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MORPHOLOGICAL PARTICULARITIES OF THE *Lama glama* SKULL

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Abstract

This study is crucial as it aims to analyze and describe the morphological characteristics of the llama's skull bones. The research provides a series of characteristics crucial for recognizing and differentiating the Lama glama, a domesticated South American camelid. These findings can be applied to identify and study this species accurately. The growth of this species in Europe has gained momentum in recent years. Two skulls, male and female, were selected from the Anatomy discipline collection for this study. The following conclusions emerge from our detailed anatomical descriptions: males' external sagittal and nuchal crests are more developed, and the supraorbital foramen continues rostrally with a reduced groove. Between the frontal, nasal, lacrimal and maxillar bones is a fronto-naso-lacrimo-maxillary foramen. Two foramina open in the orbital hiatus: the optic foramen and the orbitorotundum foramen. Accessory palatine foramina are located caudal to the greater palatine foramen. On the upper arch, at the level of the diastema, in both males and females, there are one or two dental alveoli for the rudimentary first premolar.

Key words: *camelids, Lama glama, morphology, skull.*

INTRODUCTION

The llama (*Lama glama*) is a species in the Order Artiodactyla, suborder Tylopoda, family Camelidae. Several taxonomic studies identified four species: *Lama guanicoe* (Guanaco), *Lama pacos* (Alpaca), *Lama glama* (Llama) and *Vicugna pacos* (Vicuña) (Cabrera & Yepes, 1960), although in other studies, all four species are included in the Lama genre. Studies were carried out on morphological characteristics and behavioural variations but also based on archaeological evidence, which showed that the llama descended from guanaco and the alpaca from the vicuña (Hershkovitz, 1948).

Phylogenomic analysis shows that the llama was domesticated from the guanaco and the alpaca from the vicuña (Fan et al., 2020).

Other genetic studies show a gene flow between llamas and alpaca and genetic crosses between llamas and guanacos (Varas et al., 2020).

Traditionally, morphometric techniques have been used to identify Camelidae species (L'Heureux & Hernández, 2019). However, these methods have proven less effective in differentiating the llama and other species of Camelidae from South America, especially when the differentiation faced the guanaco.

There are studies carried out on camelid`s skulls (Balcarcel et al., 2021; Cartajena, 2009, G.L.; Castañeda et al., 2016; Choudhary et al., 2021; El Allali et al., 2017; Moyano et al., 2022) that provide a detailed description of the skull bones and also of the dentition (Wheeler, 1995).

A clear distinction between the different species of Llama has not yet been made; those species are at the beginning of their domesticated stages, so the differences between their skulls and the skulls of their wild relatives are subtle (Balcarcel et al., 2021).

Morphological studies were carried out on the bones of the thoracic limb in Camelid species (Rosu et al., 2017; Belu et al., 2022; L'Heureux & Hernández, 2019) or on the pelvic limb, including the metatarsophalangeal joint and the digital flexor muscles of the pelvic limb (Constantinescu et al., 2008; Lesbre, 1903). Osteometry studies were also conducted on South American camelids (Izeta, 2010).

This study thoroughly investigated the *Lama glama* skull morphology to generate valuable

characteristics with application in species recognition and differentiation within the South American camelids group.

MATERIALS AND METHODS

The study was conducted in the Anatomy laboratory of the Faculty of Veterinary Medicine in Bucharest. Two skulls, one from an adult female *Lama glama* and one from an adult male of the same species, were used as study material. These skulls belong to the Anatomy Discipline Collection. The morphological aspects of the skull bones were described, and the most exciting aspects were photographed. The description was made according to Nomina Anatomica Veterinaria 2017.

RESULTS AND DISCUSSIONS

The skull of *Lama glama* presents specific morphological particularities, with the maximum width at the orbit level.
High nuchal ridges on the dorsal face, with an caudo-ventral disposition, form by joining a very high external occipital protuberance, drawn caudo-ventrally (Figure 1).

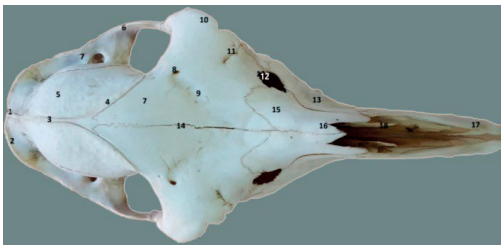

Figure 1. Llama skull (*Lama glama*) - dorsal view (original):
1. External occipital protuberance; 2. Nuchal crest; 3. External sagittal ridge; 4. Temporal line; 5. Parietal; 6. The zygomatic process of the temporal; 7. Retroarticular foramen; 8. The supraorbital foramen; 9. Supraorbital groove; 10. Zygomatic process of the frontal; 11. Supraorbital fissure; 12. Fronto-naso-lacrimo-maxillary foramen; 13. Maxilla; 14. Interfrontal suture; 15. Nasal; 16. Internasal notch; 17. Incisive; 18. Conchal crest

The external sagittal crest is arranged dorso-rostral starting from the external occipital protuberance and is better highlighted in males than females. Rostrally, it is divided into two temporal lines and is well highlighted in the male (Figure 1).
The parietal, elongated rostro-caudal, has a convex surface from one side to the other.
In the rostral extremity of the frontal bone, a subtle depression is observed. The base of the zygomatic processes is perforated by the supraorbital foramen, from which a reduced groove starts rostrally, reaching the frontonasal suture. Before the orbit, slightly dorsolaterally, there is a fronto-naso-lacrimo-maxillary foramen, also present in other wild species (deer, Bactrian camel, dromedary). The nasal bone, end bifid, is short, and an internasal notch is present (Figure 1).
There is a frontal fissure above the orbit, rostrally, slightly oblique medio-laterally.
A complete orbit, an elongated and narrow zygomatic process of the temporal, characterizes the lateral side. The zygomatic bone is divided in the caudal part into two temporal processes, one dorsal and the other ventral. The supraorbital margin has a small incision, which is more evident in the male (Figure 2).

Figure 2. Llama skull (*Lama glama*) - side view (original): 1. Incisive; 2. Nasal; 3. Canine fossa; 4. Maxilla; 5. Infraorbital foramen; 6. Maxillofacial tubercle; 7. Lacrimal; 8. Frontal; 9. Zygomatic; 10. Zygomatic process of the frontal; 11. Lacrimal tubercle; 12. Infratrochlear notch; 13. The zygomatic process of the temporal; 14. Orbital fossa; 15. Temporal fossa; 16. Orbito-temporal crest; 17. Ethmoid fossa; 18. Orbital foramen; 19. External acoustic meatus; 20. Hamulus of the pterygoid; 21. Paracondylar process; 22. Tympanic bulla; 23. Mastoid process; 24. Nuchal crest

At the level of the orbital hiatus, there are two openings: the optic foramen and the orbitorotundum foramen. The ethmoidal fossa is deep and relatively circular, and dorsal to it is the ethmoidal foramen. From the base of the zygomatic process of the frontal, a reduced orbito-temporal crest descends on the orbito-temporal face (Figure 2).

The well-marked mastoid process is on the temporal bone pyramid's lateral face. The external acoustic meatus is reduced and circular, and the obvious tympanic bulla is elongated and flattened in the rostro-caudal direction (Figure 3).
The lacrimal bone has an obvious lacrimal foramen on the orbital face, an apparent infratrochlear notch, and an evident lacrimal tubercle on the lacrimal ridge.
On the external face of the maxilla, there is a facial tubercle, better highlighted in the male. Rostrally, the maxilla shows a small canine fossa, and ventral to it is the infraorbital foramen. An obvious maxillary tuberosity is observed in the caudal extremity of the maxilla.

Figure 3. Llama skull (*Lama glama*) - lateral-ventral view (original):
1. Lacrimal gland fossa; 2. Zygomatic; 3. Fossa of the lacrimal sac; 4. Optical foramen; 5. Orbitorotundum foramen; 6. Tympanic bulla; 7. Oval foramen; 8. Spinous foramen; 9. Paracondylar process; 10. Mastoid process of the temporal bone

The pterygopalatine fossa is very elongated dorso-ventrally, and two foramina open at its level: latero-dorsal, the sphenopalatine foramen and latero-ventrally the caudal palatine foramen.
The orbit communicates with the nasal cavity through the incomplete suture between the orbital part of the lacrimal bone and the orbital part of the frontal bone, named frontolacrimal foramen. Under this incomplete suture opens the maxillary foramen (Figure 4).
Two to three evident retroarticular foramina are at the base of the temporal zygomatic process (Figure 4).
On the ventral side, a small muscular process is located at the base of the temporal bone. Ventro-medial to the mastoid process is the stylomastoid foramen. The stylomastoid fossa is very deep.
A deep and elongated ventral condyloid fossa is evident between the occipital condyle and the jugular process. Ventral to the condylar fossa is the hypoglossal canal. Lateral to the basioccipital, in a rostral direction, are three openings: the jugular foramen, the tympano-occipital fissure and the carotid foramen. Rostral to the tympanic bulla are two foramina: the spinous and oval foramen, separated by a small bony blade (Figure 5).

Figure 4. Llama skull (*Lama glama*) – side view (original):
1. Parietal; 2. Occipital; 3. Nuchal crest; 4. Temporal; 5-6. Retroarticular foramina; 7. External acoustic canal; 8. Paracondylar process; 9. Mastoid process; 10. The zygomatic process of the temporal; 11. Ethmoidal foramen; 12. Sphenopalatine foramen; 13. Frontolacrimal foramen; 14. Zygomatic process of the frontal; 15. Zygomatic

The basioccipital has the greatest width in the central portion. At the place of articulation with the basisphenoid, the two muscular tubercles (sphenobasioccipital) are well highlighted, especially in males (Figure 5).
The orbital hiatus crest is evident (Figure 3).
The pterygoid is reduced but shows, caudally, a very prominent hamulus (Figure 4).
The pterygoid fossa is delimited caudo-medially by the hamulus of the pterygoid bone and latero-medially by the pterygoid process of the sphenoid (Figure 3).
The palatine processes of the maxilla are narrower in the central portion and wider in the rostral extremity (Figure 6). The greater palatine foramen continues rostrally with a short palatine groove. On the hard palate, there are two-tree accessory palatine foramina (Figure 5).

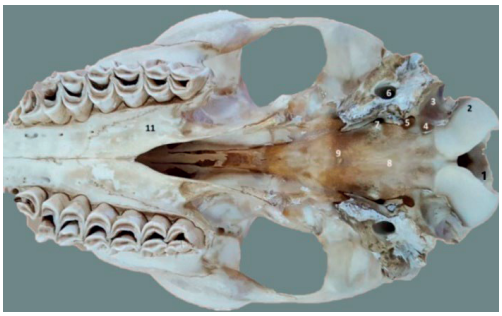

Figure 5. Llama skull (*Lama glama*) - ventral view (original):
1. Foramen magnum; 2. Occipital condyle; 3. Ventral condyloid fossa; 4. Hypoglossal canal; 5. Jugular foramen; 6. Stylomastoid fossa; 7. Carotid foramen; 8. Basioccipital; 9. Muscular tubercles; 11. Horizontal plate of the palatine

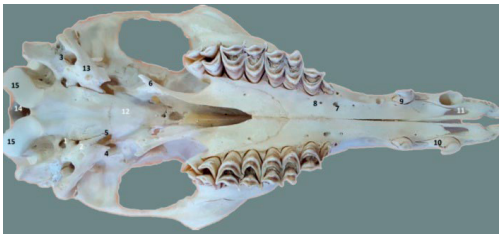

Figure 6. Lama skull (*Lama glama*) - ventral view (original):
1. Jugular foramen; 2. Carotid foramen; 3. Stylomastoid fossa; 4. Oval foramen; 5. Spinous foramen; 6. Hamulus of the pterygoid; 7. Greater palatine foramen; 8. Accessory palatine foramina; 9. Canine; 10. Incisive; 11. Palatine fissure; 12. Basisphenoid; 13. Tympanic bulla; 14. Foramen magnum; 15. Occipital condyles

The diastema on the upper arch is interrupted by the alveolus for the first premolar, both in the male and female. The palatine fissures are oval in shape and very well-defined (Figure 6).
The nuchal face presents a prominent external occipital crest, slightly more developed in the male, which descends dorso-ventrally from the external occipital protuberance to the foramen magnum, dividing this face into two symmetrical parts (Figure 7).
A dorsal condylar fossa is on either side of the external occipital crest, above the occipital condyles. At the base of the jugular process is the mastoid foramen (Figure 7).
The two halves of the mandible are articulated at the body's level by synchondrosis.
The body of the mandible is flattened dorso-ventrally; the diastema is long and presents rostrally the dental alveolus for the canine (Figure 8).
The ventral edge is convex-concave. The dorsal margin presents the alveoli for premolars and molars.

Figure 7. Llama skull (*Lama glama*) - nuchal view (original):
1. External sagittal crest; 2. External occipital protuberance; 3. Nuchal crest; 4. External occipital crest; 5. Dorsal condylar fossa; 6. Mastoid foramen; 7. Foramen magnum; 8. Paracondylar process; 9. Occipital condyles; 10. External acoustic meatus

The mental foramen opens on the lateral surface of the mandibular body, and caudally to it open the two accessory mental foramina. (Figure 8)

Figure 8. Lama mandible (*Lama glama*) - side view (original):
1. Mental foramen; 2. Accessory mental foramina; 3. Masseteric fossa; 4. Angular process; 5. Condylar process; 6. Coronoid process; 7. Mandibular notch

On the lateral face, the mandibular ramus has a concave-convex from top to bottom masseteric fossa, which is more pronounced in males. On the medial side, the pterygoid fossa is superficial and presents the mandibular foramen in the rostro-dorsal plane.
Caudo-ventrally, the branch shows an obvious angular process, much more robust in males than females. The hook-like process is slightly curved medially.
The coronoid process is highly developed, with a relatively constant width along its entire length. The process has a rounded edge and is curved slightly caudally. The condylar process is short, with a convex surface. The mandibular notch is wide (Figure 8).

CONCLUSIONS

The following conclusions emerge from our detailed anatomical descriptions. The external sagittal crest and nuchal ridges are more developed in the male. The external occipital protuberance is high and drawn caudo-ventrally. The supraorbital foramen continues rostrally with a reduced groove. At the level of the suture between the frontal, nasal, lacrimal and maxilla, there is a fronto-naso-lacrimo-maxillary foramen.
Two-tree retroarticular foramina are located at the base of the zygomatic process of the temporal. There are two openings in the orbital hiatus: the optic foramen and the orbitorotundum foramen.
The mastoid process is highly developed, the external acoustic meatus is reduced, and the tympanic bulla is obvious, elongated and flattened rostro-caudal.
In the pterygopalatine fossa, are two openings: latero-dorsal, the sphenopalatine foramen and latero-ventral, the caudal palatine foramen.
The orbit communicates with the nasal cavity through the frontolacrimal foramen. Ventral to this, the maxillary foramen opens**.**
The spinous foramen and the *foramen ovale* are separated by a small bone blade.
The sphenobasioccipital tubercles are evident, especially in the males.
The external occipital crest is more prominent in the male. Above the occipital condyles, there is a dorsal condylar fossa on either side.
The mandible is characterized by a prominent, robust, hook-like angular process, slightly curved medially. The mandible presents more than one mental foramen. The masseteric fossa is concave-convex from top to bottom, the concavity being more pronounced in males.
On the upper arch, at the level of the diastema, in both males and females, there are one or two dental alveoli for the rudimentary first premolar.

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