The Suspensory Apparatus and Digital Flexor Muscles of the Llama (*Lama glama*) 1. The Thoracic Limb

El Aparato Suspensorio y los Músculos Flexores Digitales de la Llama (*Lama glama*) 1. El Miembro Torácico

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SUMMARY: The digital flexor muscles of the thoracic limb of four llamas were dissected and illustrated to provide data about the suspensory (support) apparatus and weight bearing structures. An extensive literature search was performed and yielded incomplete information about these anatomical structures. The popularity of the llama world wide as a domesticated animal used for show and fiber has increased in the recent years. It is helpful to describe the anatomy fully to aid in understanding of the species and treatment of pathologic conditions. The description of the anatomical structures and the original illustrations demonstrate genuine peculiarities and differences between the llama and domestic ruminants. In llamas, the three heads of the deep digital flexor muscle (DDF) originate and connect with each other in a very peculiar combination, with one tendon receiving an attachment from the flexor carpi ulnaris muscle (FCU). The superficial digital flexor muscle (SDF) has a thin tendon which is fused with the palmar fascia and then broadens. There are no interflexor muscles. Additionally, unexpected lumbricalis muscles are found in the distal limb and vary in number between the fore and hind limb. The anatomy of the suspensory apparatus in the thoracic limb is evaluated in this paper.

KEY WORDS: Digital flexor muscles; Suspensory/stay apparatus; Thoracic limb; *Lama glama*.

INTRODUCTION

A literature search was performed and failed to reveal accurate, complete information regarding the digital flexor muscles of the llama. Search engines used included PubMed, CAB, Web of Science, Wildlife Worldwide, and Zoological Record. Multiple librarians were contacted at various veterinary teaching colleges in an attempt to find local references. Lesbre published an early description of the flexor muscles in 1903. Colas (1969) described briefly the muscles of the thoracic limb. References located also included a superficial dissection in the Clayton & Flood (1996) and an incompletely illustration by McCracken *et al.* (1999). However, no complete dissection and description of the digital flexor muscles of the llama exist.

Pathologic conditions of the distal limb and suspensory apparatus such as metacarpophalangeal hyperextension of the llama are debilitating (Reed *et al.*, 2007). The existence of these conditions and the financial implications of loss of use in working animals necessitate a description of the normal

anatomy in order to more completely understand the disease process in affected animals.

The complete description of the components of the suspensory apparatus of the thoracic limb will conclude this paper. Comments on the suspensory apparatus of the pelvic limb and the homology of several anatomical structures for both limbs will be addressed in a separate paper (The suspensory apparatus and the digital flexor muscles in the llama (*Lama glama*) 2. The pelvic limb.)

An explanation of the term “suspensory” versus “stay” apparatus is needed. A true “stay apparatus” is found in the horse only. This species is capable to standing the entire life without laying down. In the other species, some structures similar to those of the horse play the role of “suspension” or “support” of the body weight by the joints of the limbs. Therefore, the term “suspensory” seems to be accurate for the llamas.

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MATERIAL AND METHOD

Two llamas belonging to individual breeders were donated to the College of Veterinary Medicine in Corvallis for research. The animals were euthanized by overdose of barbituates and the four thoracic limbs were shipped frozen from Corvallis, OR to Columbia, MO. Four thoracic limbs were used fresh from two adult llamas from the Necropsy room of the College of Veterinary Medicine in Columbia, Missouri. The animals belonged to individual breeders. One llama was euthanized because of an incurable skin condition. The cause of death of the second llama was a gunshot wound to the stomach. A total of eight limbs were obtained.

The only method used in this project was the dissection with scalpel, forceps and scissors. The anatomical terminology is used in accordance to the last edition (5th) of the *Nomina Anatomica Veterinaria*, 2005, an electronic version on the web site.

RESULTS

The flexor carpi ulnaris muscle (FCU) originates from the medial epicondyle of the humerus, intermingling its fibers partially with the superficial digital flexor (SDF) and the superficial portion of the humeral head of the deep digital flexor (DDF). It sends a thin fascicle joining the tendon of the deep portion of the humeral head of the DDF (Fig. 1). The SDF originates from the base of the medial epicondyle, deep to the origin of the FCU, and cranial to the origin of the humeral head of the DDF, opposite to the origins of these muscles in the domestic ruminants. The SDF tendon passes between the multiple tendons of the DDF and runs within the carpal canal (Fig. 1). It then fuses with the palmar fascia distal to the carpus (Fig. 2); the palmar fascia, much wider and stronger than the tendon (but including it) splits proximal to the fetlock joints (FJ) into the two characteristic (for all ruminants) symmetrical tendons of the SDF (Fig. 3). Within the carpal canal, the tendon of the SDF glides alone in the

Fig. 1. Medial aspect of flexor digital muscles in the forearm – left thoracic limb.

superficial compartment, whereas the tendon of the DDF glides in the deep compartment of the carpal canal. The two tendons are accompanied by their own tendon sheaths. In the metacarpal region, a strong palmar fascia protects the palmar structures, fusing on the lateral aspect with the origin of the interosseous muscles III & IV (IM) (called improperly, and referred to on occasion as the suspensory ligament). Distal to this point the fascia is fused with the tendon of the SDF (Fig. 2). The SDF tendon of each digit surrounds the corresponding tendon of the DDF at the level of the FJ in the form of the manica flexoria (Fig. 3). The two tendons are together bound by the palmar annular ligament and the proximal digital annular ligament as they glide over the proximal scutum. In the middle of the second phalanx, the SDF tendon is split to allow the DDF tendon to pass and become a superficial structure. Transecting the DDF tendon at this point and reflecting the stumps, the tendon of the SDF appears split. Before attaching to the second phalanx by means of the middle scutum, the two portions are reunited in a single tendon plate (Fig.3). Proximal to the FJ and to the insertion of the SDF, both SDF and DDF tendons are protected by a common tendon sheath.

The DDF has three heads: humeral, radial and ulnar (Fig. 1). The humeral head originates from the medial epicondyle and shortly separates into a superficial and a deep portion, with two distinct tendons which fuse with a thin strap originating at the FCU. The radial head attaches firmly to the entire medial border and caudal aspect of the radius, enveloped by a tough septum of the antebrachial fascia. At the proximal origin, it fuses with the remnant of the pronator teres muscle, which is attached to the medial collateral ligament of the elbow joint. The distal tendon of the biceps brachii muscle passes under the ligament and the pronator teres muscle (Fig. 1). The ulnar head originates from the middle third of the ulna, as Lesbre has found in 1903. Within the carpal canal, this tendon surrounds the unique tendon of the humeral head of the DDF (including the attachment from the FCU) and fuses with the radial and humeral heads of the DDF. From this point, there is only one tendon of the DDF running distally. There are no interflexor muscles in llamas, though they are common to the domestic ruminants.

The DDF tendon splits at the proximal aspect of the fetlock joints and runs toward the palmar aspect of the FJ,

Fig. 2. The tendons of the palmar metacarpal region - left thoracic limb.

Fig. 3. Palmar and digital aspect of SDF & DDF tendons - left thoracic limb.

Fig. 4. The terminal tendons of the SDF and DDF.

between the corresponding tendon of the SDF and the interosseous muscles (IM). At the proximal end of splitting tendon, one or two (varying by individual animal) lumbricalis manus muscles are seen, which are absent in the domestic ruminants. Spindle shaped, each muscle continues with a very long and thin tendon that passes through the interdigital space close to the axial side(s) of the 3rd/4th digits and finally fuse(s) with the lateral/medial branches of the lateral tendon of the common digital extensor muscle of the 3rd/4th digit at the middle of the second phalanx (Figs. 2 and 3). After becoming superficial, the tendon of the DDF glides over the middle scutum, and passes toward the third phalanx, bound

by the distal digital annular ligament (Fig. 4). Over the middle scutum, the DDF tendon is provided with a strong cartilaginous plate, reinforcing the tendon in this critical point of overextended interphalangeal joint (Fig. 4). Passing over the palmar aspect of the second phalanx, fibers from the tendon join the phalanx under the name of vinculum, allowing blood vessels to run (Fig. 4). As it courses distally, the DDF tendon exchanges tendinous fibers with the digital cushion (Fig. 4). At the level of the distal interphalangeal joint, the tendon of the DDF passes over the distal scutum, a very thick cartilaginous plate, strongly connected to the second and the third phalanges, and to the digital cushion

Fig. 5. Superficial structures of digit – right thoracic limb medial aspect.

(Fig. 4). A distal sesamoid bone was not found in llamas, neither by dissection, nor radioscopically. Between the vinculum and the insertion of the DDF, the tendon protected by the podotrochlear bursa glides over the distal scutum thickened by cartilage (Fig. 4).

The interosseous muscle is mostly tendinous, and originates from the second row of the carpal bones, the accessory carpal bone, the caudal aspect of radius, and the base of the metacarpal bones III & IV and runs against the palmar aspect of the metacarpal bones (Fig. 3). This muscle split into two symmetrical tendons which attach to each of the four proximal sesamoid bones at facies m. interossei.

Both superficial and deep (proper) antebrachial fasciae are present. The deep fascia is very strong and

continues on the palmar aspect of carpus as the flexor retinaculum. The latter continues as the palmar fascia, strongly attached to both borders of the metacarpal bones III & IV, and then continues as the digital fascia. On the palmar aspect of the fetlock, the digital fascia is reinforced by the palmar annular ligament, which is fused with the proximal digital annular ligament. There is an adipose nucleus comparable with the ergot of the horse for each digit (Fig. 5). From the symmetrical ergot, two ligaments of the ergot originate on the abaxial aspects of the digits, ending on the corresponding digital cushion. The fascia of the digital cushion extends between the two ligaments of the ergot (Fig. 5). The proper antebrachial fascia continues on the dorsal aspect of carpus as the extensor retinaculum, which descends on the dorsal aspect of the metacarpus and digits and is illustrated in Fig. 6.

Fig. 6. Dorsal aspect of metacarpal and digital tendons – left thoracic limb. A fibrous network connects all tendons.

DISCUSSION

A comparison between the available literature and our findings is necessary. Lesbre in 1903 stated that the muscular part of the FCU is a simple vestige, and the humeral head of it is missing. This muscle is in fact very well developed, with a strong humeral head and a reduced ulnar head. Additionally, Lesbre stated that the tendon of the humeral head of the DDF sends an extension to the tendon of the SDF. However, this was not observed in the intricate dissection of these specimens, which means that there are no interflexor muscles in llamas. Lesbre did not separate the humeral head into two parts, superficial and deep, which are constantly present. As far as the lumbricalis muscle, the insertion of its tendon is wrongly described as diminishing and becoming lost in the middle of a tendon behind the FJ.

Colas in (*op. cit.*) has an own interpretation of the humeral origin of the radial head of the DDF muscle, stating that it is a fibrous epicondylar tractus (in original a fibrous epitrochlear tractus) and incorrectly stating that the SDF has a strong attachment to the accessory carpal bone. Additionally, this description did not separate the humeral head of the DDF into a superficial and a deep portion. No true connection exists between the SDF tendon and the flexor retinaculum as Colas states while accurately reporting the connection between the SDF and the palmar fascia. As far as the lumbricalis muscles, Colas described them as “two thin red cords which wind several centimeters on the lateral aspects of the flexor tendons. They originate from the middle of the metacarpal bones and it looks like they are continued by a minuscule tendon which gets lost soon at the metacarpophalangeal joint”. As far as the interosseus M, Colas described it as pure tendinous, without a trace of muscle fibers, which we know from histological sections to be inaccurate. Clayton and Flood and McCracken *at al.* showed incomplete and improper labeled illustrations of some of the muscles subject to the present paper.

It is our interpretation that the digital flexor muscles of the thoracic limb are adapted to a very complex motor activity and are implied in the suspensory apparatus. Further comments on the fetlock joint are included in our evaluation of the digital flexor muscles of the pelvic limb. The sophisticated connections between the heads of the DDF muscle are the results of the long and delicate metacarpals, posture of the limbs, and the horizontal position of the last two

phalanges. The latter is an important characteristic of llamas, in which the angle between the first phalanx and the ground is approximately 52° 5. Animals with hyperextension of the fetlock joint can show severe changes in the phalangeal-to-ground angle, as acute as 12° in severely affected llamas⁵. Explanation for the lack of the distal sesamoid bone, the presence of a mobile distal scutum (which in the domestic ruminants covers intimately the palmar aspect of the distal sesamoid bone), and the extended attachment of the DDF tendon on the palmar aspect of the third phalanx can be interpreted in evaluation of the unique biomechanics of the llama. The origin of the DDF, as cranial and extended as possible in comparison to the SDF, shifts the balance of the center of the elbow joint to exactly mid distance between the origins of these two muscles. In addition, the ulnar head of the DDF is half as long as in the domestic ruminants, providing additional power for the DDF muscle during its contraction.

The strong attachment of the SDF tendon on the palmar fascia may be interpreted as the accessory ligament of the SDF in the horse (the proximal check ligament). There is no accessory ligament of the DDF (distal check ligament) in llamas. The continuation of the extensor retinaculum over the dorsal aspect of the metacarpal and digital region intermingles its fibers with the running tendons of the lateral digital extensor and common digital extensor muscles (the latter with two tendons). The network resulting from this fusion serves as a balance between the dorsal and palmar tendons, and as a portion of a stay apparatus (Fig. 6).

In conclusion, we can homologate several structures of the thoracic limb as corresponding to a species specific suspensory apparatus bearing the weight of the body: the very peculiar origin of the SDF and of the heads of the DDF in relationships to the center of the elbow joint; the firm attachment of the SDF tendon to the palmar fascia acting as an accessory ligament of the SDF; the strap of the FCU for the humeral head of the DDF tendon; the very wide area of origin of the radial head of the DDF and its long and strong tendon; the origin of the ulnar head of the DDF only on the distal half of the ulna, and its strong tendon; the network resulting from the fusion between the dorsal metacarpal fascia and the tendons running on the dorsal side of the metacarpal bones acting as a balance between the dorsal and palmar tendons.

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RESUMEN: Fueron disecados e ilustrados los músculos flexores digitales del miembro torácico de cuatro llamas con la finalidad de aportar datos sobre el aparato suspensor (de apoyo) que soportan estas estructuras. Se realizó una extensa búsqueda bibliográfica dada la incompleta información existente de estas estructuras anatómicas. La popularidad de la llama en todo el mundo como uno de los animales domésticos utilizados ha aumentado en los últimos años. Es importante describir detalladamente la anatomía de esta especie para su tratamiento en condiciones patológicas. La descripción de las estructuras anatómicas y las ilustraciones originales demuestran peculiaridades genuinas y diferencias entre la llama y los rumiantes domésticos. En llamas, las tres cabezas del músculo flexor profundo de los dedos se originan y se conectan entre ellas en una muy peculiar combinación, con uno de los tendones recibiendo un fascículo del músculo flexor ulnar del carpo. El músculo flexor superficial de los dedos tiene un tendón delgado el cual se fusiona con la fascia palmar y luego se amplía. No existen músculos interflexores. Adicionalmente, fueron encontrados músculos lumbricales en la extremidad distal y variaban en número entre los miembros. Finalmente, en este trabajo se evalúa el aparato suspensorio del miembro torácico.

PALABRAS CLAVE: Músculos flexores digitales; Aparato suspensorio/de apoyo; Miembro torácico; *Lama glama*.

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