DOI: 10.1590/1089-6891v17i233788

MEDICINA VETERINÁRIA

MUSCULAR ANATOMY OF THE PECTORAL AND FORELIMB OF *Caiman crocodilus crocodilus* (LINNAEUS, 1758) (CROCODYLIA: ALLIGATORIDAE)

ANATOMIA MUSCULAR DO MEMBRO TORÁCICO DE Caiman crocodilus crocodilus (LINNAEUS, 1758) (CROCODYLIA: ALLIGATORIDAE)

Fabiano Campos Lima[1]
Anastácia Vale Leite[1]
André Luiz Quagliatto Santos[2]
Dayane Kelly Sabec-Pereira[1]
Eugênio Gonçalves Araújo[3]
Kleber Fernando Pereira[1*]

[1]Universidade Federal de Goiás, Regional de Jataí, Ciências Biológicas, Jataí, GO, BR
[2]Universidade Federal de Uberlândia, Faculdade de Medicina Veterinária, Uberlândia, MG
[3]Universidade Federal de Goiás, Escola de Veterinária e Zootecnia, Goiânia, GO, Brasil
[*]Autor para correspondência - kpereiraufg@gmail.com

Abstract
Among the Brazilian crocodilian, *Caiman crocodilus crocodilus* is widely distributed, given its adaptation to diverse habitats and their generalist diet. Information about the reproductive and ethological character of this species is abundant, whereas morphological data are still scarce. This study aimed to identify and report the muscles and their origin and the insertion into the pectoral and forelimb of *C. crocodilus crocodilus*. We used two male specimens, adults, belonging to the collection of the UFG – Jataí. We performed usual procedures for dissection and further individualization, withdrawal of members, and observation of muscle origins and insertions. The musculature of *C. crocodilus crocodilus* generally conservative is similar to *C. latirostris* and *A. mississippiensis*. The muscles of the pectoral girdle showed little variation among crocodilians. In the forelimb, the triceps muscle has five distinct heads and biceps has only one. The extensor and flexor surface of the hand showed similar topography to *A. mississippiensis*. We described some differences in the origin and insertion of certain muscles, as well as the classification and topography of some flexor and extensor muscles in the forearm segment. The distal segments showed more variations, which probably reflects the variety of locomotor habits among crocodilians.

Keywords: Common caiman; crocodilians; myology; muscle; reptiles.

Resumo
Dentre os crocodilianos brasileiros, *Caiman crocodilus crocodilus* apresenta ampla distribuição, haja vista sua adaptação a habitats diversificados e sua dieta generalista. Informações de caráter etológico e reprodutivo acerca desta espécie são abundantes, enquanto dados morfológicos são ainda escassos. Objetivou-se identificar e relatar os músculos e suas origens e inserções nos segmentos da cintura e membro torácico de *C. crocodilus crocodilus*. No estudo, foram utilizados dois exemplares machos, adultos, pertencentes ao acervo da UFG - Jataí. Para isto utilizaram-se métodos usuais em dissecação e posteriormente os músculos foram individualizados, descritos e sua origem e inserção determinadas. A musculatura de *C. crocodilus crocodilus* é conservativa, sendo similar a *C. latirostris* e *A. mississippiensis*. Os músculos da cintura peitoral apresentaram uma pequena variação dentre os

crocodilianos avaliados. No membro torácico, o tríceps possui cinco ventres distintos e o bíceps apenas um. O grupo de flexores e extensores da região do ante-braço apresenta topografia similar aquela descrita para *A. mississippiensis.* Algumas diferenças na origem, inserção, classificação e topografia de alguns músculos flexores e extensores foram descritas. O segmento distal do membro apresentou mais variação, o que provavelmente reflete diferenças no padrão locomotor entre os crocodilianos.
Palavras-chave: Crocodiliano; jacaretinga; miologia,; músculo, répteis.

Enviado em: 28 janeiro 2015
Aceito em 26 fevereiro de 2016

Introduction

Among vertebrates, reptiles were the first animals to adapt to the life in dry environments. Among reptiles, crocodilians differed as a group approximately 200 million years ago, in the Triassic, and belong to the subclass Archosauria. The Archosauria from Crocodylia is included in the living crocodilians. Anatomically, they have elongated skull, terminal nostril, secondary palate, thecodont teeth, with webbed fingers, and an excluded pubis from the acetabulum.[1,2]

The Alligatoridae family includes alligators and caimans.[3-6] These reptiles have a relatively broad snout and an unclearly demarcated skull, small or secondarily closed supratemporal opening, strong teeth, and mandibular teeth fitting into the internal cavity of the mouth. They live in flooded regions throughout the American continent and China,[7,8] consisting of *Alligator mississippiensis*, *Alligator sinensis*, *Caiman crocodilus crocodilus*, *Caiam latirostris*, *Caiman yacare*, *Melanosuchus niger*, *Paleosuchus palpebrosus*, and *Paleosuchus trigonatus*.

Popularly known in Brazil as black alligator, glasses caiman, and jacaretinga, *C. crocodilus crocodilus* (Linnaeus, 1758) inhabits floodplains in the Midwest, Southeast and Northern in basins of the Amazon, Orinoco, Araguaia, and Tocantins rivers.[9-11] It presents a broad distribution concerning other species of Brazilian crocodilians, and in some places, the introduction of this species happened by the scape from zoos and breeding farms. Recently it was reported at the border between Ceará and Piauí States.[12]

C. crocodilus crocodilus have a diversified diet, feeding on snails, fish, amphibians, birds, and small mammals. They can reach 2.5 meters in total length, and they have the lightest color of all species occurring in Brazil. When compared to *M. niger*, *C. crocodilus crocodilus* is a generalist animal that may use environments modified by humans, such as canals and dams, and present a more varied diet. This species builds nests in an igloo format, using material from the litter, or that could be the basis of a semi-shrub formation, shrubs and trees, from environments of forests, savannas, and fields.[10,11,13]

Tetrapoda quadrupeds have a diversified postural capacity during the locomotion.[6] Crocodilians have different locomotion patterns. They can drag on the ground, move slightly upright, or swim.[5,14] The anatomy of modern representatives of this group presents similar characteristics among locomotor species,[15] and an equivalent morphology and function could lead to the conclusion that members, for example, have a high degree of conservatism. The maintenance of these features should be similar to the occupation of ecological niches along the evolutionary history of this group.[16]

Hutchinson and Gatesy,[17] based on the functional anatomy, reconstructed the phylogeny of the Archosauria group of locomotion and inferred the evolution was gradual, involving a plesiomorphic postural mechanism. Hutchinson[18] reported these changes altered the anatomy and motor control, although in some cases the member function evolved without modifications in motor control.

The evolution of reptiles was a milestone for the adaptation to terrestrial life and occupation. It contributed to other living creatures that came from other reptiles; therefore, the aim of this paper is to describe the muscular anatomy of the forelimb of *C. crocodilus crocodilus*, offering subsidies for interpreting the anatomy and physiology of the locomotion muscle of this group.

Materials and Methods

For this study, we used two young adult, male *C. crocodilus crocodilus*, measuring approximately 1.5 m in length, belonging to the collection of the Human and Comparative Anatomy Laboratory of the Federal University of Goiás – Jataí.

We started the usual dissection procedures with a longitudinal incision along the midline, and later we refuted the skin in the region. The specimens were fixed in formalin 10% and kept in 70% alcohol solution. Following muscle individualization of regions of interest, we identified the muscles, removed the members for a better observation of the origins, and performed muscle insertions. All the material was photographed with a digital camera (Camera Sony a200, 10.2mpx).

We collected the animals in November 2007, in Araguaia river, Goiás, Brazil, under the permit number 13159-1/2007 SISBIO. We kept the animals in the lab for other experiments. They came to death, and we used their bodies in this investigation under license of the Research Committee of Ethics in Animal Experimentation of Federal University of Uberlandia (CEUA 032/09).

Results and Discussion

A description of the anatomy, topography, origin and insertion of the pectoral girdle and forelimb muscles of *C. crocodilus crocodilus* follows in Tables 1, 2, and 3, and in Figures 1, 2, and 3.

The pectoralis muscle is usually large and runs the sternal margin or adjacent structures, such as the humerus or scapula[(19-21)] (Fig 1). According to Romer,[(19)] for reptiles to present a pleisiomorphic condition, they have to have a single chest, as in lepdosauria and testudines[(22)]. Crocodilians, however, presents segmentation on superficial and deep head.[(20)] Romão et al.[(23)] reported the existence of a cranial parallel fiber segment and other caudal oblique fiber segment. This was also reported with three heads,[(22,24)] an inconstant deep head, superimposed by the flow head that may occur. Birds have two divisions,[(25)] with some consideration by Hudson et al.,[(26)] the existence of a third head. *C. crocodilus crocodilus* division between segments (head) of the chest was not conspicuous but the extensive source along the sternal border and the direction of the fibers suggests the division.

In all described crocodilians, the segments converged into one tendon that inserted into the deltopectoral crest of the humerus.[(19,22-24)] Meers[(24)] pointed out, in the *Crocodilus actus*, the pectoralis had a unique origin fixed in the third gastralia. According to Diogo et al.,[(21)] the different segmentations of the pectoralis between reptiles and Archosauria indicated that this configuration was acquired independently in evolution. According to Romão et al.,[(23)] the pectoralis in *C. latirostris* showed greater longitudinal distance from *A. mississippiensis, C. siamensis, C. actus, O. tetraspis*, and *G.* gangeticus,[(24)] offering better possibility of mobility.

The supracoraoideus complex consists of three muscles in *A. mississippiensis, C. siamensis, C. actus, O. tetraspis, G. gangeticus*,[(24)] and *C. latirostris*.[(23)] For *C. crocodilus crocodilus*, the intermediate head is not defined as showed in reports for other crocodilians. Meers[(24)] described a common tendon of insertion for intermediate and short heads, which can be difficult to distinguish in the bellies of *C. crocodilus crocodilus*. An alleged mechanical advantage was observed among *C. latirostris*, *A. mississippiensis, C. siamensis, C. actus, O. tetraspis*, and *G. gangeticus*[(24)] for the supracoraoideus complex, originating in the lateral humerus in proximal aspect.[(23)]

Deep to the pectoralis muscle there was a pair of costocoracoideus (superficialis and profundus) it assisted in retraction of the coracoid, although there was no significant action to provide stability to this segment. In *A. mississippiensis, C. siamensis, C. actus, O. tetraspis, G. gangeticus*,[(24)] and *C. crocodilus crocodilus*, its origin occurs in the costal margin and insertion into the caudal border of the coracoid (superficialis) and craniolateral margin of sternal plate and ventral surface of the coracoid (profundus) (Fig 1). Romão et al.,[(23)] however, described the costocoracoideus superficialis and profundus both originating in the deep sternal border of *C. latirostris.*

Table 1: Dorsal and ventral muscles of the pectoral girdle of *C. crocodilus crocodilus*

Muscle	Origin	Insertion	Features
Trapezius	Thoracodorsal fascia, spinous process along the midline in cervical and thoracic segment	Cranial margin of the scapula	Broad and thin, occupying the cranial portion of the dorsal face
Latissimus dorsi	Thoracodorsal fascia, caudally by trapezius	Through a common tendon with the teres major in craniodorsal surface, distal to the head of the humerus	Superficial, overlaying by serratus ventralis thoracis. Flat, triangular and parallel fibers, continuous with trapezius
Levator scapulae	Cervical ribs	Craniodorsal margin of the scapula	Elongated with fibers logintudinally arranged, deep by trapezius
Deltoideus scapularis	Craniodistal margin of the scapula	Proximal humerus, distal of deltopectoral crest	Thick overlaying the triceps longus lateralis tendon
Deltoideus clavicularis	Proximal surface of the cranial margin of scapula	Medial tubercule of the humerus	Broad and triangular. Occupies large area on the surface of the scapula
Teres major	Distal caudal surface of the scapula	Proximal humerus	Short and broad, located on ventral margin of the scapula
Supracoracoideus longus	Ventral surface of the coracoid	Medial tubercule of the humerus	Robust, thick and superficial to the supracoracoideus brevis
Supracoracoideus brevis	Lateral surface of the acromion	Deltopectoral crest	Slender and broad, deep to the supracoracoideus longus
Pectoralis	Broadly along the lateral margin of the sternum, on midline	Apex of the deltopectoral crest	Extensive, thick, flat and triangular. Superficial on the ventral aspect
Costocoracoideus superficialis	Cranial margin of the first sternal rib	Caudal margin of the coracoid	Broad belly. The insertion also can occur on the sternum
Costocoracoideus profundus	Caudal margin of sternal ribs	Cranial edge of the medial surface of the coracoid	Overlapped by costocoracoid superficialis. It is small and shows oblique fibers
Supracoracoideus longus	Ventral surface of the coracoid	Medial tubercule of the humerus	Robust, thick fan-shaped and superficial to the supracoracoideus brevis
Supracoracoideus brevis	Lateral surface of the acromion	Deltopectoral crest	Flat and relatively broad, deep to the supracoracoideus longus
Subscapularis	Medial surface of the scapula	Proximal humerus, into the glenohumeralis joint capsule	Broad, thick e long. Occupies the medial surface of the scapula
Scapulohumeralis	Lower portion of the dorsal surface of the scapula near the glenoid edge	Proximal humerus	Small and deep to teres major, completely overlaid by it on lateral aspect of the scapula

Table 2: Forelimb muscles of the proximal segment of *C. crocodilus crocodilus*

Muscle	Origin	Insertion	Features
Coracobrachialis brevis ventralis	Ventral surface of the coracoid	Proximal humerus in caudoventral surface	Broad, fan-shaped and extensive. Deep to pectoralis
Biceps brachii	Cranial edge of the coracoid	Caudal surface of proximal radius (short tendon on the radial tuberosity)	Thick, large, prominent and fusiform parallel-fibered muscle. The tendon of origin overlaid the pectoralis.
Braquialis	Proximal humerus dyaphisis, distal to the deltopectoral crest	Caudal surface of proximal radius	Broad muscle that occupies the craniomedial aspect of humerus and inserts with conjunction the biceps
Triceps longus lateralis	Dorsal glenoid edge of the scapula	Proximal ulna, lateral aspect of the olecranon	Superficial, longitudinal parallel fibers and with a largely origin tendon
Triceps longus caudalis	Surface of the scapula and coracoid via a tendinous arc attached to these bones	Proximal ulna, olecranon process	Long, broad, pinnate and superficial, caudal located to the longus lateralis belly
Triceps brevis cranialis	Proximal humerus	Proximal ulna, olecranon process	Short and overlapped by longus lateralis and lies dorsal to the humeroradialis
Triceps brevis intermedius	Dorsal surface of the proximal humerus	Proximal ulna, olecranon process	Occupies the largest area of the deep surface of the humerus. overlapped by longus lateralis and humeroradialis
Triceps brevis caudalis	caudal humerus in the medial surface	Proximal ulna, olecranon process	Long and narrow with longitudinal fibers deep to longus lateralis belly
Humeroradialis	Proximal humerus, distal to the deltopectoral crest	Proximal radius, humeroradialis crest	Robust, long, thick and superficial in the cranial surface of the humerus.

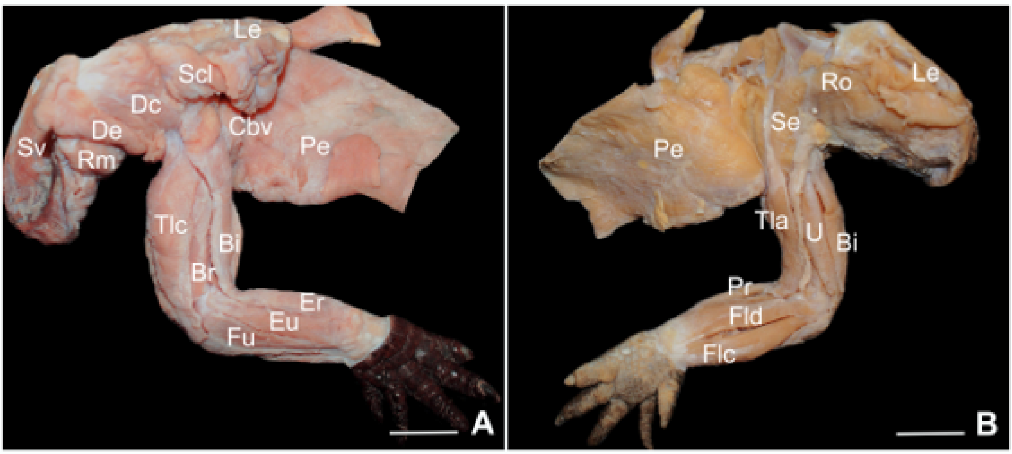

Figure 1: Pectoral and Forelimb of the *Caiman crocodilus crocodilus,* lateral view (A). Pe, pectoralis; Scl, supracoracoidus longus; De, deltoideus scapularis; Dc, deltoideus clavicularis; Le, levator scapulae; Cbv, coracobrachialis brevis ventralis; Rm, teres major; Sv, serratus ventralis; Br, brachialis; Bi, biceps brachii; Tlc, triceps longus caudalis; Eu, extensor carpi ulnaris; Er, extensor carpi radialis; Fu, flexor ulnaris. Medial view (B). Se, subscapularis; Ro, rhomboideus; Tla, triceps longus lateralis; U, Humeroradialis; Pr, pronator teres; Fld, flexor digitorum longus; Flc, flexor carpi ulnaris. ScaleBar = 1cm.

Table 3: Forelimb muscles of the distal segment of *C. crocodilus crocodilus*

Muscle	Origin	Insertion	Features
Supinator	Cranial epicondyle of the humerus	Distal radius, cranial surface	Large and superficial. Lateral to the extensor carpi radialis longus
Extensor carpi radialis brevis	Pars radialis: distal half of the radius Pars ulnaris: medial edge of the ulna	Proximal surface of the radiale	The pars radialis is small and deep to supinator. The pars ulnaris is large and occupies the deep region
Extensor carpi ulnaris	Cranial epicondyle of the humerus	Metacarpal II	Long and broad, superficially located in the cranial aspect
Flexor ulnaris	Cranial epicondyle of the humerus	Distal ulna	Broad, fusiform, superficial and lateral of the antebrachium
Abductor radialis	Cranial epicondyle of the humerus	Proximal half of the radius	Small and deep to supinator and extensor carpi radialis longus
Extensor carpi radialis longus	Cranial epicondyle of the humerus	Radiale	Long, fusiform and parallel fibers
Pronator teres	Caudal epicondyle of the humerus	Distal half of the radius	Large, thick and longitudinal
Flexor digitorum longus	Pars humeri: caudal epicondyle of the humerus Pars ulnaris: caudal surfasse of the ulna. Pars carpalis: distal carpals	Broad tendon related to the Pisiform and the palmar aponeurosis. Attached in distal phalangx of the digits I, II and III	Three belly complex muscle. Long and parallel-fibered with a common tendon on the palmar region that branches and inserts on digits
Flexor carpi ulnaris	Caudal epicondyle of the humerus and ulna	Ulnare	Muscle with two origins. It is large, thick and fusiform. Medial to the pronator quadratus and deep to the flexor digitorum longus
Pronator quadratus	From a broad attachment to the ulna	Distal lenght of the radius	A broad muscle deeply located in the antebrachium
Trasversus palmaris	Distal radius	Metacarpal V	Most superficial flexor of the manus. Strap-like, thin and transversal fibered, attached to a long tendon
Flexor digiti quinti	Lateral margin of the radiale	Distal phalanx V	Small, thin and triangular superficial muscle in the manus
Flexor digitorum brevis superficialis	Proximal metacarpal bones (I – IV digits)	Phalanx II (I –IV digits)	Complex of four small, fusiform, and deep muscles in the palmar surface.
Extensor digitorum superficialis	Distal carpal and proximal metacarpal	Distal phalanx (I – V digits)	Complex of various muscle heads. Small, elongated and superficial in the dorsal manus.

According to Abdala and Diogo,[22] the infraespinatus and supraespinatus muscles in mammals derive from supracoracoideus, although it occupies a ventral and not dorsal portion in the current tetrapoda[21], except for chameleons, where the dorsal position supracoraoideus would be an autopomorphical condition.[19] Crocodilians have no infraespinatus and supraespinatus muscles.

The deltoideus appeared as two distinct muscles. The deltoideus scapularis is usually connected to the scapula, but it can occasionally be present in the humerus.[25] It is present in crocodilians, birds, testudines and lepdosauria.[22, 25, 27] Diogo et al.[21] claimed that it is present in reptiles, mammals and amphibians basically with the same topography and function that, according to Meers[24] and Romão et al.,[23] performs the extension of the humerus and assists in stability of the joint. In *C. crocodilus crocodilus* and the reported crocodilians, it is a robust muscle, with extensive areas of cross sections topographically deep to the trapezius of the dorsal region (Fig. 1). It is inserted into the deltopectoral crest of the humerus by a strong tendon.

The teres major muscle is present in all the reported crocodilians corroborating Dilkes[25] to further confirm its presence in testudines and many lizards (except *Iguana*). In *A. mississippinensis*[24] and *C. latirostris*,[23] this muscle has interdigitated fibers with the latissimus dorsi. Its insertion occurs by a single and fused tendon between these. Such union of fibers was not observed in *C. crocodilus crocodilus,* being both distinct. The extensive cross-sectional area suggests that this muscle provides great mechanical support for the stability of the forelimb. Howell[28] infered that the greatest round in mammals is not homologous to the reptiles, Diogo et al.,[21] however, defended this homology. Based on the descriptions by Meers,[24] this homology is plausible because of the topography and innervation of that muscle.

From a simple survey, it is possible to observe the large degree of variation in the number of divisions present in the crocodilian triceps towards other reptile and tetrapoda. The triceps is present in lepdosauria with four heads,[25,27] with two heads in testudines,[27] although only one head is reported in *Dermochelys*, and three heads in poultry.[25]

Holmes[27] described four heads for this muscle in crocodilians and defended that this is a plesiomorphic condition for reptiles, while for Diogo et al.,[21] this would be a pleisiomorphy for all tetrapods. Meers,[24] however, reported five heads, corroborating Dilkes,[25] as well as our description for *C. crocodilus crocodilus* (Fig. 1). Romão et al.[23] described five heads and an additional one, acessorius to the longus medialis head, with the proximal origin in the aponeurosis that covers the longus medialis head. This characteristic has been described by Meers[24] in an exemplar of *A. mississippiensis* and *C. actus*.

Romão et al.[23] described in *C. latirostris* a head of triceps originated from a double tendon forming a tendinous arch linking the scapula and the coracoid, and nnamed it "tríceps longo medial" (triceps longus medialis). However, the same description for the other crocodilians, including *C. crocodilus crocodilus,* is named triceps longus caudalis.[22, 24] Such tendinous arch is present in all crocodilians, although with different topography. The existence of this structure in the triceps muscle highlights the need for additional studies aiming to explain the phylogeny and homology of the muscles in Archosauria.[24]

All descriptions of the biceps brachii to crocodilians, also in *C. crocodilus crocodilus,* have reported the existence of a long and slender fusiform head, originated in the cranial margin of the coracoid and a robust insertion into the radius tuberosity[22-24] (Figs. 1, 2).

The biceps brachii in testudines has two heads. Meers[24] and Romão et al.[23] reported the existence of a second belly inconspicuous, inconstant and originated in the capsule of the shoulder joint in *C. latirostris* and *A. mississippiensis.* In *C. crocodilus crocodilus*, this characteristic was not observed, and the biceps brachii had a single fusiform head as described by Diogo et al.[21]

Some species showed a shift of the biceps brachii origin ventromedially that provides mechanical advantage by promoting strong flexion, although no explicit description depicted such a feature in the reported species.[24]

The forearm muscles can be divided into three groups: ventral (flexor and pronator), dorsal (extensor and supinator) and hand muscles. These are topographically organized in layers flexor/extensor ulnaris, flexor/extensor radialis and flexor/extensor digitorum.[21] Observing the reported topography for *A. mississippiensis, C. latirostris* and *C. crocodilus crocodilus* this relationship can be easily noticed.

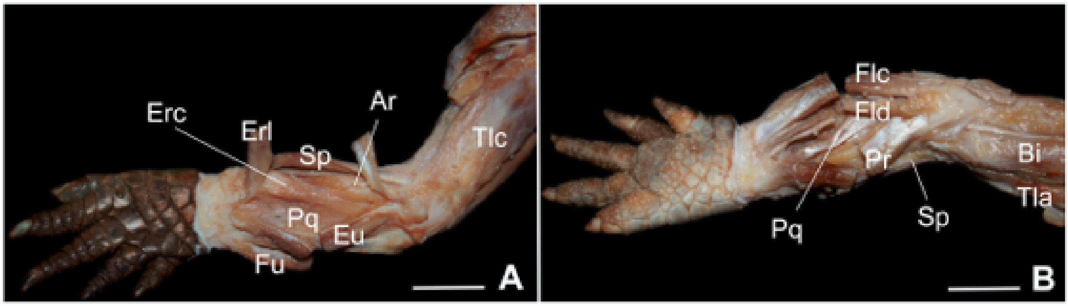

Figure 2: Antebrachium of the *Caiman crocodilus crocodilus,* lateral view (A). Tlc, triceps longus caudalis; Ar, abductor radialis; Sp, supinator; Eu, extensor carpi ulnaris; Pq, pronator quadratus; Fu, flexor carpi ulnaris; Erc, extensor carpi radialis brevis; Erl, extensor carpi radialis longus. Medial view (B). Flc, flexor ulnaris; Fld, flexor digitorum longus; Pr, pronator teres; Bi, biceps brachii. ScaleBar = 3cm.

Some variations between the flexor and extensor muscles in the forearm can be punctuated in crocodilians. According to Diogo et al.,[21] there is some confusion in the identification of the flexor carpi and the pronator teres in reptiles. According to the authors, both heads of the flexor carpi and pronator teres correspond topographically with these in mammals. Some groups of reptiles, such as testudines and lepdosauria, show an accessory pronator, lost by crocodilians.[22,24,29] We classified the forearm muscle present in the flexor compartment of *C. crocodilus crocodilus* as flexor digitorum longus (and respective heads), as reported by Meers[24] for *A. mississippiensis* and Romão et al.[23] for *C. latirostris.* Our findings corroborated Meers,[24] who described a humeral head originated from the caudal epicondyle, pars ulnaris with the source on the surface of the ulna and another pars carpalis. To *C. latirostris* only the pars humeralis and pars ulnaris were described.[24] All divisions form a common tendon on the palmar surface. Starting from a branch point, it occurs in three separate tendons that go to the digits I-III, as in *C. crocodilus crocodilus.* Regarding *C. latirostris*,[23] this last branch of the tendons to the digits was not reported (Figs. 1, 2).

As for the extensor muscles, the existence of two radialis carpalis extensors muscles is not a consensus. Howell[30], Meers,[24] and Romão et al.[23] described one short and another long muscle in crocodilians, but some authors defended that the reptile present a single muscle. Diogo et al.[21] described a single extensor carpi radialis (brevis), but with three heads (superficialis, profundus and supinator) as in testudines, lepdosauria and amphibians,[25,26,31] except for some variations. Meers[24] reported that crocodilians present two discrete heads for the extensor carpi radialis brevis muscle (pars radialis and pars ulnaris), both described in *C.* latirostris,[23] and *C. crocodilus crocodilus*; however, with a slight variation in the insertion points.

Meers[24] and Romão et al.[23] described the extensor ulnaris that, according to Abdala and Diego,[22] corresponds to the extensor ulnaris of the carpi and the antebrachium described by Holmes[27] and Dilkes.[24] This extensor ulnaris has the same morphology and topography for *C crocodilus crocodilus*, it originated from the cranial epicondyle of the humerus and inserted in the caudal surface of the ulna (Figs. 1, 2). According to Haines,[32] it is a muscle with a wide variation among the vertebrates, which shows different actions. In crocodilians it acts as a postural stabilizer.

Several extensor digitorum muscles were reported by Meers[24] and Diogo et al.[21] There are five superficial, six deep, two extenders for the metacarpal and a superficial extensor for the digits I and II,[24] probably corresponding to extensor digitorum, extensor longus digit 1 and abductor pollicis longus described by Diogo et al.[21] From these ones, the extensor digitorum superficialis had been described for *C. crocodilus crocodilus* with similar morphology, presenting five bellies with insertion through individual tendons at the distal phalanx of each digit (I-V).

The flexor digitorum superficialis brevis in *C. crocodilus crocodilus* corresponds to four small, elongated and peniform bellies originated in the retinaculum flexor level and insertion in the phalanx II (Fig. 3). The digit V has a distinct flexor muscle, as observed by Meers.[24] He reports the existence of an additional muscle, flexor digitorum intermedius digiti V in *A. mississippiensis*, and according to him, it commonly occurrs at the digiti IV and V, although it was not observed in *C. crocodilus crocodilus* or other crocodilian.

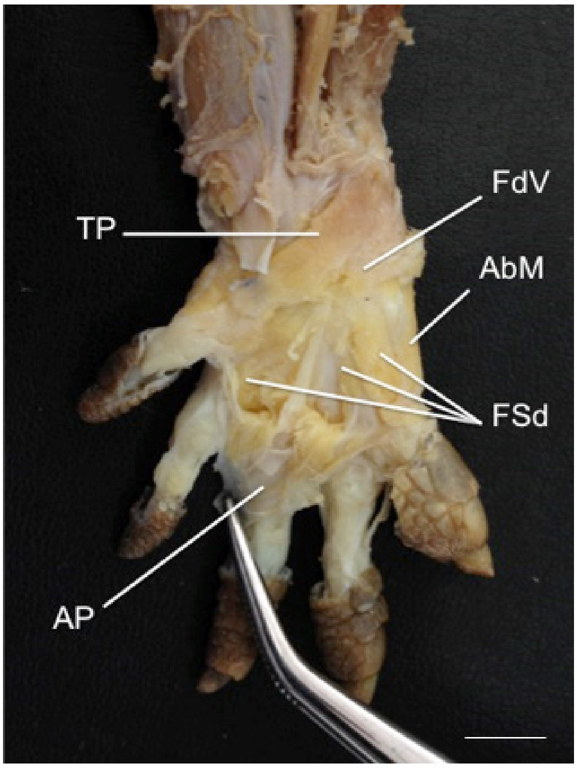

Figure 3: Manus of the *Caiman crocodilus crocodilus,* palmar view. Tp, trasversus palmaris; FdV, flexor digiti quinti; Abm, abductor metacarpi I; FSd, flexor digitorum superficialis brevis; AP, palmar aponeurosis. ScaleBar = 3 cm.

Conclusion

Although there is a reduction or loss of some muscle structures from the comparison between crocodilians and other reptiles, it is possible to determine the presence of various muscles, including the same morphological characteristics in larger groups of reptiles including birds, suggesting the existence of a similar pattern in this group. The proximal segments have some variation, but large differences are reported in the distal member. These changes derive from this segment specialization in different groups and species with the development of specific skills, especially related to the locomotion pattern.

Acknowledgments

The authors thank to National Center for Research and Conservation of Reptiles and Amphibians (RAN), of the Chico Mendes Institute for Biodiversity Conservation (ICMBio).

References

1. Rieppel O, Reisz RR. The origin and early evolution of Turtles. Annu. Rev. Ecol. Syst., 1999; 30: 1-22.

2. Schoch RR. Early larval ontogeny of the Permo-Carboniferous temnospongyl Sclerocephalus. Paleontol., 2003; 46: 1055-1072.

3. Colbert EH. Relationships of the saurischian dinosaurs. Am. Mus. Nov., 1964; 2181: 1–24.

4. Brinkman D. The hind limb step cycle of *Caiman sclerops* and the mechanics of the crocodile tarsus and metatarsus. Can. J. Zool. 1980; 58: 2187–2200.

5. Reilly SM, Elias JA. Locomotion in *Alligator mississippiensis*: Kinematic effects of speed and posture and their relevance to the sprawling-to-erect paradigm. J. Exp. Biol. 1998; 201: 2559–2574.

6. Reilly SM, Blob RW. Motor control of locomotor hindlimb posture in the American alligator (*Alligator mississippiensis*). J. Exp. Biol., 2003; 206: 4327–4340.

7. Naish D. Fossils explained: Crocodilians. Geol .Today, 2001; 17: 71-77.

8. Brochu CA. Phylogenetic approaches toward crocodylian history. Anuu. Rev. Earth Pl. Sc. 2003; 31: 357-397.

9. Magnusson WE, Sanaiotti TM. Growth of *Caiman crocodilus crocodilus* in central Amazônia, Brazil. Copeia, 1995; 2: 498–501.

10. Campos Z, Coutinho M, Magnusson WE. Terrestrial activity of caiman in the Pantanal, Brazil. Copeia, 2003; 3: 628–634.

11. Da Silveira R, Campos Z, Thorbjarnarson JB, Magnusson WE. Growth rates of black caiman (*Melanosuchus niger*) and spectacled caiman (*Caiman crocodilus*) in two different Amazonian flooded habitats. Amphibia-Reptilia, 2013; 34: 437–449.

12. Borges-Nojosa DM, Arzabe C. Diversidade de anfíbios e répteis em áreas prioritárias para a conservação da Caatinga. In: Araújo FS, Rodal MJN, Barbosa MRV. eds. Análise das variações da biodiversidade do bioma Caatinga. 1st ed. Brasília: Ministério do Meio Ambiente, 2005. 226p.

13. Campos Z, Mourão G, Coutinho M, Magnusson W. E.Growth of *Caiman crocodilus yacare* in the Brazilian Pantanal. PloS ONE, 2014; 9: 1-5.

14. Gatesy SM. Hind limb scaling in birds and other theropods: implications for terrestrial locomotion. J. Morphol., 1991; 209: 83–96.

15. Erickson GM, Gignac PM, Steppan SJ, Lappin AK, Vliet KA, Brueggen JD, Inouye BD, Kledzik D, Webb GJW. Insights into the ecology and evolutionary success of crocodilians reveals through bite-force and tooth-pressure experimentation. PLoS ONE, 2012; 7, 1-12.

16. Chamero B, Buscalioni AD, Marugán-Lobón J. Pectoral girdle and forelimb variation in extant Crocodylia: the coracoid-humerus pair as an evolutionay module. Biol. J. Linn. Soc., 2013; 108: 600-618.

17. Hutchinson JR, Gatesy SM. Adductors, abductors, and the evolution of archosaur locomotion. Paleobiol., 2000; 26: 734–751.

18. Hutchinson JR. Biomechanical modeling and sensitivity analysis of bipedal running ability. Extinct taxa, J. Morphol., 2004; 262: 441–460.

19. Romer AS. The development of tetrapod limb musculature – the shoulder region of Lacerta. J. Morphol., 1944; 74: 1–41.

20. Russell AP, Bauer, AM. The appendicular locomotor apparatus of Sphenodon and normal-limbed squamates. In: Gans C, Gaunt AS, Adler K. Biology of Reptilia. 2 st ed. New York: Society for the Study of Amphibians and Reptilian; 2008. 295p.

21. Diogo R, Abdala V. Aziz MA, Lonergan N, Wood BA. From fish to modern humans – comparative anatomy,

homologies and evolution of the pectoral and forelimb musculature. J. Anat., 2009; 214: 694–716.

22. Abdala V, Diogo R. Comparative anatomy, homologies and evolution of the pectoral and forelimb musculature of tetrapods with special attention to extant limbed amphibians and reptiles. J.Anat., 2010; 217: 536-573.

23. Romão MF, Santos ALQ, Lima FC. Anatomia descritiva aplicada a cinesiologia e biomecânica básica dos músculos da cintura peitoral, estilopódio e zeugopódio do jacaré do papo amarelo. Cienc. Rural, 2013; 43: 631-638.

24. Meers MB. Crocodylian forelimb musculature and its relevance to Archosauria. Anat. Rec., 2003; 274A: 891–916.

25. Dilkes DW. Appendicular myology of the hadrosaurian dinosaur Maiasaura peeblesorum from the Late Cretaceous (Campanian) of Montana. T. Roy. Soc. Edin-Earth, 2000; 90: 87–125.

26. Hudson GE, Schreiweis DO, Wang SYC. A numerical study of the wing and leg muscles of Tinamous (Tinamidae). Northwest Sci., 1972; 46: 207–255.

27. Holmes R. The osteology and musculature of the pectoral limb of small captorhinids. J. Morphol., 1977; 152: 101–140

28. Howell AB. Morphogenesis of the shoulder architecture, Part IV – Therian Mammalia. Q. Rev. Biol., 1937; 12: 440–463.

29. Straus WL. The homologies of the forearm flexors: urodeles, lizards, mammals. Am. J. Anat., 1942; 70: 281–316.

30. Howell AB. Phylogeny of the distal musculature of the pectoral appendage. J. Morphol., 1936; 60: 287–315.

31. Abdala V, Manzano AS, Herrel A. The distal forelimb musculature in aquatic and terrestrial turtles: phylogeny or environmental constraints? J.Anat., 2008; 213: 159–172.

32. Haines RW. The flexor muscles of the forearm and hand in lizards and mammals. J. Anat., 1950; 84: 13–29.