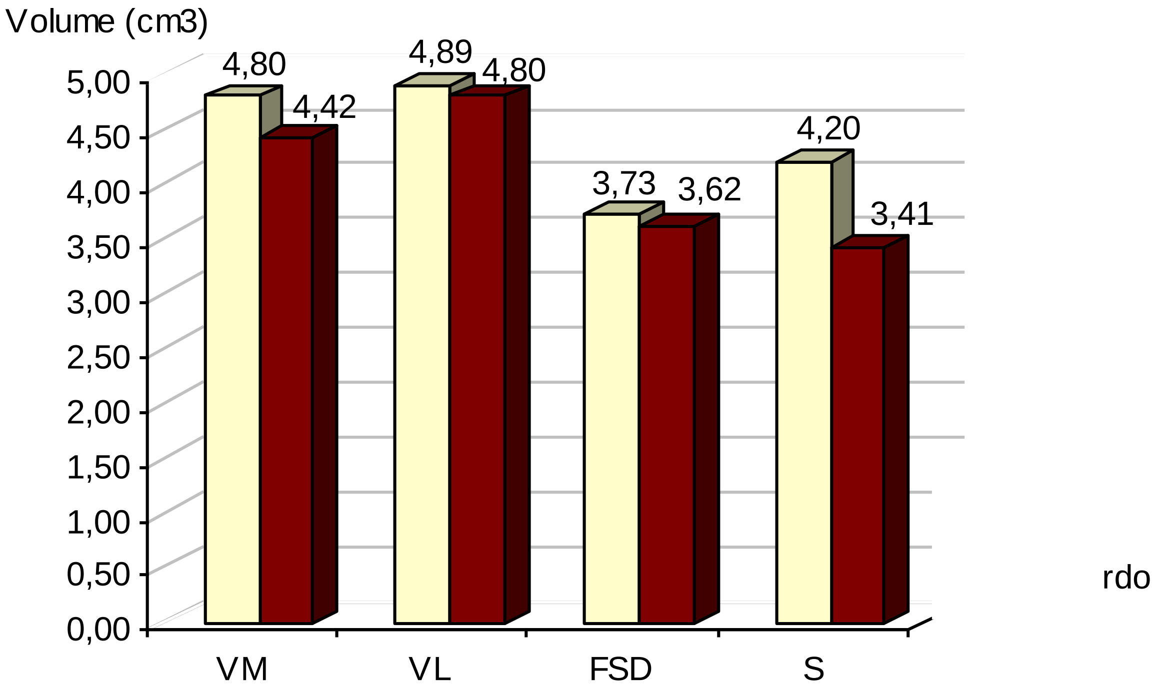

Fig.7: Volumetric values of muscles on the right and left sides of muscles Coati (Nasua nasua). MB = medial belly; SB = side belly; SFF = superficial flexor of the fingers; S = soleus.

IV. DISCUSSION

Gastrocnemius muscle is divided into medial and lateral heads in most species previously studied (MILLER, et al., 1964) in dog; (SCHÖN, 1968) in Bugio; (TESTUT et al., 1979), in humans; (HERMANSON et al., 1993) and (DYCE et al., 2004), in domestic animals; (GETTY, 2008) in pigs and carnivores **[8-13]**. The same was also identified in the present study performed in coati, where the gastrocnemius muscle was made up of two heads, one lateral and a medial. Also similar to other species, the proximal origin of the heads of gastrocnemius muscles was identified in the flexor aspect of the distal end of the femur, with a sesamoid bone included in the tendon of origin. Miller et al. (1964) reported that in the dog, originate from the plantar surface of the distal end of the femur by strong tendons, with a sesamoid bone that articulates with the femoral condyle. Schön (1968) described the origin of lateral head of gastrocnemius muscle to be located on lateral epicondyle of femur and knee joint capsule, with a fleshy origin of the medial head in the medial epicondyle **[8-9]**. Pérez-Arévalo et al. (2009) reported the gastrocnemius origin in rabbits in the medial and lateral condyles of the femur **[14]**. Testut et al. (1979) described human anatomy of the heads of the m. gastrocnemius originating at the distal end of the femur, with each head set at the condyle by strong tendons. Sesamoid bones were not present at the origin, but instead a cartilaginous core was located in their place **[10]**. Getty (2008) indicated that in domestic carnivores, the heads of the m. gastrocnemius originate in the medial supra-condylar spines and lateral femur by strong tendons that incorporate sesamoid bones **[13]**.

The origin of gastrocnemius muscle by strong tendons that occurs in coati, and is elsewhere described in other species in the literature, suggests the importance of this muscle in the maintenance of posture and body movements, such as scaling trees. Despite the presence of sesamoid bones within tendons, which could minimize possible wear as they cross the knee joint and create lever arm loading that improves efficiency, the origin structures are subjected to great stresses and strength requirements in animals that run and jump. This does not occur in humans where the corresponding anatomical formations are cartilaginous or do not exist.

Raccoon is a sturdy animal with prominant arch support. This species is semi-arboreal that is quick to get around or climb trees, hence the need for powerful muscles that can provide needed strength. This can result in large torque on the knee and ankle in a short time. According to Camargo Filho (2006), the human

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gastrocnemius muscle has a predominance of type II fibers (glycolytic) **[15]**. Moraes et al. (2007) described that this muscle has the capacity to develop great tension in a short time. It is therefore possible that the gastrocnemius muscle in coati has an equal predominance of glycolytic fibers, as they are very agile in climbing and get around well both in trees and on the ground. In domestic animals, the literature states that the two bellies of the gastrocnemius almost surround the superficial flexor digitorum muscle belly, a condition also observed in coati **[16]**.

The gastrocnemius muscle in Coati is very robust relative to the length of the tibia and, therefore, the physical size of the animal. Coati had a gastrocnemius muscle of 10.0cm³ in the right antimere and 9.5cm³ on the left, with a tibia of approximately 8.6 cm and 8.5 cm respectively, equivalent to a medium-sized specimen (1.8–2.0 kg). The right muscle had a relatively higher volume than the left without a plausible explanation. Asymmetry was observed between the right and left sides, with the dimensions of the right muscle belly larger than the left. The small fleshy origin of raccoon gastrocnemius muscle could be a remnant of plant or popliteus muscle, since it was not identified anatomically in this taxon but is located in the same location. The proximal third of the gastrocnemius muscle was roughly cylindrical as in domestic animals, while the middle portion was wide and slightly flattened **[8, 12-13]**. According to Miller et al. (1964), in dogs, the medial head of the gastrocnemius is independent, while the lateral head is partially fused to the superficial flexor digitorum muscle belly. This condition was researched in domestic animals by Getty (2008): in human, by Testut et al. (1979). In other animals, the two heads are entirely separate. In coati, the medial belly is totally separate from the side belly and the superficial flexor digitorum muscle belly; however, the lateral belly and the superficial flexor digitorum muscle belly are partially fused throughout its length. On the cranial surface, only a groove marks the separation, while on the surface, two grooves are present between the belly of the flexor and both heads of the gastrocnemius **[8, 10, 13]**.

Previous descriptions of the formation of the Achilles tendon and insertion on the end of the calcaneus support the assertion that the aponeuroses of the two heads of the gastrocnemius condense and combine to constitute the great Achilles tendon, since the flexor digitorum superficialis tendon in domestic dogs circumvents the Achilles tendon and distally opens in blade involving the distal part of the Achilles tendon and the end of the calcaneus bone, spreading into the plantar aponeurosis **[8, 12-13]**. This condition was also identified in the raccoon, but the distal part of the Achilles tendon was joined by the soleus tendon, which is absent in the dog.

With regard to the soleus muscle, Testut et al. (1979) disclosed that, in humans, it has a similar shape of a shoe sole that is wide, thick and long, and located deep to the gastrocnemius. Its origin is the head of the fibula, tibia and proximal interosseous membrane. The origin is a tendon divided into three parts: peroneal, tibial and intermediate. The ramifications inherent in the source are just the tendon. Its insertion is at the end of the calcaneus, the deepest part of the Achilles tendon. Distally its tendon enters the Achilles tendon, a common occurrence in anthropoids **[10]**. Sometimes muscle fibers reach the calcaneus. According Dyce et al. (2004), the soleus muscle is absent in dogs, but developed in the cat, and as in horses, is a single structure extending from the fibula to the calcaneus. Getty (2008) reported that the soleus muscle was absent in dogs and developed in cats and pigs. In pigs, the soleus muscle is attached to the lateral head of the gastrocnemius, and its origin is at the lateral epicondyle of the femur and deep knee fascia. The insert is in the Achilles tendon **[12-13]**.

Coati soleus muscle is quite robust, with an approximate volume of 4.2cm³ in the right antimere and 3.4cm³ on the left. It is located in the caudal part of the leg, deep to the gastrocnemius, and originates from the lateral aspect of the head of the fibula and the interosseous membrane. It also is fixed in the intermuscular fascia between him and the long deep flexor muscle of the fingers. Its distal third is free and inserts with the gastrocnemius. The plantar aponeurosis of the tendon of the tensor muscle runs beside the Achilles tendon. The presence of a strong soleus muscle appears to be associated with plantigrade stepping, which is well developed in humans and other primates. The origin of the soleus muscle is common with the origin of the lateral head of the gastrocnemius. After dissection and study the anatomy of the superficial flexor digitorum muscle, it seems likely that this muscle has no direct action on the fingers but on the plantar aponeurosis, acting indirectly to flex the fingers, at least in plantigrade animals.

V. CONCLUSION

The present study demonstrated that gastrocnemius muscle of Coati is robust with respect to physical size of this animal and compared with other mammals, were bellies of lateral and medial heads of gastrocnemius muscle of Coati almost entirely surround the belly superficial flexor digitorum muscle. In addition this work show that gastrocnemius muscles, soleus and

flexor surfaces of Coati fingers, are relatively larger in right antimere, than left antimere. The raccoon has a strong soleus muscle, similar to non-human primates. Our findings contribute to the description of an important muscle and best knowledge of Coati biological system.

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