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MORPHOLOGICAL FEATURES OF THE ZONOSKELETON, STYLOPODIUM, AND ZEUGOPODIUM OF THE THORACIC AND PELVIC LIMBS IN THE MANDRILL (*MANDRILLUS SPHINX*): A CASE STUDY

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Abstract

This study aims to describe the anatomical features of the thoracic and pelvic limbs in Mandrillus sphinx. Detailed analysis has highlighted the distinctive morphological features of this species. The scapula has an accessory scapular spine that divides the infraspinous fossa into two unequal portions and a prominent acromion flanked by a small para-acromion. The lateral and superior margins are strongly developed, continuing with sharp bony prominences curved towards the neck of the scapula. The humerus has a large prominent tubercle and a small tubercle of reduced size. The deltoid surface is markedly expanded and the deltoid tuberosity is very well developed. The supinator crest, clearly evident, extends proximally from the lateral epicondyle. The radius has a prominent radial crest and the ulna has a medially oriented trochlear notch and a tuberous olecranon. The coxal bone is notable for a well-developed dorso-caudal ischium, thus forming the ischial tuberosities. The femur does not have a third trochanter, which is replaced by the gluteal tuberosity. The tibia has a prominent tibial crest, slightly bent laterally, medially to it, with an extended distal tuberosity. On the medial side of the fibula, there is a prominent crest representing the surface for the insertion of the interosseous membrane. Following the detailed description of the bone structures that make up the pelvic limb, we can classify this species as intermediate between higher and lower primates, being adapted to a mixed arboreal-terrestrial environment.

Key words*: mandrillus sphinx, thoracic limb, pelvic limb, primates.*

INTRODUCTION

Mandrills are non-human primates belonging to the *Cercopithecidae* family, genus Mandrillus, of which there are two species: Mandrillus sphinx and Mandrillus leucophaeus, known as mandrills and drills, respectively (Barrett, 2000). This species is notable for its unusual colouring and the highest grade of sexual dimorphism among all primate species, with males being up to three times larger than females (Ankel-Simons, 2007; Setchell & Dixson, 2001).

Mandrills are semi-terrestrial, being adapted both for life on the ground and for occasional climbing in trees. On the ground, they move by digitigrade quadrupedalism, walking on their toes rather than on the entire side of their feet - a type of locomotion similar to that found in domestic carnivores (Ankel-Simons, 2007; Sabater, 1972). In trees, although not as agile as arboreal primates, mandrills can climb to search for food or shelter. Due to their semi-terrestrial locomotion, their forelimbs are longer and more developed, which is reflected in the morphology of the bones (Fleagle & McGraw, 1999). Thus, the combination of these traits gives mandrills an advantage in both types of environments, contributing to the survival and behavioural diversity of the species. The detailed anatomy of the mandrill is insufficiently documented, with the literature mainly treating it in a comparative context. Given its relevance as a biomedical model and the importance of species conservation, this study aims to explore the anatomical features of the thoracic and pelvic limb bones in Mandrillus sphinx.

MATERIALS AND METHODS

The study was conducted by analysing osteological material from an adult mandrill specimen in the collection of the Anatomy Department of the Faculty of Veterinary Medicine in Bucharest.

The bones were obtained by applying standard cleaning, maceration and bleaching procedures

in order to preserve the anatomical structures. The analysis focused on a detailed description of the components of the thoracic and pelvic zygopodium, stylopodium and zeugopodium, with an emphasis on the morphological characteristics specific to the species. The most relevant morphological structures were documented photographically.

RESULTS AND DISCUSSIONS

The scapula in the mandrill is positioned laterally, has a triangular appearance and is quite robust compared to other primates (Figure 1). The lateral side of the spine is divided by the scapular spine into two fossae with a ratio of approximately 1:2. The supraspinous fossa is small, while the infraspinous fossa is remarkably developed, being segmented into two unequal portions by a small ridge called the accessory scapular spine (Figure 1).
The medial surface of the spine of the mandible has a deep subscapular fossa and several muscle insertion surfaces (Figure 2). Its lateral edge is strongly marked and continues with a sharp, curved protrusion oriented towards the neck of the spine. A similar formation can also be described at the upper edge.

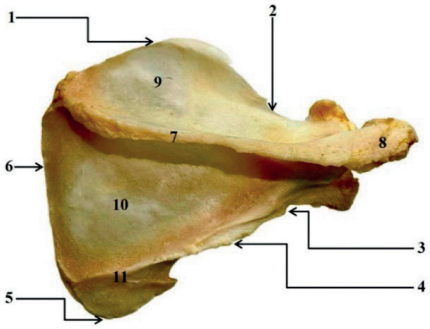

Figure 1. Mandrill right scapula – lateral view.
1. Superior angle; 2. Superior margin; 3. Lateral angle; 4. Lateral margin; 5. Inferior angle; 6. Medial margin; 7. Scapular spine; 8. Acromion; 9. Infraspinous fossa; 10. Supraspinous fossa; 11. Accessory scapular spine.

The aforementioned features are functional adaptations for supporting robust muscle insertions and are similar to those found in other primates with a mixed terrestrial and arboreal lifestyle. This feature is much more evident in the specimen examined compared to those described in various studies (Fleagle, 2002), where the spine examined shows blurred formations. The pronounced nature of this feature in the specimen examined could reflect an evolutionary adaptation to living conditions in captivity.

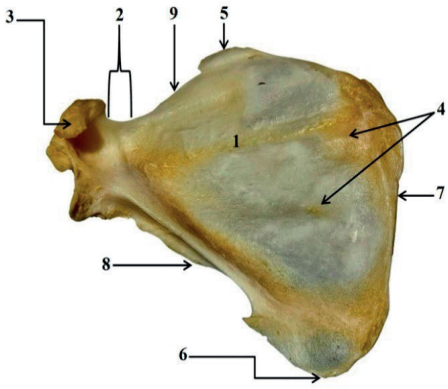

Figure 2. Mandrill right scapula – medial view.
1. Subscapular fossa; 2. Neck of the scapula; 3. Coracoid process; 4. Muscle insertion ridges. 5. Superior angle; 6. Inferior angle; 7. Medial border; 8. Lateral border; 9. Superior border.

Examining the lateral side of the scapula, the scapular spine is well developed and inclined towards the infraspinous fossa, a feature that can be found especially in arboreal primates. From its aboral end, the spine continues with a robust acromion, flanked by a small para-acromion. The glenoid cavity is oval in shape and laterally oriented, facilitating moderate arm mobility, similar to the morphology found in terrestrial primates such as baboons, members of the *Cercopithecidae* family (Casteleyn et al., 2023) (Figure 3). The coracoid process is prominent, providing additional stability to the scapulohumeral joint and serving as an insertion point for the coracobrachialis muscle.
The humerus, characterised by a robust morphology, has a large tubercle at the proximal end, which aligns with the humeral head, while the small tubercle does not project beyond it (Figure 4).
However, the most striking feature of the humerus in the mandrill is an extensive deltoid surface on its cranio-lateral side and a well-developed deltoid tuberosity, thus providing a strong insertion for the deltoid muscle.
At the distal end, the humerus is notable for a narrow and deep olecranon fossa, resulting from the need for a stable joint necessary for locomotion on the ground.

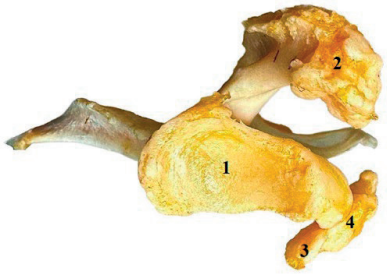

Figure 3. Mandrill right scapula - glenoid angle.
1. Glenoid cavity; 2. Para-acromion; 3. Coracoid process; 4. Supraglenoid tuberosity

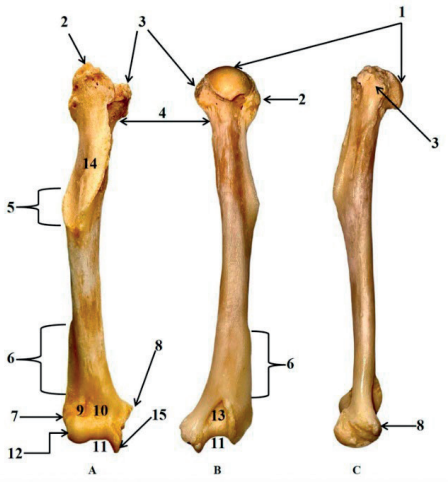

Figure 4. Mandrill right humerus
A. Cranial view; B. Caudal view; C. Medial view
1. Humeral head; 2. Greater tubercle; 3. Lesser tubercle; 4. Neck of the humerus; 5. Deltoid tuberosity; 6. Supinator crest; 7. Lateral epicondyle; 8. Medial epicondyle; 9. Radial fossa; 10. Coronoid fossa; 11. Humeral trochlea; 12. Head of humerus; 13. Olecranon fossa; 14. Deltoid surface; 15. Medial lip of trochlea.

A representative feature is the very prominent supinator crest, which extends proximally from the lateral epicondyle, thus favouring an extended insertion surface for the extensor and supinator muscles. The medial lip of the trochlea in the mandrill is more prominent than in other species, probably reflecting a different evolutionary direction that may reflect behavioural differences from other baboons.
A distinctive feature is the markedly developed supinator crest, which extends proximally from the lateral epicondyle, thus favouring an extended insertion surface for the extensor and supinator muscles. The medial lip of the trochlea in the mandrill is more prominent than in other species, probably representing a different evolutionary direction, which may reflect behavioural differences from other papionines.
In primates, including terrestrial ones, the radius and ulna remain separate, thus allowing a high degree of mobility. This aspect is, of course, also present in the mandrill (Figure 5). The appearance of the radius in the mandrill, at the proximal end, has a single articular surface represented by the head of the radius, followed by a well-defined neck under which a robust radial tuberosity can be observed (Figure 6).

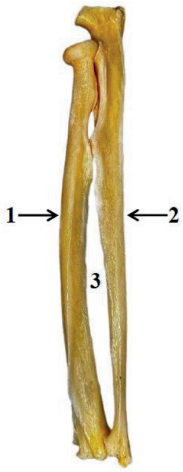

Figure 5. Mandrill radius and ulna
1. Radius; 2. Ulna; 3. Interosseous space

The body of the radius is characterised by a prismatic, elongated appearance, which narrows slightly towards its distal end.
At the distal proximity, the radial crest can be identified, well differentiated and slightly curved towards the ulnar notch.
The ulna also has a prismatic body, which narrows significantly towards the distal end, presenting three faces and three edges (Figure 7). The cranial face has a rough appearance at the proximal end, which serves as the articulating surface with the radius, while the lateral and medial faces are characterised by a smooth appearance.
At the distal proximity, the articular surface with the radius has a cylindrical formation.
Regarding the particularities observed at the proximal end of the ulna in the mandrill, the trochlear notch is medially oriented, while theolecranon has a distinct tuberous appearance (Figure 8).

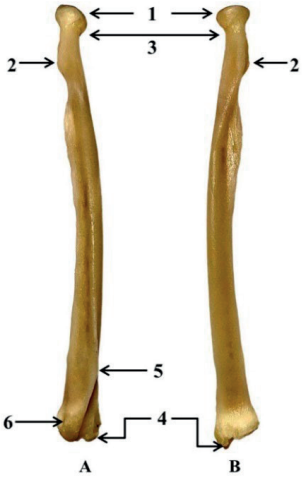

Figure 6. Mandrill radius
A. Medial view; B. Cranial view
1. Head of the radius; 2. Radial tuberosity; 3. Neck of the radius; 4. Styloid process of the radius; 5. Radial crest; 6. Ulnar notch.

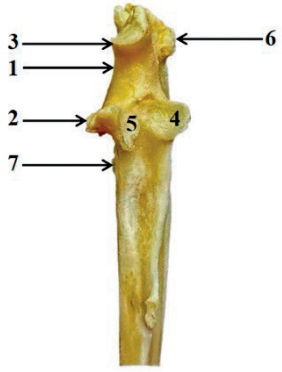

Figure 8. Mandrill ulna - proximal extremity
1. Greater semilunar notch; 2. Radial notch; 3. Olecranon process; 4. Lateral coronoid process; 5. Medial coronoid process; 6. Olecranon tuberosity; 7. Ulnar tuberosit

The pelvic zonoskeleton, also called the pelvic girdle, represented by the pelvis, is a unique anatomical structure, composed on each side of three fused bones that form the *os coxae*, a bone that connects the pelvic limb to the spine (Figure 9).

The ilium is located at the upper end of the *os coxae*, continuing its body with the wing of the ilium or ilium blade, thus representing the largest portion of the coxal bone.

On the lateral face of the ilium, there is a deeply excavated surface called the iliac fossa, which has a simple *os coxae* tubercle at its angles and two well-differentiated spines at the sacral angle, represented by the dorso-cranial iliac spine and the dorso-ventral iliac spine, respectively.

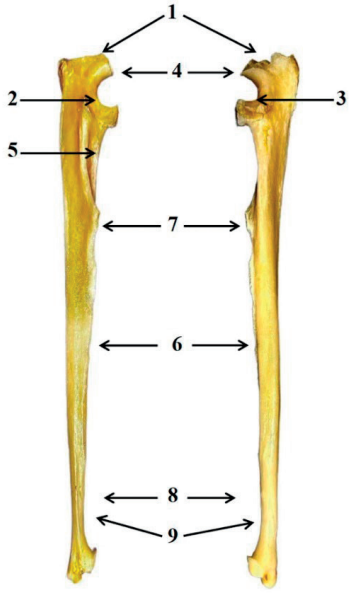

Figure 7. Mandrill ulna
A. Lateral view; B. Medial view
1. Olecranon with olecranon tuberosity; 2. Lateral coronoid process; 3. Medial coronoid process; 4. Trochlear notch with anconeal process; 5. Supinator crest; 6. Body of the ulna; 7. Articular surface for the radius; 8. Styloid process of the ulna; 9. Articular surface for the radius

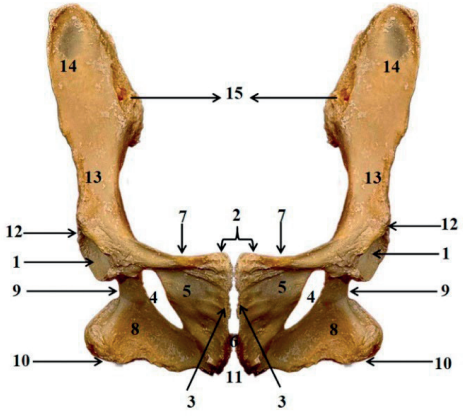

Figure 9. Mandrill pelvis - ventral view
1. Acetabulum; 2. Pubic tubercle; 3. Pubic crest; 4. Obturator foramen; 5. Caudal surface of the pubis; 6. Ischial symphysis; 7. Ilio-pubic eminence; 8. Flat surface of the ischium; 9. Branch of the ischium; 10. Ischial tuberosity; 11. Ischial arch; 12. Ischial spine; 13. Ilium; 14. Wing of the ilium; 15. Sacro-pelvic face (for articulation with the sacrum).

At the caudal edge, the ilium is characterised by a long and slightly deep notch (which continues with the ischium) called the greater sciatic

notch, while on the medial face there is an obvious articular surface for the wing of the sacrum called the sacro-pelvic face.
The greater and lesser ischial notches are wide and shallow.
The acetabular surface is located on the lateral side and has a semilunar articular surface known as the lunate surface, which is interrupted by the acetabular notch.

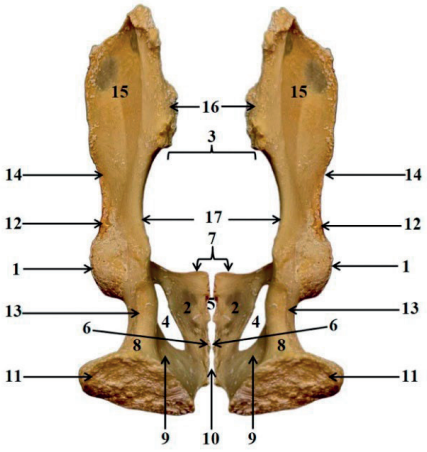

Figure 10. Mandrill pelvis - dorsal view
1. Acetabulum; 2. Pubis; 3. Pelvic cavity; 4. Obturator foramen; 5. Pubic symphysis; 6. Pubic crest; 7. Ilio-pubic eminence; 8. Ischium; 9. Branch of the ischium; 10. Ischial symphysis; 11. Ischial tuberosity; 12. Ischial spine; 13. Small ischial notch; 14. Ischium; 15. Wing of the ilium; 16. Sacro-pelvic face (for articulation with the sacrum); 17. Great ischial notch

A characteristic feature of the coxal bone in mandrills, also found in other Old-World monkeys, is that the ischium is very well developed dorso-caudally. This helps to form flat surfaces called ischial tuberosities. These structures are hairless and covered with horny tissue, allowing the animal to sit for long periods without discomfort (Ankel-Simons, 2007) (Figure 10).
The pubis is oriented ventro-cranially from the acetabular cavity and is the last structure contributing to the formation of the obturator foramen. Regarding the locomotor adaptation of the pelvis in mandrills, the study conducted by Ward et al. (2018) demonstrates that monkeys in the *Cercopithecidae* family have a greater ventral width of the pelvis than other monkeys, thus being adapted for rapid terrestrial locomotion.
Analysing the acetabulum in the mandrill, it can be observed that it is characterised by a robust and deep shape, adapted to support body weight during terrestrial locomotion (Figure 11).

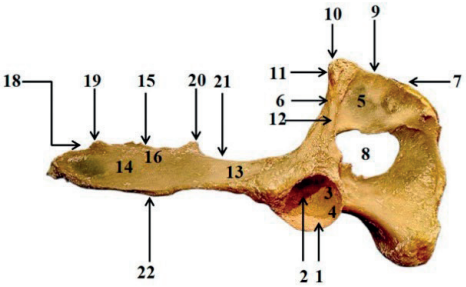

Figure 11. Mandrill os coxae - lateral view
1. Acetabulum; 2. Acetabular fossa; 3. Lunate face; 4. Acetabular notch; 5. Pubic body; 6. Cranial branch of the pubis; 7. Caudal branch of the pubis; 8. Obturator foramen; 9. Pubic symphysis; 10. Pubic tubercle; 11. Ilio-pubic eminence; 12. Pubic crest; 13. Iliac body; 14. Iliac wing; 15. Sacropelvic face; 16. Gluteal face; 17. Iliac crest; 18. Sacral tubercle (dorsal iliac spine); 19. Dorso-cranial iliac spine; 20. Dorso-caudal iliac spine; 21. Greater sciatic notch; 22. *Os coxae* tubercle (ventral iliac spine).

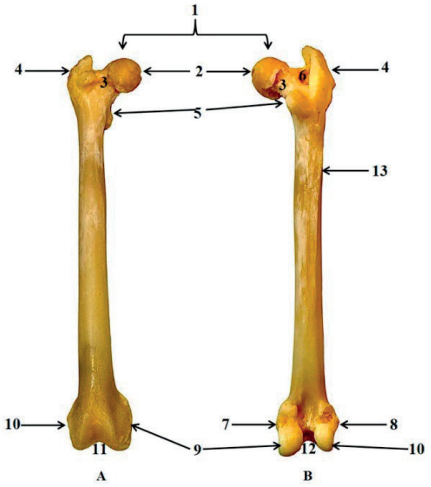

Figure 12. Mandrill femur
A. Cranial view; B. Caudal view
1. Femoral head; 2. Fovea of the femoral head; 3. Femoral neck; 4. Greater trochanter; 5. Lesser trochanter; 6. Trochanteric fossa; 7. Lateral epicondyle; 8. Medial epicondyle; 9. Lateral condyle; 10. Medial condyle; 11. Femoral trochlea; 12. Intercondylar fossa; 13. Trochanteric crest

The ilium in the mandrill is elongated and narrow and has a prismatic-looking neck, similar to some prosimians (Ankel-Simons, 2007).
The gluteal surface is oriented dorsol-aterally, the iliac surface ventromedially, and the sacral surface medially.
The femur of the mandrill is characterised by a moderately sized femoral head, due to its quadrupedal locomotion (Figure 12). Studies also state that "In quadrupedal primates, the

diameters of the humeral head and femoral head are approximately equal" (Ankel-Simons, 2007), an aspect that is also confirmed in the skeleton of the specimen examined.

Another significant study by Janis and Martín-Serra (2020) shows that arboreal primates that jump vertically or laterally tend to have a semi-cylindrical femoral head, while terrestrial or semi-terrestrial primates, such as the mandrill, have an oval femoral head, adapted to walking on the ground and occasional climbing.

Although Sabater (1972) also described lateral jumps in mandrills, these behaviours do not appear to be frequent enough to leave a significant morphological imprint on the femur.

In the mandrill, the third trochanter is not sufficiently developed, being replaced by a protuberance called the gluteal tuberosity, which continues with the rough line, an essential insertion surface for muscles such as the gluteus medius and biceps femoris.

The greater trochanter of the mandrill is well developed, indicating adaptations characteristic of its semi-terrestrial lifestyle.

The body of the femur in this species is straight and longer than the body of the humerus, and on the lateral side, below the greater trochanter, there is a rough surface represented by the gluteal tuberosity.

The distal end of the femur has numerous articular surfaces. At the cranial end, the articular surface is represented by the femoral trochlea. Caudally, two condyles can be observed, lateral and medial, separated by a deep intercondylar fossa.

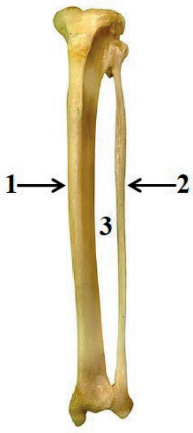

Figure 13. Mandrill tibia and fibula
1. Tibia; 2. Fibula; 3. Interosseous space.

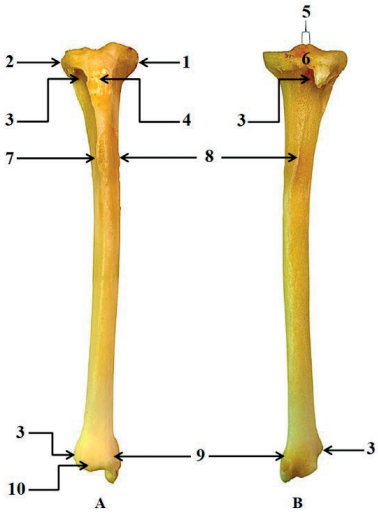

Figure 14. Mandrill tibia.
A. Cranial view; B. Caudal view
1. Medial condyle; 2. Lateral condyle; 3. Articular surface with fibula; 4. Tibial tuberosity; 5. Intercondylar eminence; 6. Lateral and medial intercondylar tubercles. 7. Tibial crest; 8. Muscle insertion surface; 9. Medial tibial malleolus; 10. Tibial cochlea.

The condyles are flanked on the lateral and medial sides of the
femur by two epicondyles, lateral and medial, respectively.

Following analysis of the size of the condyles in this specimen, it was concluded that they are approximately equal.

The pelvic zeugopodium is represented by the tibia and fibula, two bones that are joined at both ends, thus forming an interosseous space similar to that of the radius and ulna (Figure 13).

In terms of size, the tibia is much more developed than the fibula, and in terms of length, Ankel-Simons (2007) described that, in the case of *Cercopithecidae*, the fibula is generally shorter than the tibia, which can also be confirmed in the case of this mandrill studied.

The tibia has a body that initially, starting from the proximal end, is characterised by a prismatic and robust appearance, which then takes on a cylindrical shape and becomes thinner towards its distal end (Figure 14).

At the cranial margin, there is a clearly visible tibial crest that slopes slightly laterally, and on its medial side there is a tuberosity that extends distally, representing a muscle insertion surface.

The proximal end of the tibia has two condylar surfaces, positioned medially and laterally, separated by an intercondylar eminence, also

called the tibial spine. This is also formed by two tubercles separated by a relatively small notch. The anterior and posterior intercondylar areas are represented by the two rough ligament insertion surfaces located anteriorly and posteriorly to the tibial spine.

On the lateral side of the proximal end of the tibia, the articular surface for the proximal end of the fibula can be seen.

As for the distal end of the tibia, the articular surfaces represented by the tibial cochlea, which serves as the articular surface with the trochlea of the talus, can be seen, and on the lateral side, the articular surface with the fibula is highlighted.

From the distal perspective, the tibia has a triangular appearance and a tibial malleolus can be observed, which has articular surfaces for the talus on its plane, and posterior to it, a tendon slide is evident.

The fibula in the mandrill has a broad body that becomes slightly more robust at its distal end, a proximal end where numerous articular surfaces

with the tibia are evident, and a distal end that also articulates with the tibia (Figure 15).

On the medial surface, there is a prominent crest that represents the surface for the insertion of the interosseous membrane. Both ends of the fibula in the mandrill have a triangular appearance (Figure 16).

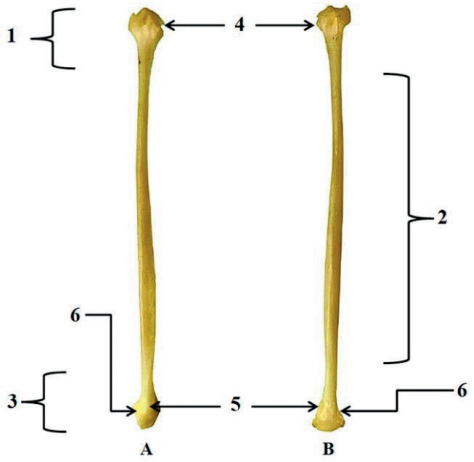

Figure 15. Mandrill fibula
A. Lateral view; B. Medial view
1. Proximal epiphysis; 2. Diaphysis; 3. Distal epiphysis; 4. Head of the fibula (articular surface with the tibia); 5. Lateral malleolus of the fibula; 6. Articular surface with the tibia.

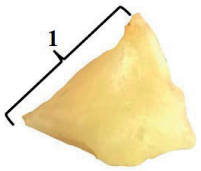

Figure 16. Mandrill fibula - proximal end
1. Articular surface with the tibia

CONCLUSIONS

The particularities of the thoracic and pelvic limbs support the hypothesis that the skeleton of the thoracic and pelvic limbs in the mandrill is the result of a complex evolutionary adaptation, in which locomotion, social behaviour and the living environment played decisive roles.

The mandrill is notable for its bone structure, which perfectly reflects its adaptation to a mixed arboreal and terrestrial lifestyle.

The features described are essential in the context of comparative anatomy, for understanding their ecology, as well as for supporting the differentiation of bone fragments discovered in various contexts.

ACKNOWLEDGEMENTS

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