

University of Veterinary Medicine Budapest

Department of Anatomy and Histology



Anatomical mapping of a Rothschild's giraffe forelimb

By:

Barak Wolnerman

Supervisor:

Dr. Kondor Milán, Research fellow

Budapest, 2022

Table of contents

1. INTRODUCTION	2
1.1. THE MODERN GIRAFFE	2
1.2. GOAL OF THE THESIS	3
2. LITERATURE REVIEW	4
2.1. OVERVIEW OF THE ANATOMICAL STRUCTURES OF THE GIRAFFE FORELIMB	4
2.2. ANATOMY OF THE FORELIMB	4
2.2.1. <i>Bones and joints of the forelimb</i>	4
2.2.2. <i>Muscles of the forelimb</i>	6
2.2.3. <i>Arteries of the forelimb</i>	7
2.2.1. <i>Nerves of the forelimb</i>	8
3. MATERIALS AND METHODS	10
4. RESULTS.....	11
5. DISCUSSION AND CONCLUSION	27
5.1. LIMITATIONS.....	27
5.2. MUSCLES	28
5.3. BLOOD VESSELS.....	29
5.4. CONCLUSION.....	30
6. SUMMARY.....	32
7. ÖSSZEFOGLALÓ	33
8. ACKNOWLEDGEMENTS	34
9. BIBLIOGRAPHY	35

1. Introduction

1.1. The modern giraffe

The modern Giraffe (*Giraffa Camelopardalis* [1]), best known for being the tallest living terrestrial mammal [2], is one of two extant genera of the family *Giraffidae* [3] in the order *Artiodactyla* [4], the even-toed ungulates. The closest extant relative in this family is the Okapi (*Okapia johnstoni* [5]). Despite being the tallest mammal, with males and females averaging 5.5 and 4.3 meters respectively, it is only ninth in weight, with males and females weighing an average of 1,200 and 800 kilograms respectively [6–11].

The International Union for Conservation of Nature (IUCN) recognizes a single giraffe species, *Giraffa camelopardalis*, with nine subspecies differentiated by morphological features and geographical range [12, 13]. However, a recent coalescence-based multi-locus and population genetic analyses, conducted by The Giraffe Conservation Foundation (GCF), identified four distinct monophyletic species with five subspecies [14, 15]. Fennessy *et al.* (2013) further suggested subsuming the Rothschild's giraffe subspecies (*Giraffa camelopardalis ssp. rothschildi* [1]), the subject of this study, under the Nubian giraffe subspecies (*Giraffa camelopardalis ssp. camelopardalis* [1]) [7]. Though the IUCN traditional classification is commonly accepted, the GCF taxonomy classification appears to be the most accurate.

The wild giraffe population has shown a large decline 36-40% over the past thirty years [16]. In 2016, its status changed from Least Concern (LC) to Vulnerable (VU) in the IUCN Red List of Threatened Species. Although overall wild population has declined, the numbers of the Rothschild's giraffe subspecies have shown a 26% increase and has therefore been upgraded from Endangered (EN) to Near threatened (NT). Though slightly increased, numbers remain very low as latest estimates of the subspecies suggest approximately 2,098 individuals remain in the wild [17].

Giraffes are ruminants of the browsing type and have been adapted to populate habitats varying from arid deserts to woodlands, shrublands and open savannas of sub-Saharan Africa [14, 15]. As such, giraffes are vital to the function of their ecosystem, as they disperse seeds, stimulate new forage growth, and indirectly pollinate various plants while foraging [18].

Whereas giraffes once existed in vast areas that overlapped with humans, their natural habitats have shrunken, becoming increasingly degraded by growing human agriculture, livestock rearing, and urban development [19]. It can be concluded that the rapid decline in giraffe

populations, together with the decrease in their geographic range, is attributed to the previously mentioned human activities, such as illegal poaching, together with climate change [18]. Projections indicate that with growing human population, which is expected to double by the year 2050, giraffe populations will continue to become increasingly fragmented [20].

1.2. Goal of the thesis

Nowadays, much has been researched regarding the functional anatomy and physiology of the giraffe in regard to the digestive [21–24], locomotion [25–27], respiratory [28, 29], and vascular systems. The attention, to a large extent, has focused on the heart [30] and the maintenance of stable blood pressure from the heart cranially through the neck [31, 32] and distally along the limbs [33–35].

However, there are still few studies on the detailed muscular and vascular anatomy of the giraffe forelimb. In fact, most of the knowledge obtained regarding the muscle anatomy of the giraffe forelimb still relies upon three dissections performed by Owen [4], Joly and Lavocat [36], Murie [37], and upon the studies by Kühlhorn [38] and Gambaryan [39]. Descriptive as these sources may be, the dissection studies have only provided diagrams of the hindlimb. Gambaryan (1974) was the only one of those who had given attention to the forelimb as well. Unfortunately, aside from focusing on muscle functionality, his works have not been easy to interpret either, having been written solely in Russian for Russian scientific journals which are not easily accessible. Despite several case study publications, which include radiological imagery, very few papers cover the anatomy of the forelimb and provide actual imagery of the soft tissues. Furthermore, aside from images reviewing osteology of the forelimb and hindlimb, we could not establish evidence of additional relevant anatomical studies and imagery of clinical importance.

Furthermore, as the lifespan of giraffes in the wild reaches a maximum of 22 years in males and 28 years in females [40], with captive giraffes reaching a similar age [41], lameness becomes a common health issue of the adult giraffes kept in captivity [42]. Multiple abnormalities can be associated to lameness, including congenital deformities, ligament injuries [43, 44], tenosynovitis [45], and trauma, all of which have diagnostic and clinical relevance to this study. The purpose of this study was therefore set to provide a modern anatomical atlas, in which actual photographs can depict anatomical forelimb structures, in parts unique to the giraffe, and provide explanations that may be of clinical use in addition to current available literature. This atlas contains colored photographs, each tagged with its structures.

2. Literature review

2.1. Overview of the anatomical structures of the giraffe forelimb

Reaching an evolutionary height and upright posture such as that of the giraffe was accompanied by the formation of very straight limbs and their bones. To establish how straight the giraffe forelimb is, Gambaryan (1974) summed the angles formed by *articulatio cubiti* and *articulatio carpi* in a standing giraffe [39]. When completely straight, each joint reaches an angle of 180° and 360° combined. Whereas in other ungulates the sum of the angles is usually under 200°, giraffes never reach below 250°. This straightness indicates that the giraffe joints are not flexed or bent to a great degree as they are in other ungulates, which in effect means giraffes walk and run on ‘stilts’ - movement of the forelimb is initiated by a small angle movement at the top of the limb bringing about a larger angle movement distally. Moreover, the straightness does not form by the angle of the joints alone, but additionally by the decreased longitudinal curvature of the bones themselves. This curvature is described as the deviation from a line that connects the center of the bone’s two articulating surfaces [46]. An advantage of this straightness is the reduction in the horizontal loading force, diverting the stress axially, directly to the dense bone matrix. An additional advantage is the reduced force the muscles are required to produce to maintain the giraffe’s posture. As a result of this upright posture, over time the muscles of the shoulder have become tendinous, allowing better fixation of the joint at a lower energy cost, a great benefit to an animal which spends the majority of the day on its legs.

2.2. Anatomy of the forelimb

2.2.1. Bones and joints of the forelimb

The bones of the giraffe forelimb have several morphologically unique features when compared with other mammals. Though the *scapula* is triangular in appearance in the horse [47] and ruminants [48], its appearance in giraffes is slightly different. Its dorsal border is somewhat convex, its cranial border concave, and its caudal border is convex proximally and concave distally [49, 50]. The *spina scapulae* was described by Jahan (2020) to be well-developed and straight [51], however Damian *et al.* (2012) noted that it was slightly twisted [49]. Furthermore, for Onwuama *et al.* (2021) and Jahan (2020) the *spina scapulae* did not possess a *tuber spinae scapulae* and ended without an *acromion*. The *processus coracoideus* is minimized to a tubercle

size in the giraffe [52]. The absence of the *acromion* has led Onwuama *et al.* (2021) to the assumption that the *pars acromialis* of *m. deltoideus* may be absent in this species [50].

In their work on two West African giraffes (*Giraffa camelopardalis peralta*), Onwuama *et al.* (2021) have shown that the *humerus diaphysis* is smooth on all its sides to the extent it lacks the *tuberositas deltoidea* and *tuberositas teres major*. In addition, they claimed the *humerus* had a very shallow *sulcus nervi radialis*. Leading to the suggestion that *m. deltoideus* and *m. teres major* were either absent or not inserted on the humeral shaft. Of the two options, it was the absence of the *m. deltoideus* that seemed more likely since there was no *acromion* [50]. The *caput humeri* resembles that of the equine as it possesses *tuberculum intermedium*, whereas it is rudimentary in the ruminants [51].

The *humerus* differs from the rest of the appendicular bones by being the only one to grow increasingly stronger postnatally in regard to body mass and bone length. This suggests a functional adaptation of the bone to the increasing weight load of the growing neck of the giraffe and to the need of the forelimbs to bend and splay in order to drink [53].

The ulnar shaft of the giraffe is reduced to a thin plate compared to the dog, pig, and other ruminants [54, 55]. Despite having a reduced shaft, the *ulna* runs distally along the entire *radius*, ending as the *processus styloideus lateralis*, as opposed to that of the horse that has a reduced shaft, however, ends more proximally.

In regard to the *ossa carpi*, their morphology and arrangement were found to be similar to those of other ruminants as it was previously described in the work of Adams and Crabtree [56].

The *os metacarpale* possesses a shallow sagittal groove on its palmar side. Together with the presence of *condylus medialis* and *lateralis*, it raised the assumption the *os metacarpale* is formed as a result of fusion of *os metacarpale tertium* and *os metacarpale quartum* [50]. Moreover, it is worth noting that a recent study by Yohe and Solounias (2020) supported the bone fusion hypothesis and challenges the current one of digit loss [57]. Having been conducted on the *ossa metatarsalis*, the study by Yohe and Solounias (2020) may call for further studies on the forelimb of the giraffe as well. When examining the thickness of the *ossa metacarpalis*, a greater increase in wall thickness is measured in the giraffe compared to its large artiodactyl counterparts, represented by a ‘conventional artiodactyl’, the buffalo (*Syncerus caffer*), as shown in a study by van Schalkwyk [58]. In addition to the thickness increase, an additional feature presented was two thickenings at the palmar aspect of *os metacarpale* cross section.

These thickenings, together with a decreased vertical angle of *os metacarpale* may suggest further functional adaptation of the long bone to the animal's weight load.

2.2.2. Muscles of the forelimb

The muscles of the forelimb have two main functions, to support the weight of the body, while countering the effect of gravity, and to generate movement. Supporting the weight of the body is a role shared by all quadrupedal animals, however this task is amplified as giraffes are required to bear the weight created by their unique, long, and heavy neck [59]. Additionally, whereas in all other mammals the junction between the neck and thoracic vertebrae is between the last cervical and first thoracic vertebra, the junction in giraffes is between the first and second thoracic vertebra [53]. Simplified, this means the weight load of another vertebrae is added to the total weight load of the neck. Therefore, in giraffes, these features all factor in together to create a proportionally higher total body mass that weighs on the forelimb in comparison with other mammals.

It is therefore the role of the shoulder and elbow joint extensor muscles to prevent the shoulder and elbow joint from collapsing under the weight of the giraffe. Since giraffes do not have a *clavicula* bone as some other mammals do, they rely entirely on the muscles of the shoulder girdle for this task [59]. In contrast to common logic, which argues that muscles under a higher load are larger than those under a lesser load, these muscles of the giraffe are smaller in size compared with other mammals as they are more tendinous [39].

As this study focuses on the limb itself, disconnected from the rest of body, this literature review will focus on the muscles distal to the shoulder girdle.

Extension and straightening of the *articulatio humeri* are performed by *m. supraspinatus* and *m. infraspinatus*, which originate from the cranial and caudal side of the *spina scapulae* respectively, inserting on the proximal end of the *humerus*. The contraction capacity of these muscles is limited, meaning they function more as ligaments than muscles as they are relatively less well developed and are more inelastic than in other ungulates [59]. *Musculus brachiocephalicus* and *m. latissimus dorsi* assist the action of the *m. supraspinatus* and *m. infraspinatus*. *Musculus latissimus dorsi* originates from *fascies thoracolumbalis* that covers the *processus spinatus* of the *vertebrae lumbales* and *vertebrae thoracicae* and inserts on the *humerus*. The *m. latissimus dorsi*, together with *m. deltoideus*, *m. teres major*, and *m. coracobrachialis* act as the flexors of the *articulatio humeri*. Extensors of *articulatio cubiti* are

large and well-developed muscles as they account for 21% of the forelimb total muscles mass [39], justifying their role in providing most of the forelimb movement. *Musculus triceps brachii*, one of the elbow extensors muscles, was believed to be unique to the giraffe as it was argued to have five heads instead of the three as its name suggests [36]. Its *caput longum* originates from the caudal border of the *scapula* and continues down the caudal surface of the *humerus* to insert on the *olecranon* process of the *ulna*. *Musculus triceps brachii* is well developed due to the forces the elbow is subjected to. However, functionally, it contracts by only 8% of its length in giraffes, whereas it contracts 23-47% in other ungulates [39]. Another large extensor is *m. anconeus*, it is twice as large in giraffes than in other ungulates and assists the *m. triceps brachii* action. The lateral and the medial heads of the *m. triceps brachii* originates from the distal third of the *humerus* and inserts on the *olecranon*. Flexors of the elbow, *m. brachialis* and *m. biceps brachii*, are not as well developed and account for a third of the mass of the extensors, however in giraffes they account for a larger total mass than their ungulate counterparts [39]. The *m. brachialis* originates from the *humerus* and inserts on the *radius*, whereas the *m. biceps brachii* inserts on the *radius* as well but originates from the *scapula*. The muscles of the carpus and digits were not detailed in the literature.

2.2.3. Arteries of the forelimb

Arteries in the limbs of the giraffe endure a very high blood pressure of around 500 (± 49) mmHg [35]. In fact, it is the highest pressure found within its body, higher than the pressure in vessels close in proximity to the heart [33]. Two factors contribute to this fact, pressure generated by the heart together with hydrostatic pressure generated by gravity [59]. The giraffe has two mechanisms to counter this increasing blood pressure and protect the limbs against edema. The first, increase in muscle layer within the arterial wall. Goetz and Keen (1957) were the first to argue that as arteries progress distally along the limb the thicker the arterial walls grow on the expense of the decreasing lumen diameter [33]. This thickening occurs by a process of hyperplasia of the muscle cells. This was validated later on in a study done on the forelimb by Petersen *et al.* (2013), who demonstrated that, under sympathetic stimulation, the small arterioles of the lower limb can contract against 500 mmHg, far higher than 260 mmHg, the average pressure found in that region [35]. The second mechanism, the presence of a sphincter, was initially found in the hindlimb arteries by Kimani *et al.* [60] yet later confirmed in the forelimb as well by Peterson *et al.* [35]. Their study showed that within the *arteria mediana*,

below the elbow, lies a discrete sphincter. This sphincter was shown to be an abrupt narrowing, in and below which, nerves are distributed more densely. Combination of these two mechanisms enables, upon need, shunting the blood flow to locomotor muscles of the upper limb [60].

In order for the blood to return to the heart it must counter the hydrostatic pressure created by gravity. This is achieved with the help of the venous system. One mechanism is the prevention of backflow. Amoroso *et al.* (1947) have shown that both *vena axillaris* and *vena brachialis* contain a large number of valves preventing backflow [61]. Not only these two vessels but also their tributary veins contain bicuspid and tricuspid valves. Whereas bicuspid valves guard small tributary veins, tricuspid guard the larger tributaries. Prevention of backflow, however, is not enough, hence why Hargens *et al.* (1987) were the first to bring up the assumption that a pump, effective enough against the gravitational hydrostatic pressure, must exist in the giraffe [62]. They hypothesized that a form of cyclical compression and decompression associated with muscle activity working against the tight skin was the mechanism for pumping the blood upwards. This cyclical mechanism could also be associated to a hoof pump, which has yet to be proven in giraffes as it has been in horses. Hooves of horses contain venous sinuses, which lie between *cartilago ungularis lateralis* of the hoof and *os ungulare* [62]. When a horse lifts its foot, negative pressure forms in the sinuses, which draws the blood into them. When the horse places its foot on the ground, the sinuses are compressed between the cartilage and phalanx, creating a positive pressure, which expels the blood out. Kimani *et al.* (1991) suggested a third explanation which was based on the function of a hindlimb arterial sphincter, which they presumed to exist in the forelimb as well [60]. They speculated that the tibial sphincter closes as a giraffe is walking or running, shunting the blood to the upper hindlimb locomotor muscles. When the muscles themselves contract they pump, the now venous blood, back to the heart.

To the authors best knowledge, to this present there is no documentation describing the topography of the vascular branching as previous works have focused on the morphology of the vessels in connection with blood pressure maintenance.

2.2.1. Nerves of the forelimb

Similar to other artiodactyls, giraffes have evolved in such a way that large muscles responsible for movement are close to the body core. As a result, motor nerves arising from the spinal alpha and gamma motor neurons are shorter [59]. Despite their long limb length, giraffes do not show slow reaction or incoordination that might have otherwise suggested a delay between sensation

and reaction. Many hypotheses have been suggested, the one seeming as the most acceptable explanation suggested that conduction velocity is higher in nerve fibers with larger diameter body [63]. It was later shown by More *et al.* (2013) that *nervus ischiadicus*, used for that study, did not have bigger diameter axons, but rather had somewhat, yet not substantially, higher number of myelinated fibers than expected according to predictions on other species of similar body mass [64]. Mitchell (2021) used *nervus ischiadicus* as well to suggest, however, the nerve composition as an explanation. Mitchell assumes the nerve has approximately 85% sensory and 15% motor fibers [59]. Considering giraffes have large skin surface area whilst having many large muscles with few motor units and few muscles that require fine coordinated movements, Mitchell argues each motor fiber supplies approximately 4 grams of muscle tissue while each sensory fiber supplies approximately 1 gram of tissue. High neural fiber density per tissue can be seen as well in the rich sympathetic innervation of the giraffe arteries, which was shown by Kimani and Opole [65] and Nilsson *et al.* [66], then later corroborated by Peterson *et al.* [35]. Similarly, as in the vessels, there is yet to be any documentation on the neural topography of the forelimb.

3. Materials and Methods

For the purpose of our research, the University of Veterinary Medicine in Budapest was given the opportunity to use one fresh yet frozen forelimb of a recently deceased 10-day old female Rothschild's giraffe calf from the Kittenberger Kálmán Zoo & Botanical Garden (Veszprémi Állatkert) in Veszprém, Hungary.

The calf had shown signs of walking on the tip of the forelimbs' hooves from the first few days of life in captivity. Since the veterinarian suspected contracture of the digital flexors, the calf was treated with oxytetracycline (for calcium retention) together with active massage. Treatment led to full healing after a few days as the calf managed to walk normally prior to its sudden death. Considering the carcass did not show any pathognomonic signs of a limb-related lesion and that the calf was recorded as walking normally after treatment and prior to death, the authors do not believe this should interfere with the results of the study.

Once the carcass had undergone a full pathological examination its limbs were separated, skinned, and kept in refrigeration at -4°C until our work had begun. The limb was placed to thaw 48 hours prior to dissection. During the 72 hours between the first and second dissection days on the left forelimb it was placed in a water tank at $+4^{\circ}\text{C}$ refrigeration to maintain moisture.

The dissection followed a strategic workplan made beforehand and was conducted from the brachium and continued distally towards the digits. It included the separation and demonstration of the major muscles and their blood vessels and nerve supply.

Images were taken using a Minolta DiMage A1, F/2.8-4, exposure time 1/50-1/500 seconds, focal distance 28-200mm.

4. Results

To the authors knowledge until today, photographic illustrations of the forelimb musculature, and vascular anatomy were not present for the use of practicing veterinarians. Therefore, there were no landmark features to facilitate surgical manipulations in the field, apart from those relating directly to osteology.

Our goal was to perform the dissection naturally, minimising use of any artificial substances as preservation measures other than manipulation, freezing and soaking of the limb to maintain and emphasise anatomical structures. The left forelimb was dissected in the utmost gentle way possible, which was therefore a very time-consuming process. Extreme caution was given to pay attention and maintain integrity of small branching vessels and nerves where possible.

The dissection began with exposing the lateral musculature and vessels of the *articulatio humeri* using standard blades, forceps and scissors. This followed with separating and exposing the medial aspect of the shoulder structures. Afterwards, the *articulatio cubiti* was demonstrated in the same methodological fashion. The muscles and blood supply of the carpal joint and the phalanges were demonstrated together due to their similar origin.

Through meticulous caution together with the help of more than 200 photos generated and several videos taken during the dissection, we were able to achieve our aim and create an image series of the dissection of the forelimb of the Rothschild giraffe, which highlights major anatomical features. These structures were carefully exposed to enable practicing veterinarians a clear view (Figures 1-17).

After completing the dissection, we removed all remaining tissues and preserved the reassembled skeleton of the left forelimb for students to observe in comparison with the skeletons of other exotic and domestic species in the Anatomical Museum of the university.



Figure 1: The forelimb, Medial view.

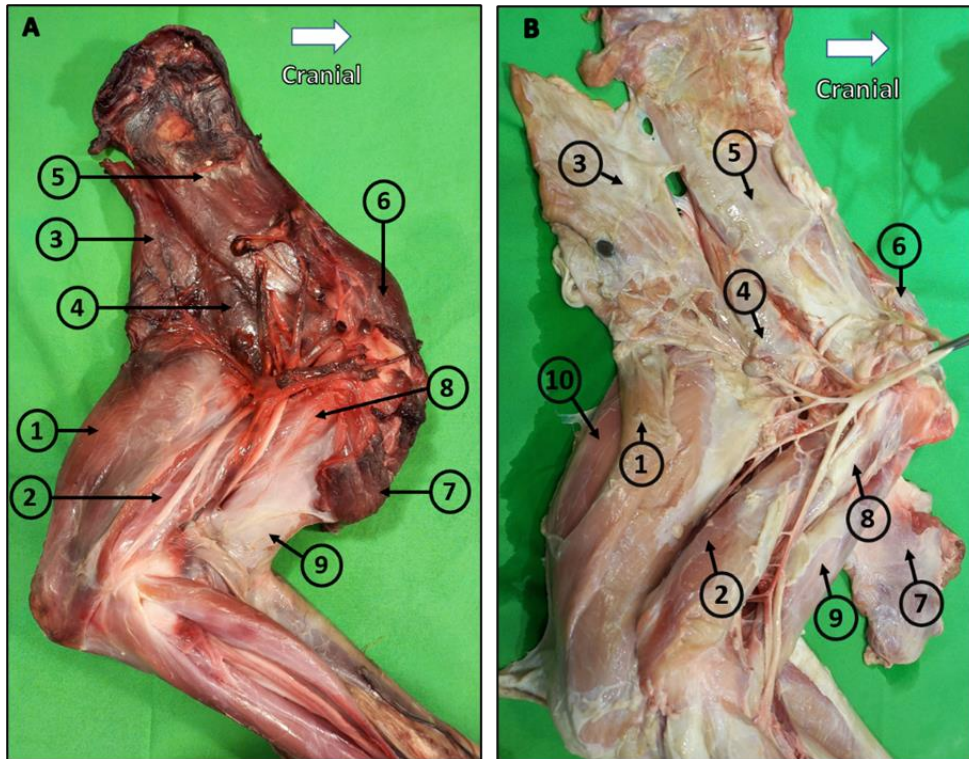


Figure 2: Musculature of the scapula and shoulder region, Medial view.

(A): Prior to two-day soak in water, (B): After two-day soak in water.

- (1) *M. tensor faciae antebrachii*, (2) *M. triceps brachii* (caput mediale), (3) *M. latissimus dorsi*, (4) *M. teres major*, (5) *M. subscapularis*, (6) *M. supraspinatus*, (7) *M. pectoralis transversus* (resected), (8) *M. coracobrachialis*, (9) *M. biceps brachii*, (10) *M. triceps brachii* (caput longum)

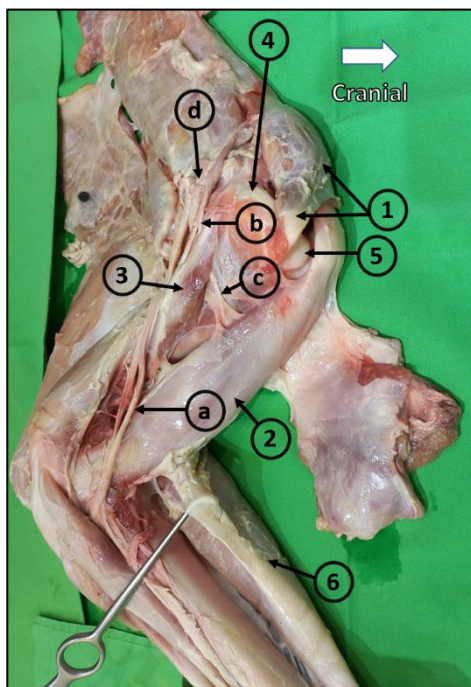


Figure 3: Scapula and shoulder region, Cranio-Medial view

(After two-day soak in water).

- (1) *M. supraspinatus* (two tendinous insertion points – medially on tuberculum minus (pars cranialis) and laterally on tuberculum majus (pars cranialis)), (2) *M. biceps brachii*, (3) *M. coracobrachialis*, (4) Tuberculum minus, (5) Tuberculum intermedium, (6) Lacertus fibrosus (hooked)
 (a) *N. medianus*, (b) *N. musculocutaneus*, (c) *Ramus muscularis proximalis*, (d) *Ansa axillaris*

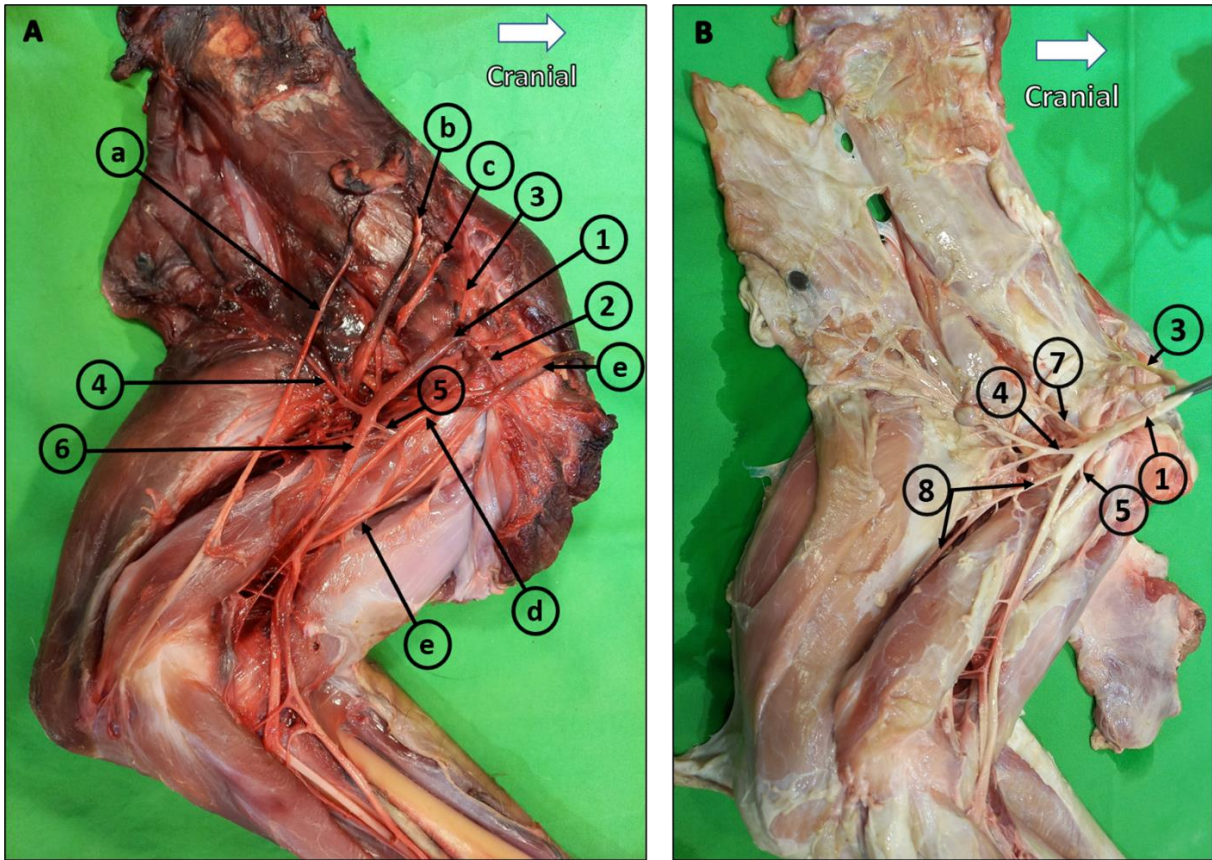


Figure 4: Scapula and shoulder region, Medial view.

(A): Prior to two-day soak in water, (B): After two-day soak in water.

- (1) *A. axillaris*, (2) *A. thoracica externa*, (3) *A. suprascapularis*, (4) *A. thoracodorsalis*,
 (5) *A. circumflexa humeri cranialis*, (6) *A. brachialis*, (7) *A. subscapularis*, (8) *A. profunda brachii*,
 (a) *N. ulnaris*, (b) *N. radialis*, (c) *N. axillaris*, (d) *N. medianus*, (e) *N. musculocutaneus*.

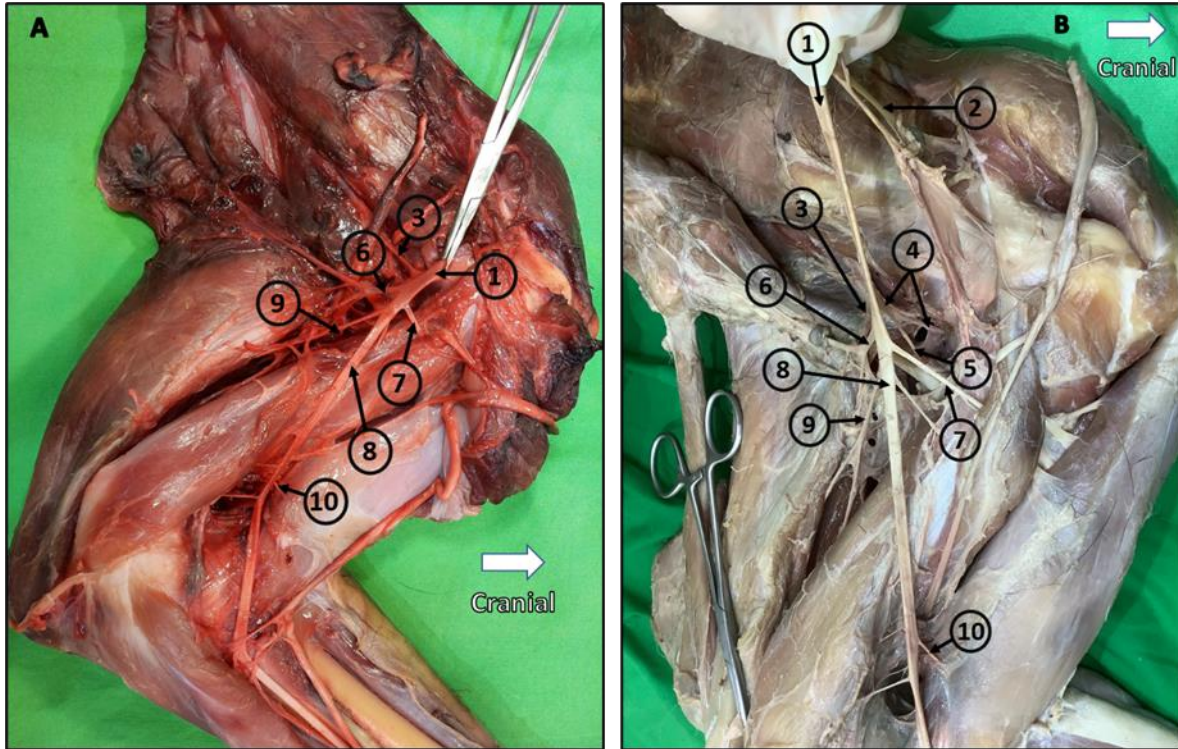


Figure 5: Shoulder region, Medial view.

(A): Prior to two-day soak in water, (B): After two-day soak in water.

- (1) A. axillaris, (2) A. suprascapularis, (3) A. subscapularis, (4) A. circumflexa humeri caudalis, (5) A. collateralis radialis, (6) A. thoracodorsalis, (7) A. circumflexa humeri cranialis, (8) A. brachialis, (9) A. profunda brachii, (10) A. bicipitalis

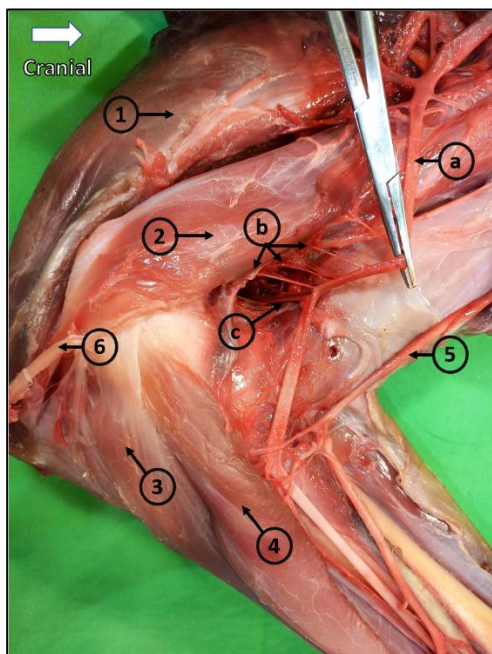


Figure 6: Elbow region, Medial view.

(Prior to two-day soak in water).

- (1) M. triceps brachii (caput longum), (2) M. triceps brachii (caput mediale), (3) M. flexor carpi ulnaris (caput ulnare), (4) M. flexor carpi ulnaris (capus humerale), (5) N. medianus, (6) N. ulnaris (reflected)
 (a) A. brachialis, (b) Muscular branches, (c) A. transversa cubiti

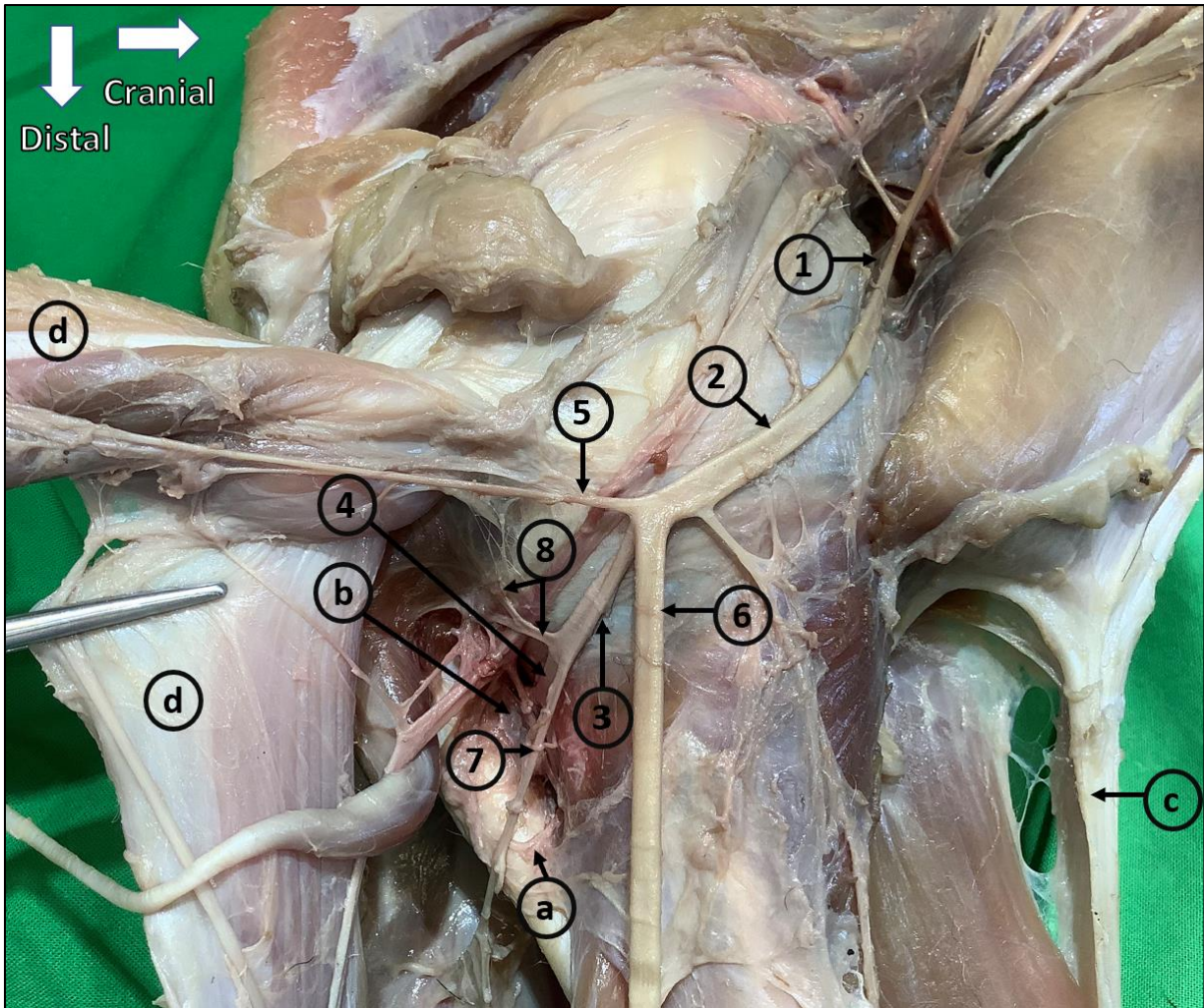


Figure 7: Elbow region, Medial view.
(After two-day soak in water).

- (1) *A. transversa cubiti*, (2) *A. brachialis*, (3) *A. interossea communis*, (4) *A. interossea cranialis* (going into (b)),
 (5) *A. profunda antebrachii*, (6) *A. mediana*, (7) *A. collateralis ulnaris*, (8) *A. recurrens ulnaris*,
 (a) Ulna, (b) *Spatium interosseum antebrachii proximale*, (c), *Lacertus fibrosus* (d) Flexor muscles of the carpus and digits (clamped)

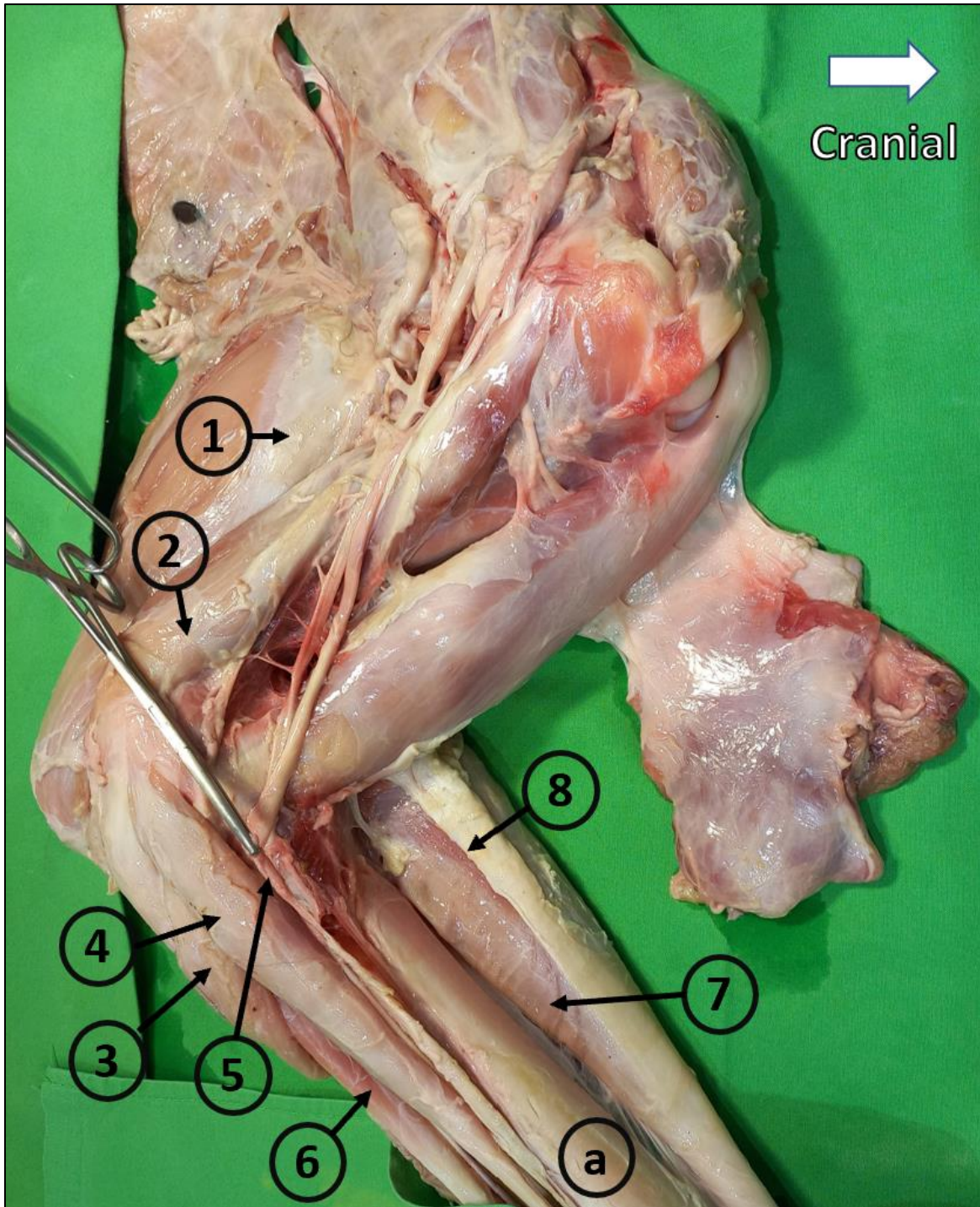


Figure 8: Elbow region, Medial view.
(After two-day soak in water).

- (1) *M. triceps brachii* (caput longum), (2) *M. triceps brachii* (caput mediale), (3) *M. flexor carpi ulnaris* (caput ulnare), (4) *M. flexor carpi radialis*, (5) *M. pronator teres* (rudimentary structure - clamped), (6) *M. flexor digitorum superficialis*, (7) *M. extensor carpi radialis*, (8) *Lacertus fibrosus*,
(a) Radius.

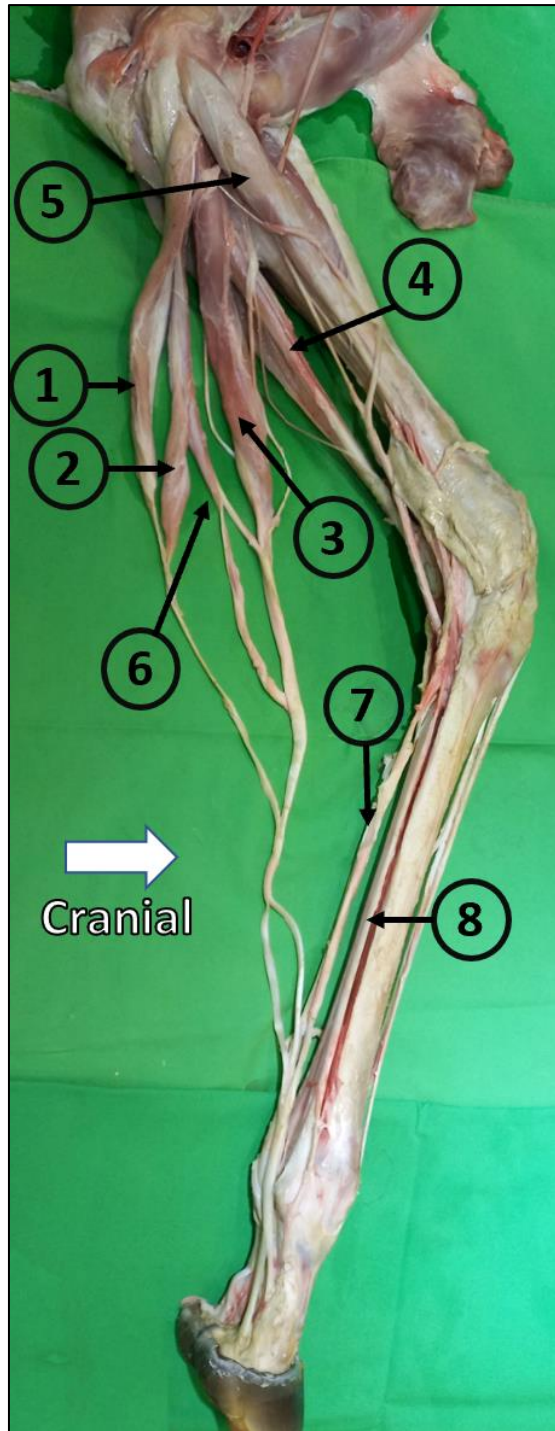


Figure 9: Flexor muscles of the carpus and phalanges, Medial view.
(After two-day soak in water).

- (1) *M. flexor digitorum superficialis* (pars superficialis), (2) *M. flexor digitorum superficialis* (pars profundus), (3) *M. flexor digitorum profundus* (caput humerale) with caput ulnare & radiale on each side, (4) *M. flexor carpi ulnaris*, (5) *M. flexor carpi radialis*, (6) *Mm. Interflexorii*, (7) Band analogous to ligamentum accessorium (check ligament), (8) *M. interosseus medius*.

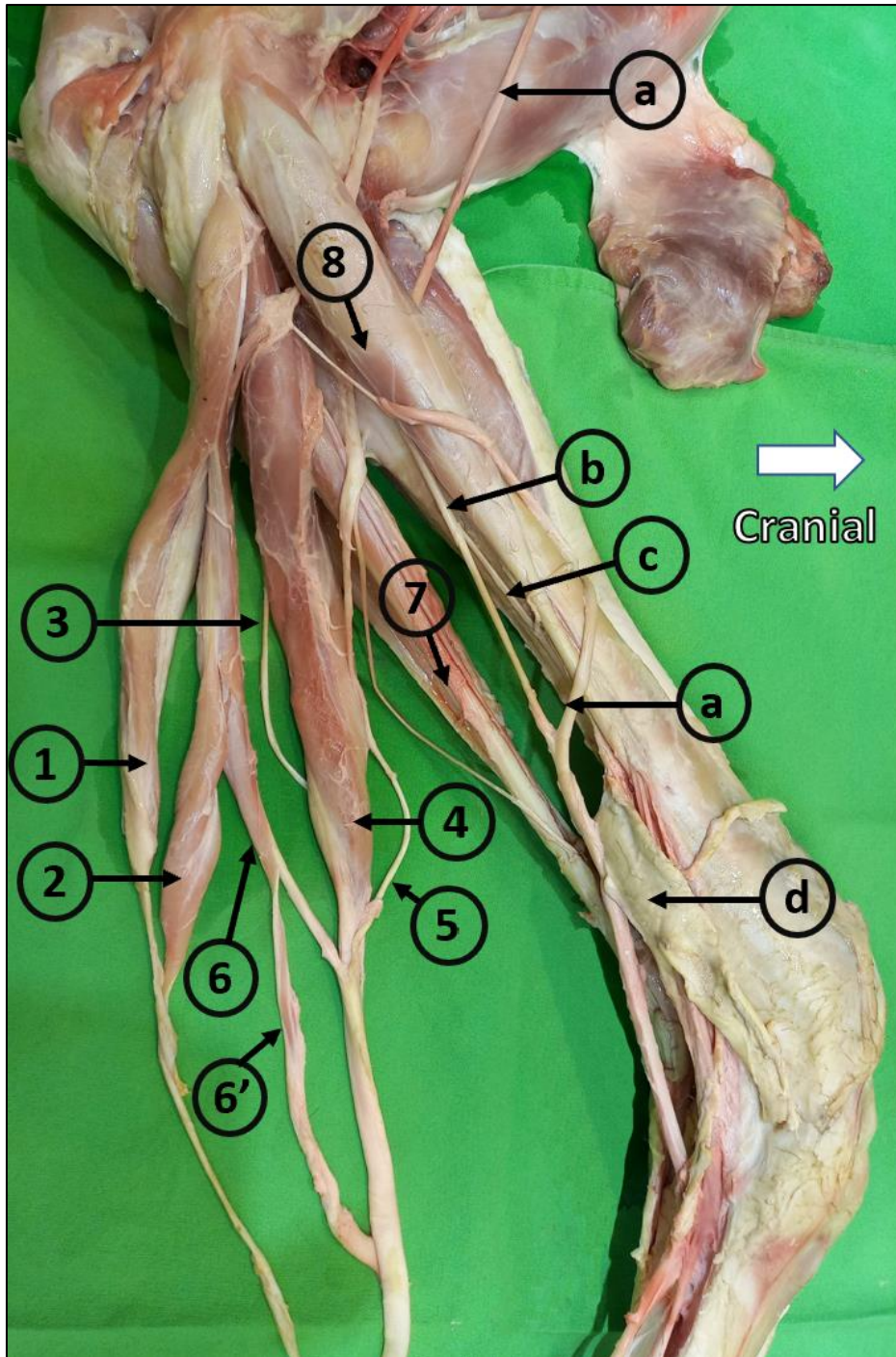


Figure 10: Elbow and carpus region, Medial view.
(After two-day soak in water).

- (1) *M. flexor digitorum superficialis* (pars superficialis), (2) *M. flexor digitorum superficialis* (pars profundus),
 (3) *M. flexor digitorum profundus* (caput ulnare), (4) *M. flexor digitorum profundus* (caput humerale),
 (5) *M. flexor digitorum profundus* (caput radiale), (6) *M. interflexorius proximalis*, (6') *M. interflexorius distalis*,
 (7) *M. flexor carpi ulnaris*, (8) *M. flexor carpi radialis*,
 (a) *N. medianus*, (b) *A. mediana*, (c) *A. radialis*, (d) *Retinaculum flexorum* (transected).

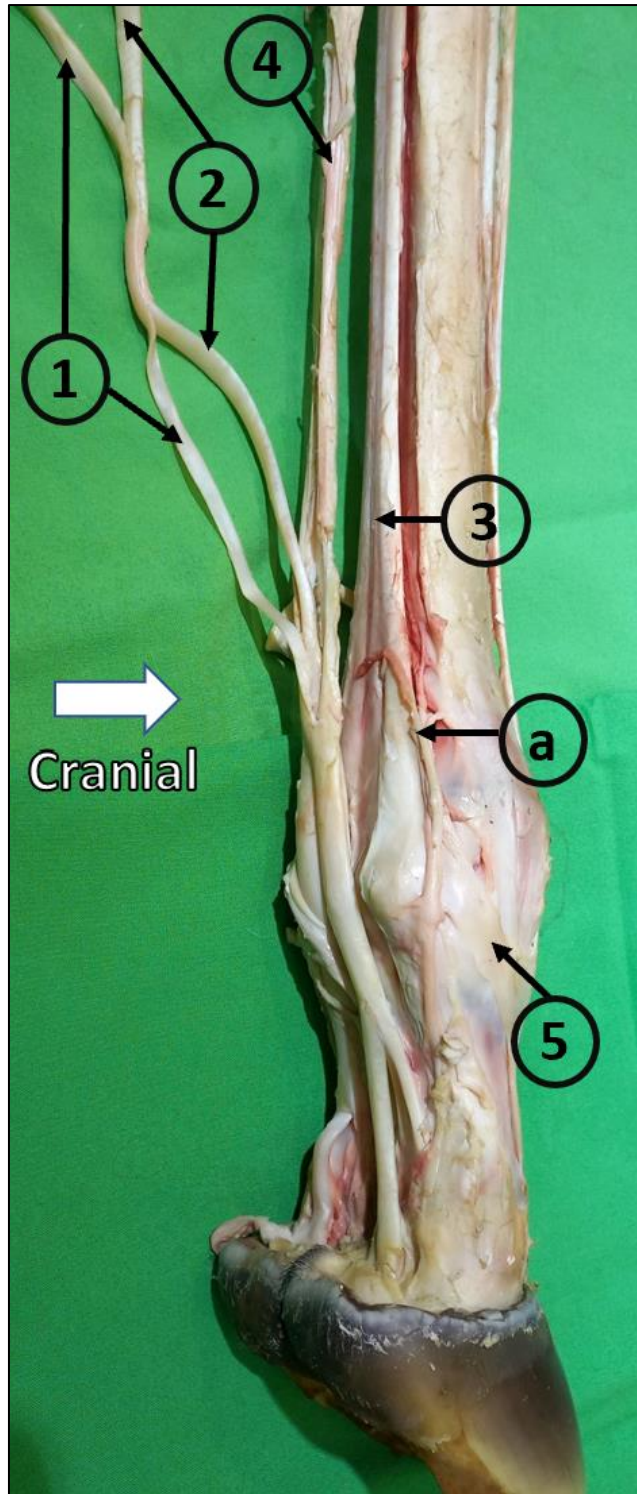


Figure 11: Distal metacarpal and phalanges region, Caudo-Medial view.
(After two-day soak in water).

- (1) *M. flexor digitorum superficialis*, (2) *M. flexor digitorum profundus*, (3) *M. interosseus medius*,
- (4) Band analogous to ligamentum accessorium (check ligament),
- (5) Tractus appositus (ex *m. interosseus medius*),
- (a) *A. & N. palmaris medialis* (transected).

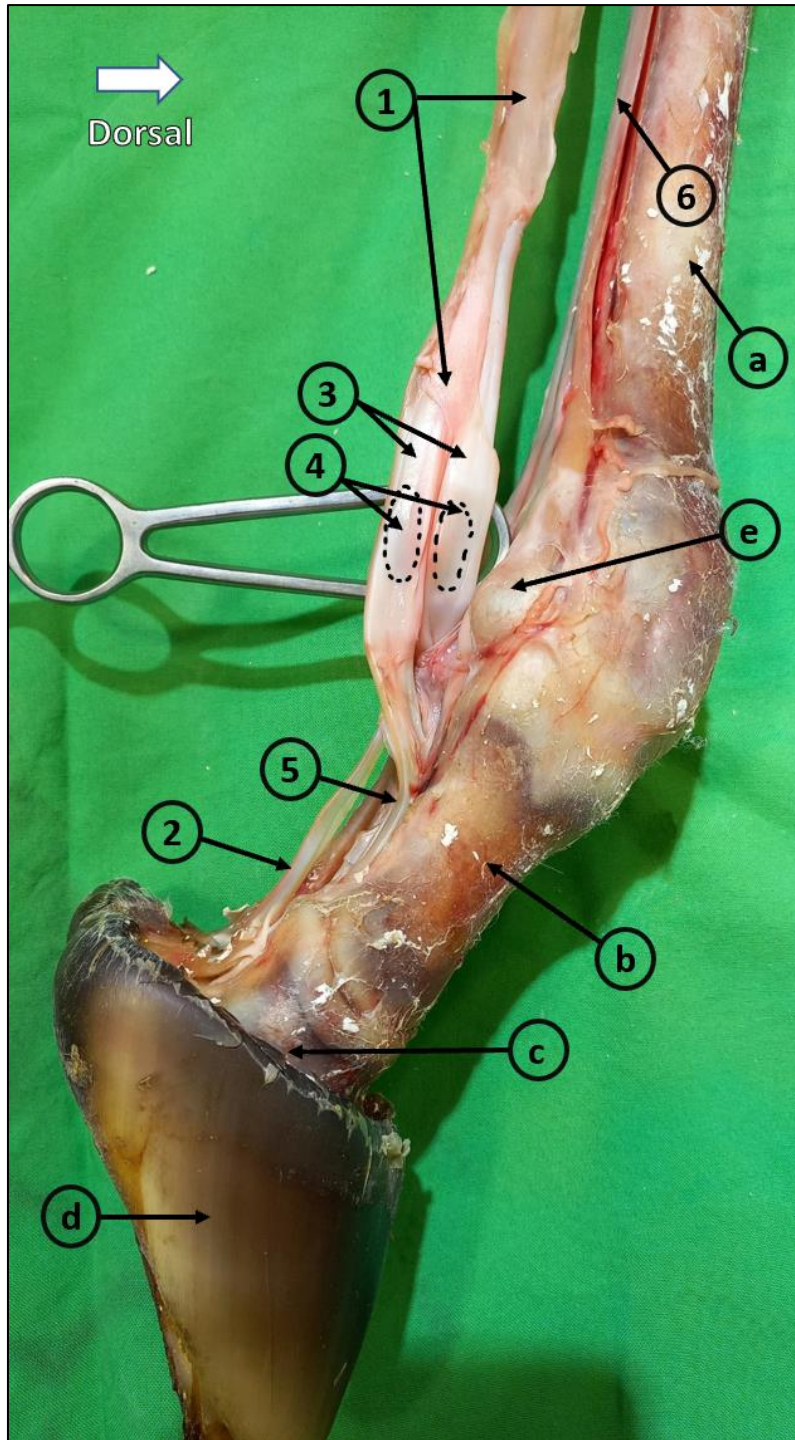


Figure 12: Phalanges region, Medial view.
(After two-day soak in water).

- (1) Vagina synovialis tendinum digitorum manus, (2) Insertion tendon of m. flexor digitorum profundus, (3) Manica flexoria, (4) Dorsal oval opening of the manica flexoria (inverted medially, marked in a dotted line), (5) Insertion tendon of m. flexor digitorum superficialis, (6) M. interosseus medius, (a) Os metacarpale tertium et quartum, (b) Os compedale, (c) Os coronale, (d) Hoof of Os unguare, (e) Ossea sesamoidea proximalia.

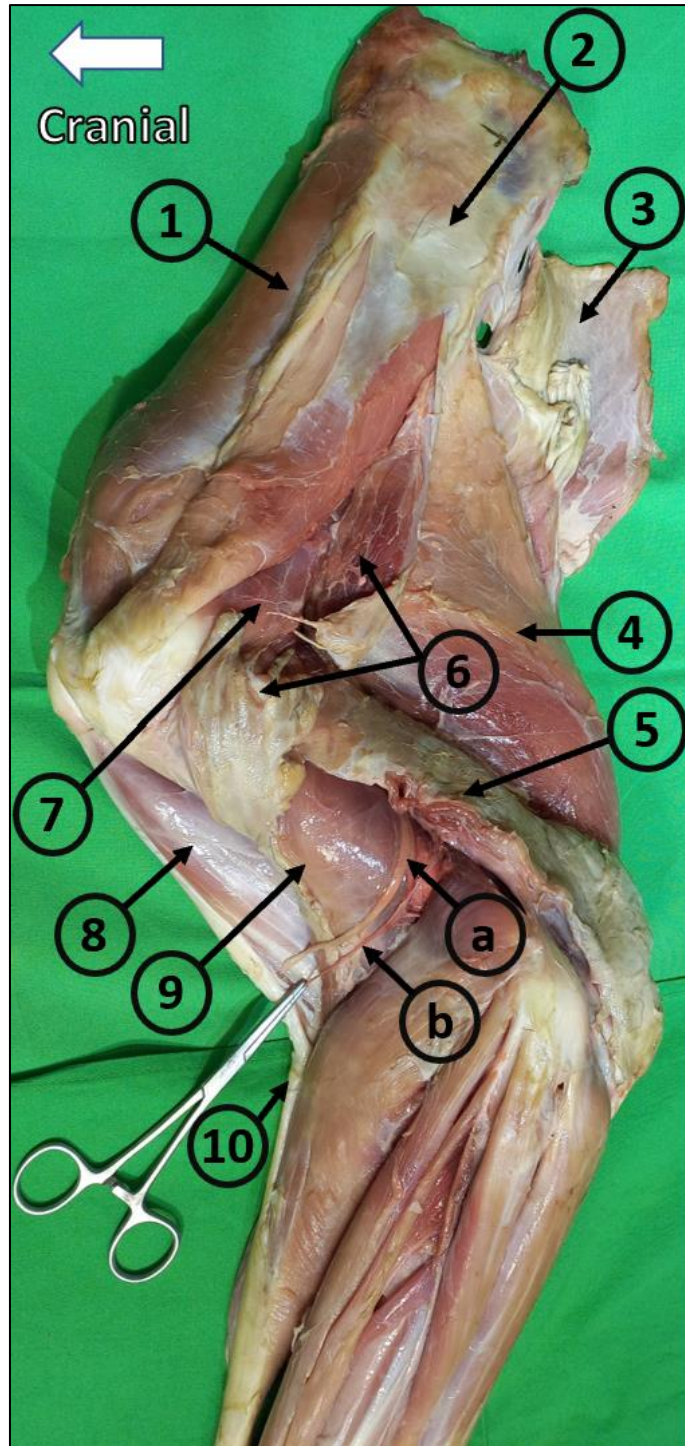


Figure 13: Shoulder and elbow region, Lateral view.
(After two-day soak in water).

- (1) *M. supraspinatus*, (2) *M. infraspinatus*, (3) *M. latissimus dorsi*, (4) *M. triceps brachii* (caput longum),
 (5) *M. triceps brachii* (caput laterale), (6) *M. deltoideus* (transected), (7) *M. teres minor*,
 (8) *M. biceps brachii*, (9) *M. brachialis*, (10) *Lacertus fibrosus*
 (a) *N. radialis*, (b) *A. collateralis radialis* (clamped)

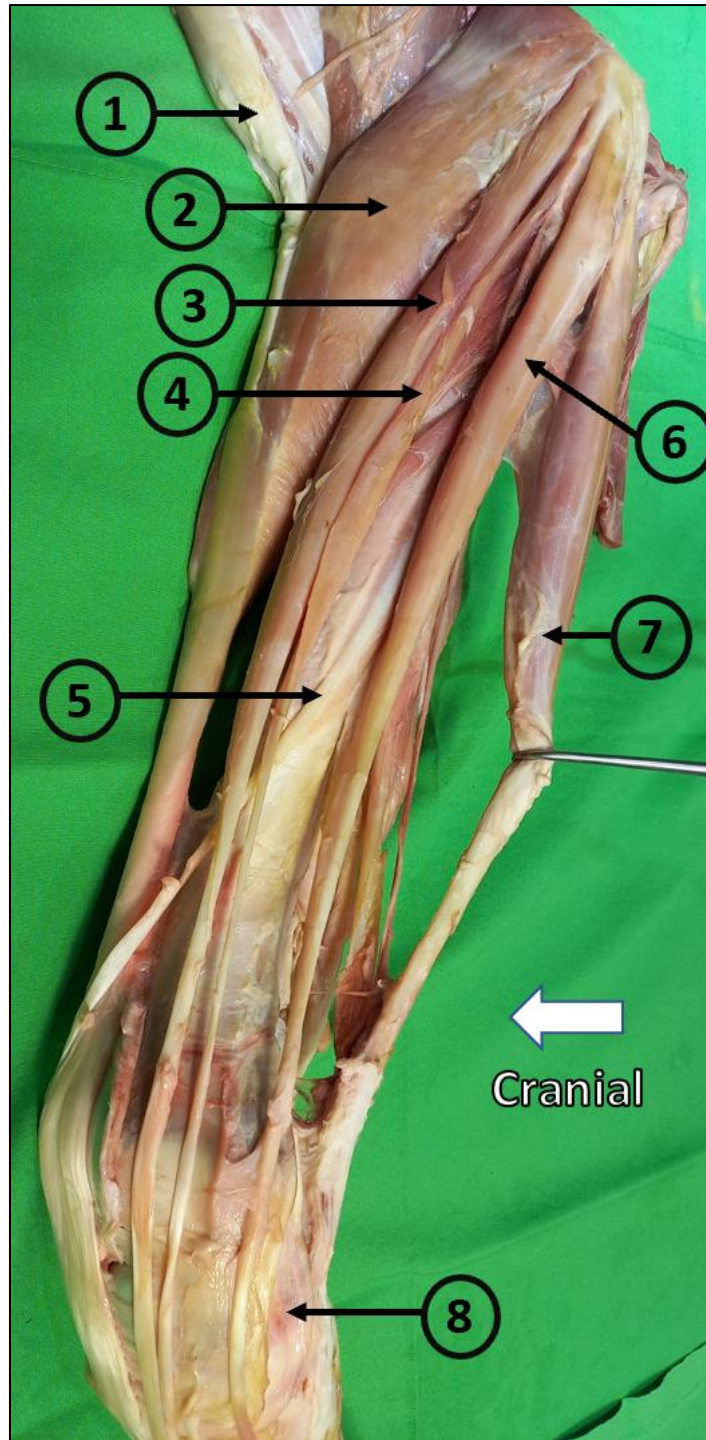


Figure 14: Extensor muscles of the carpus and phalanges, Lateral view.
(After two-day soak in water).

- (1) Lacertus fibrosus, (2) M. extensor carpi radialis, (3) M. extensor digitorum communis (medialis),
 (4) M. extensor digitorum communis (lateralis),
 (5) M. abductor digiti I longus, (6) M. extensor digitorum lateralis,
 (7) M. extensor carpi ulnaris, (8) Retinaculum extensorum.

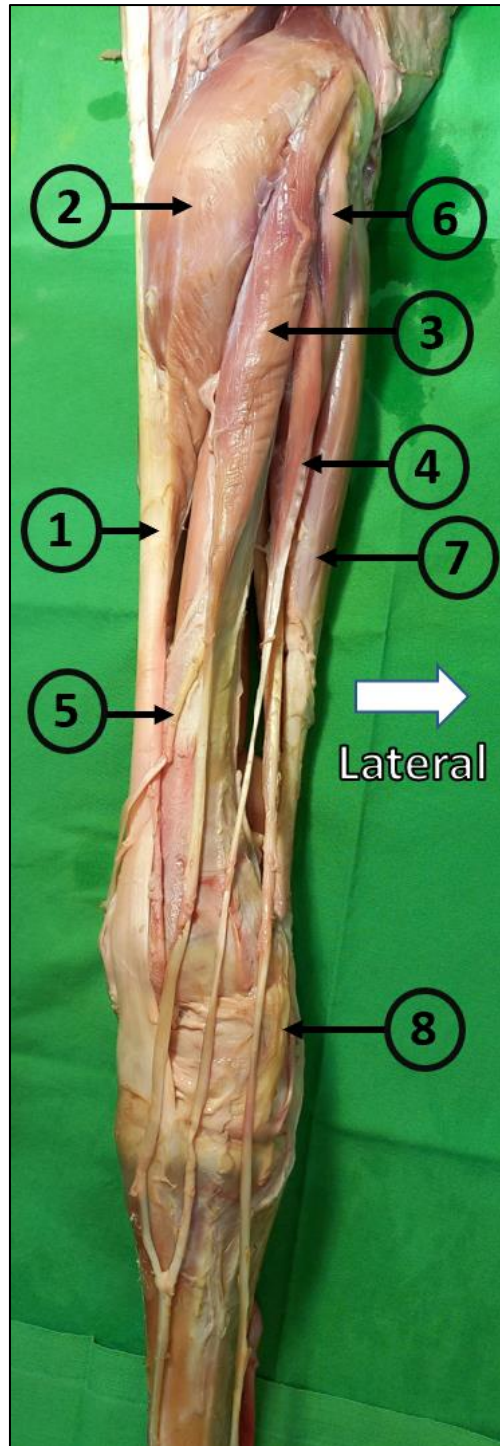


Figure 15: Extensor muscles of the carpus and phalanges, Cranial view.
(After two-day soak in water).

- (1) Lacertus fibrosus, (2) M. extensor carpi radialis, (3) M. extensor digitorum communis (medialis),
 (4) M. extensor digitorum communis (lateralis), (5) M. abductor digiti I longus,
 (6) M. extensor digitorum lateralis, (7) M. extensor carpi ulnaris, (8) Retinaculum extensorum.

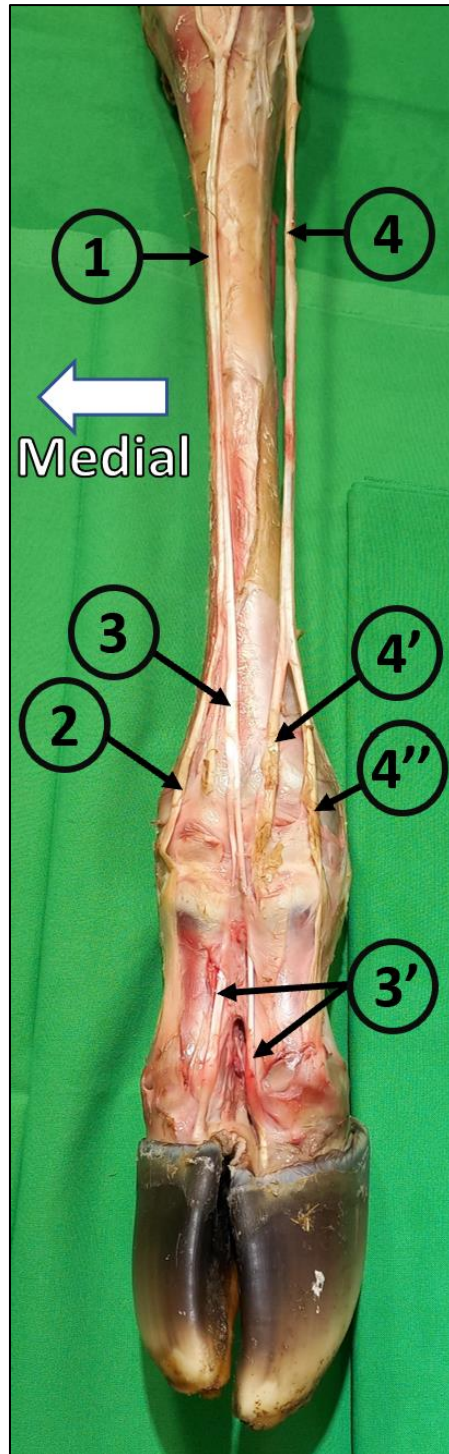


Figure 16: Extensor tendons of the phalanges, Dorsal view.
(After two-day soak in water)

- (1) Common sheath of M. extensor digitorum communis, (2) M. extensor digitorum communis (medialis), (3) M. extensor digitorum communis (lateralis), (3') Its axial branches to Os unguare, (4) M. extensor digitorum lateralis, (4') Its medial branch, (4'') Its lateral branch.

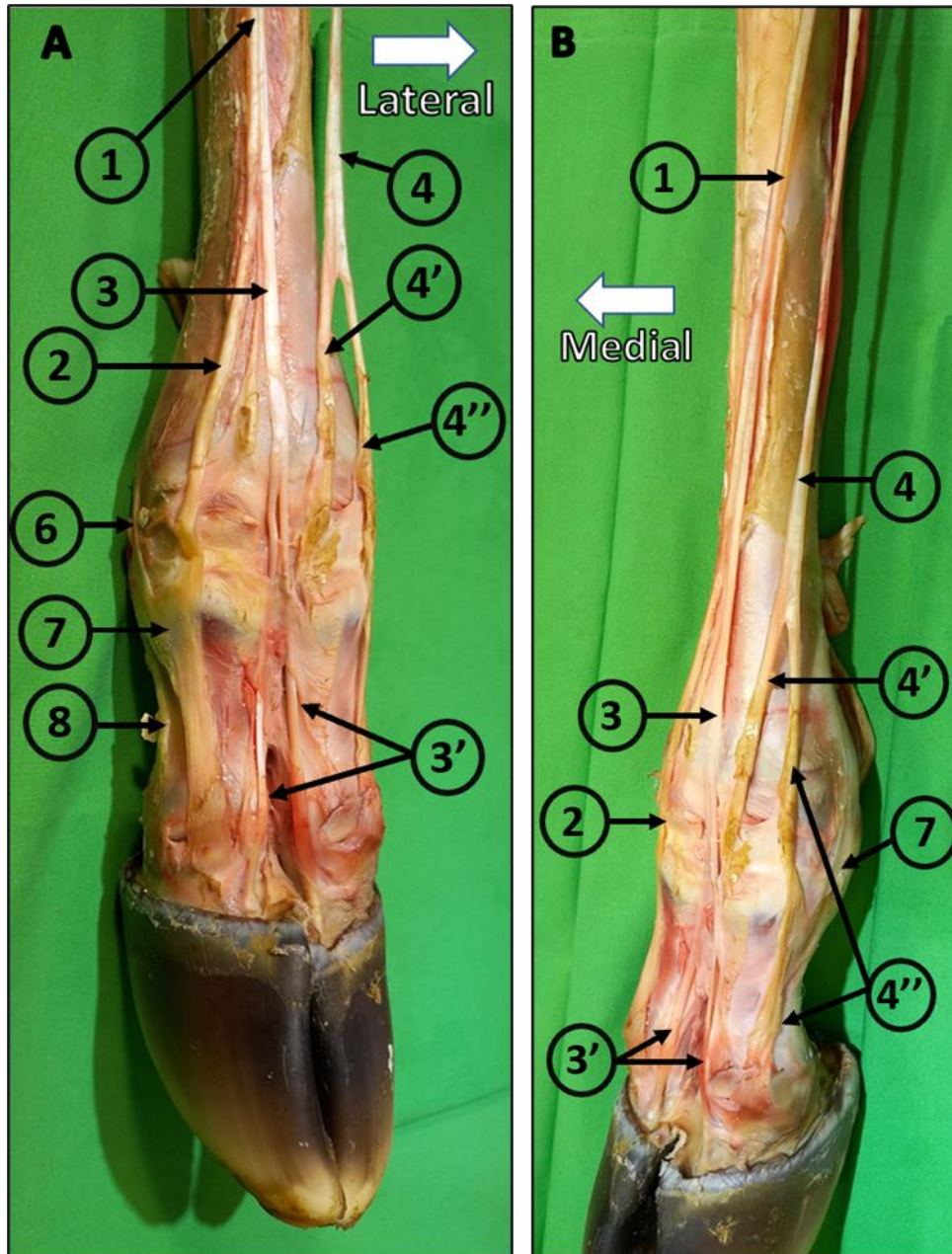


Figure 17: Tendons and ligaments of the fetlock joint.

(A): Dorso-Medial view.

(B): Dorso-Lateral view.

(1) Common sheath of *M. extensor digitorum communis*, (2) *M. extensor digitorum communis* (medialis), (3) *M. extensor digitorum communis* (lateralis), (3') Its axial branches to *Os unguare*, (4) *M. extensor digitorum lateralis*, (4') Its medial branch, (4'') Its lateral branch, (5) *retinaculum extensorum*, (6) *Lig. collaterale mediale* of fetlock joint, (7) *Tractus appositus* (ex *m. interosseus medius*), (8) *Ligamentum palmare abaxiale articulationis interphalangis proximalis*

5. Discussion and conclusion

5.1. Limitations

One of the biggest limitations of this study is that the findings highlighted in this research may be attributed to this single individual specimen. On the other hand, these findings may justify further research in order to establish or negate additional morphological variations among the sub species. As previous papers have established osteological subspecies differences [43], it is only logical to assume there may be myologic, vascular or neural variations as well that can be used to better understand these subspecies.

In addition, due to the nature of this dissertation and limited technical resources available, the theory of cyclical compression-decompression via a hoof pump, first hypothesized by Hargens *et al.* [62], could not be inspected as this requires a living specimen. To better understand how the giraffe is able to counter the gravitation hydrostatic pressure to pump venous blood back towards the heart, the authors recommend further work including the application of positive contrast imaging. Furthermore, the venous valves of the giraffe, described in the literature, were not studied in this research as they were thoroughly examined in the cited papers [34, 61].

In the neurological aspect, many hypotheses have been suggested regarding the mechanism which enables the giraffe to transfer an electric impulse along its long limbs. As some of these hypotheses were based on research performed on *nervus ischiadicus* of the hindlimb [59, 64], the authors suggest performing complementary research on the forelimb as well and assess the diameter of the main nerves, the number of myelinated fibers, and the motoric-sensory composition of the nerve fibers.

The young age of the calf presented a challenge of not having all muscles and tendons fully developed, however it allowed us a somewhat easier access to the demonstrate the structures. Development of the bone features, such as the small *tuberositas deltoidea* indicated in the literature, could not be evaluated due to the very young age of the calf.

Finally, this work has attempted to focused on the main arteries of the forelimb, however in order to get a better and more wholesome understanding of the entire vascular system, including the smaller arteries and veins of the digits, the authors recommend filling the vessels with silicone filling material prior to future dissections to facilitate future research.

The following findings are compared with two common domesticated species, the equine and bovine, as the giraffe forelimb appears to share characteristics with both species, together and

separately. For anatomical comparisons with the equine and bovine the work of Nickel *et al.* [44] and Illustrated Veterinary Anatomical Nomenclature [67] was consulted unless indicated otherwise.

5.2. Muscles

In the work on this individual Rothschild's Giraffe, the authors have found both *m. deltoideus* (figure 12) and *m. teres major* (figure 2) to exist. This finding contradicts the assumption made by Onwuama *et al.* (2021) assuming the absence of *m. teres major* in addition to the absence of *tuberositas deltoidea* and *tuberositas teres major* as both were found as the clear insertion points of their counterpart muscles. It is important for the authors to note that *m. deltoideus* of this individual only consisted of *pars scapularis* as the *acromion* was indeed absent, corresponding to its absence in Jahan's work (2020). Although the *acromion* is commonly found in other ruminants, this find shows similarity to the equine as horses also do not possess an *acromion*, yet they have the two muscle heads blended. However, it is important to add that in the work by Damian *et al.* (2012), the *acromion* was present and may have had *pars acromialis*, this could not be further established as their work was oriented on the osteological aspect rather than the myology. In our individual giraffe, *m. deltoideus* originates from the *spina scapulae* by a strong *fascia* whilst a distinct tendinous portion originated from the proximal part of *margo caudalis* of the *scapula*, not a fleshy attachment as in the equine.

An additional note to be taken into consideration is that the work of Onwuama *et al.* (2021) was performed on West African Giraffes whereas in the work of Damian *et al.* (2012) and Jahan (2020) the subspecies were not identified. Therefore, the above-mentioned morphological differences may be attributed to subspecies differences.

The authors were not able to find *ligamentum transversum humeri* between tuberculum majus and minus, however, the authors did find *bursa intertuberculatis* around the tendon of *m. biceps brachii* as it is in equine.

The *lacertus fibrosus*, stemming from *m. biceps brachii* appears to be somewhat developed to the extent it resembles the level of development in the equine muscle counterpart as it was found to occupy a relatively large surface area of *m. extensor carpi radialis* (Figure 3, 8, 12, 13, 14). Joly and Lavocat (1846) argued that *m. triceps brachii* is unique to the giraffe by having five heads instead of the three its name suggests [36]. The authors however, verified the existence of only three heads, *caput longum* (Figure 2, 6, 8, 12), *caput laterale* (Figure 12), and *caput*

mediale (Figure 2, 6, 8), on this individual, similarly to equine. The authors suggest that the reason for Joly and Lavocat's assumption resides in the close proximity to a neighboring muscle that may have led to misidentification. However, subspecies morphological differences cannot be negated entirely. There is room for more research, which may indicate either the existence of a fifth muscle or an adaptation of the existing muscle heads that may split their origin.

Musculus pronator teres appears to exist as a rudimentary ligament (Figure 8), similarly as in the equine.

Musculus flexor carpi ulnaris in the equine has both *caput humerale* and *caput ulnare* whereas in the bovine it has only an *caput ulnare* [52]. It is important to note that there are some conflicting opinions regarding the bovine having two muscle points of origin as well. Given these facts, in this dissection two muscle heads were identified (Figure 6, 8).

The *m. extensor digitorum lateralis* inserts on the dorsal surface of *os compedale* as a single tendon in the equine. In the ruminants, this muscle has one insertion tendon which is further distal in the proximal interphalangeal joint area. However, the authors have found that in this individual giraffe the tendon of *m. extensor digitorum lateralis* splits distinctively more proximal, at the distal area of *os metacarpale* (Figure 15, 16). Its medial branch appears to insert on the proximal aspect of *os compedale* (Figure 16A), similar as in the equine, however its placement is rather more medial to that described in the literature. Meanwhile, its lateral branch appears to insert dorso-laterally at the level between *os compedale* and *os coronale* of the fourth digit (Figure 16B), similarly to as it inserts in the ruminant dorso-laterally on *os coronale*. This in fact indicates that in the giraffe, the tendon of this muscle attributes a functional combination of both the equine and ruminant.

5.3. Blood vessels

The arteries of the forelimb branch out from one large trunk which consists of three main segments which will be discussed – *arteria axillaris*, *a. brachialis*, and *a. mediana*. The arteries of the forelimb begin with the *arteria axillaris*. This main trunk crosses the shoulder to continue distally and caudally to the humerus whilst giving out several important branches that supply the muscles of the brachium. Amongst these arteries are the *a. subscapularis*, *a. suprascapularis*, *a. thoracodorsalis*, and *a. circumflexa humeri cranialis*.

A feature worth noting is that unlike both the equine and the bovine, in which *a. thoracodorsalis* is a branch of *a. subscapularis*, in the giraffe *a. thoracodorsalis* originates as a separate artery directly from *a. axillaris* (Figure 4, 5).

The *a. collateralis radialis* originates from *a. circumflexa humeri caudalis* to follow *n. radialis* as it does in the bovine whereas in the equine it branches from *a. profunda brachii* (Figure 5B). The *a. axillaris* becomes *a. brachialis* once reaching the level of *tuberositas teres major*. In turn, the *a. brachialis*, passes craniomedially to the *articulatio cubiti*. This artery gives out several important branches as well, such as *a. profunda brachii*, *a. bicipitalis*, *a. transversa cubiti*, *a. interossea communis*, and *a. profunda antebrachii*. These branchings are responsible to supply muscles at the elbow level. In the giraffe, the *a. bicipitalis* appears to branch out of *a. brachialis* further distally (Figure 5A, 5B). This shows closer similarity to the bovine, since in the equine the distance between the branching of *a. profunda brachii* and *a. bicipitalis* is somewhat larger. In addition, in the bovine *a. bicipitalis* branches out well before *a. transversa cubiti* branches as well. However, in the giraffe, just as in the equine, *a. bicipitalis* branches fairly adjacent to *a. transversa cubiti* (Figure 5A, 5B). Whereas in equine the *a. transversa cubiti* branches from *a. brachialis* at the same level as *a. interossea communis* branches out as well, in the giraffe the *a. transversa cubiti* branches from *a. brachialis* further proximally to the branching of *a. interossea communis* (Figure 4, 6, 7). This is in correlation with the morphology of the bovine. The *a. collateralis ulnaris* issues from the *a. interossea communis* in a similar fashion as it does in the bovine, whereas in the equine it issues more proximally and separately from the *a. interossea communis*. The *a. recurrens ulnaris* was found to be branching from *a. interossea communis*.

The next segment of *a. brachialis* is named *a. mediana*, which runs caudomedially along the *nervus medianus* and under the protection of *m. flexor carpi radialis*. During its course distally it arches with branches of *a. interossea communis*, arches from which the palmar aspect of the distal limb is supplied.

5.4. Conclusion

Our research was the first to demonstrate in detail the anatomical topography of the giraffe forelimb musculature and vasculature. The nerves demonstrated similarity to the ruminant until the height of *articulatio cubiti*, the authors did not follow precisely further distally as the focus

was on other aspects of the limb. Despite the limitations presented, we believe our work could be a useful tool for clinicians in the effort to treat and conserve this wonderful species.

In order to achieve this goal, we have created images and videos, together with a reconstructed skeleton of the limb to be presented in the university's museum, which are available on the university's official website for both students and clinicians to observe. In the future we are aiming to perform the same documentation on the hindlimb and, if opportunity presents, on an adult.

6. Summary

The Rothchild's giraffe (*Giraffa camelopardalis rothschildi*) is one of nine recognized giraffe subspecies. The International Union for Conservation of Nature recognizes the species vulnerable and the subspecies near threatened, therefore great importance is placed upon their conservation. As case studies show that limbs of ungulates require critical care, it is important for veterinarians tasked with the treatment of these species, both wild and in captivity, to understand the intricate anatomy of such species in order to best treat health concerns which may arise, and therefore best support the overall conservation efforts.

Literature already exists regarding the anatomy of the giraffe; however only descriptive sources can be found in regard to the muscles and vasculature of the limbs. Previous dissection studies had only produced diagrams and of the hind limb alone. Despite additional available osteological research of the hind limb and several case studies that involve radiological interpretations there was no actual descriptive imagery to be found. This led our team to the clear conclusion that an imagery atlas of the forelimb muscles and vasculature structures was an essential supplementation to the available literature.

During the course of this work, we dissected the body of a deceased 10-day old female Rothschild's giraffe calf and documented the dissection with photographs. The images were then processed and labelled according to the literature and based on comparative anatomy.

The aim of this work was to create an anatomy atlas that shows the intricate interaction of muscles and blood vessels of the giraffe forelimb. The macroscopic anatomy of the animal is presented with images taken at autopsy to provide veterinarians and researchers with a well-detailed clinical approach to the anatomy of the giraffe.

7. Összefoglaló

A zsiráf kilenc alfajának egyike a Rothschild-zsiráf (*Giraffa camelopardalis rothschildi*). A Természetvédelmi Világszövetség (International Union for Conservation of Nature) besorolása alapján a zsiráf faj a sebezhető, míg a Rothschild-zsiráf a veszélyeztetett állatok közé tartozik, így nagy hangsúlyt kell fektetni az alfaj megőrzésére. A patásokról szóló esettanulmányok alapján a lábvég kritikus terület, emiatt fontos, hogy az állatorvosok, akik a vadon élő illetve a fogságban tartott zsiráfok gyógyításával foglalkoznak, ismerjék e faj bonyolult anatómiáját a lehető legjobb gyógyítás érdekében, ezzel elősegítve a zsiráfok védelmében tett erőfeszítéseket. A zsiráf anatómiájáról számos szakirodalom található, de a végtagok érrendszeréről és izomzatáról csak egyszerűbb, illusztrációk nélküli leírások elérhetőek. Korábbi boncolási tanulmányokban kizárólag a hátsó végtagokról készítették ábrák jelentek meg. Leszámítva pár csonttani kutatási eredményt, illetve néhány radiológiai vonatkozású esettanulmányt, nem áll rendelkezésre semmiféle jelentős és részletes képanyagot tartalmazó irodalmi anyag a témával kapcsolatban. Emiatt csapatunk arra a következtetésre jutott, hogy szükség lenne a jelenleg meglévő tanulmányok kiegészítéséhez egy képekkel ellátott atlaszra, amely bemutatja az első végtagok izomzatát és érrendszerét.

A kutatásunk során csapatunk felboncolt egy elpusztult 10 napos nőstény Rothschild-zsiráf borjút és a boncolást fényképekkel dokumentálta. Ezt követően a képeket feliratoztuk a meglévő tanulmányok, illetve az ismert fajokkal végzett összehasonlítások alapján

A munkánk célja az volt, hogy egy olyan anatómiai albumot készítsünk, amely tartalmazza a zsiráf elülső végtagján az izmok és az erek aprólékos leírását és szemléltetését. A zsiráf makroszkopikus anatómiáját a boncolás során készült képekkel mutattuk be abból a célból, hogy állatorvosok és kutatók számára egyaránt teljeskörű betekintést nyújthassunk a zsiráf anatómiájába.

8. Acknowledgements

I would like to wholeheartedly thank the Department of Anatomy and Histology of the Budapest University of Veterinary Medicine, and especially its head, Prof. Dr. Sótonyi Péter, for the opportunity of performing this research.

In addition, I would like to acknowledge Kittenberger Kálmán Zoo & Botanical Garden and its veterinarian, Dr. Tóth-Almási Péter, for referring the carcass to the University of Veterinary Medicine in Budapest.

I would like to express my sincere gratitude to my direct supervisor, Dr. Kondor Milán, and to my advising supervisor, Dr. Reinitz László Zoltán, for showing confidence in me and giving me the opportunity to perform this study under their guidance.

A big thank you to Mr. Pethes Zoltán, technician at the department of Anatomy and Histology, for his assistance in preparation of the limb and facilitating the dissection.

I wish to extend a personal gratitude and to acknowledge the help provided by Mr. Björn Benedikt Sigurðarson who has assisted greatly in the labelling work, and to Miss Louise Sarah Skinner for offering deep insights into this study. A thank you goes as well to Miss Elsa Similowski for her editorial help.

9. Bibliography

1. Linnaeus C (1758) Mammalia Pecora - 30. Cervus. In: *Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis synonymis, locis*, 10th ed. Laurentii Salvii, Holmiae [Stockholm], p 66
2. Owen-Smith RN (1988) *Megaherbivores - the influence of very large body size on ecology*. Cambridge University Press, Cambridge
3. Gray JE (1821) On the Natural Arrangement of Vertebrate Animals. *London Medical Repository* 15:297–310
4. Owen R (1848) Description of teeth and portions of jaw of two extinct anthracotherioid quadrupeds (*Hyopotamus vectianus* and *Hyop. bovines*) discovered by the Marchioness of Hastings in the Eocene deposits of the N.W. coast of the Isle of Wight: with an attempt to develop Cuvier's idea of the classification of Pachyderms by the number of their toes. *Geological Society of London* 4:103–141
5. Sclater PL (1901) On an apparently new species of zebra from the Semliki forest. In: *Proceedings of the general meetings for scientific business of the Zoological Society of London*. Longmans, Green and Co., London, pp 50–51
6. Bush R M (2003) Giraffidae. In: *Zoo & Wild Animal Medicine*. Elsevier, St. Louise, MO, pp 625–633
7. Fennessy S, Tutchings A, Marais A, Fennessy J (2013) *Africa's Giraffe (Giraffa camelopardalis). A Conservation Guide*. Giraffe Conservation Foundation
8. Kingdon J (1988) *East African Mammals: An Atlas of Evolution in Africa*, 1st ed. University of Chicago Press, Chicago
9. Kingdon J (2004) *The Kingdon Pocket Guide to African Mammals*, 1st ed. Princeton University Press, Princeton, NJ
10. Skinner JD, Smithers RHN (1990) *The Mammals of the Southern African Sub-region*, 2nd ed. University of Pretoria, Pretoria
11. Stuart C, Stuart M (1997) *Field Guide to the Larger Mammals of Africa*, 3rd ed. Ralph Curtis Publishing, Sanibel, FL
12. Lydekker R (1904) On the Subspecies of *Giraffa camelopardalis*. *Journal of Zoology* 74:202–229
13. Dagg AI, Foster BJ (1982) *The Giraffe: Its Biology, Behavior, and Ecology*, 2nd ed. R.E. Krieger Publishing Company, Malabar, FL
14. Winter S, Fennessy J, Janke A (2018) Limited introgression supports division of giraffe into four species. *Ecology and Evolution* 8:10156–10165. <https://doi.org/10.1002/ece3.4490>
15. Fennessy J, Bidon T, Reuss F, Kumar V, Elkan P, Nilsson MA, Vamberger M, Fritz U, Janke A (2016) Multi-locus Analyses Reveal Four Giraffe Species Instead of One. *Current Biology* 26:2543–2549. <https://doi.org/10.1016/j.cub.2016.07.036>
16. O'connor D, Stacy-Dawes J, Muneza A, Fennessy J, Gobush K, Chase MJ, Brown MB, Bracis C, Elkan P, Zaberirou ARM, Rabeil T, Rubenstein D, Becker MS, Phillips S, Stabach JA, Leimgruber P, Glikman JA, Ruppert K, Masiaine S, Mueller T (2019) Updated geographic range maps for giraffe, *Giraffa* spp., throughout sub-Saharan Africa, and

- implications of changing distributions for conservation. *Mammal Review* 49:285–299. <https://doi.org/10.1111/mam.12165>
17. Fennessy S, Fennessy J, Muller Z, Brown M, Marais A (2018) *Giraffa camelopardalis* ssp. *rothschildi*. International Union for Conservation of Nature
 18. Muller Z, Bercovitch F, Brand R, Brown D, Brown M, Bolger D, Carter K, Deacon F, Doherty JB, Fennessy J, Fennessy S, Hussein AA, Lee D, Marais A, Strauss M, Tutchings A, Wube T (2018) *Giraffa camelopardalis*. International Union for Conservation of Nature
 19. Ogotu JO, Piepho H-P, Said MY, Ojwang GO, Njino LW, Kifugo SC, Wargute PW (2016) Extreme Wildlife Declines and Concurrent Increase in Livestock Numbers in Kenya: What Are the Causes? *PLoS ONE* 11:e0163249. <https://doi.org/10.1371/journal.pone.0163249>
 20. Dos Santos S, Adams EA, Neville G, Wada Y, de Sherbinin A, Mullin Bernhardt E, Adamo SB (2017) Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. *Science of The Total Environment* 607–608:497–508. <https://doi.org/10.1016/j.scitotenv.2017.06.157>
 21. Sasaki M, Endo H, Kogiku H, Kitamura N, Yamada J, Yamamoto M, Arishima K, Hayashi Y (2001) The Structure of the Masseter Muscle in the Giraffe (*Giraffa camelopardalis*). *Anatomia, Histologia, Embryologia* 30:313–319. <https://doi.org/10.1046/j.1439-0264.2001.00342.x>
 22. Pérez W, Lima M, Clauss M (2009) Gross Anatomy of the Intestine in the Giraffe (*Giraffa camelopardalis*). *Anatomia, Histologia, Embryologia* 38:432–435. <https://doi.org/10.1111/j.1439-0264.2009.00965.x>
 23. Pérez W, Michel V, Jerbi H, Vazquez N (2012) Anatomy of the mouth of the Giraffe (*Giraffa camelopardalis rothschildi*). *International Journal of Morphology* 30:322–329. <https://doi.org/10.4067/S0717-95022012000100057>
 24. Furuuchi K, Koyabu D, Mori K, Endo H (2013) Physiological Cross-Sectional Area of the Masticatory Muscles in the Giraffe (*Giraffa camelopardalis*). *jmam* 38:67–71. <https://doi.org/10.3106/041.038.0109>
 25. Basu C, Wilson AM, Hutchinson JR (2019) The locomotor kinematics and ground reaction forces of walking giraffes. *Journal of Experimental Biology* 222:jeb.159277. <https://doi.org/10.1242/jeb.159277>
 26. Basu CK, Deacon F, Hutchinson JR, Wilson AM (2019) The running kinematics of free-roaming giraffes, measured using a low cost unmanned aerial vehicle (UAV). *PeerJ* 7:e6312. <https://doi.org/10.7717/peerj.6312>
 27. Basu CK, Hutchinson JR (2022) Low effective mechanical advantage of giraffes' limbs during walking reveals trade-off between limb length and locomotor performance. *PNAS* 119:e2108471119. <https://doi.org/10.1073/pnas.2108471119>
 28. Mitchell G, Skinner JD (2011) Lung volumes in giraffes, *Giraffa camelopardalis*. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 158:72–78. <https://doi.org/10.1016/j.cbpa.2010.09.003>
 29. Cano I, Pérez W (2009) Quantitative Anatomy of the Trachea of the Giraffe (*Giraffa camelopardalis rothschildi*). *Int J Morphol* 27:. <https://doi.org/10.4067/S0717-95022009000300042>

30. Perez W, Lima M, Pedrana G, Cirillo F (2008) Heart anatomy of *Giraffa camelopardalis rothschildi*: a case report. *Veterinari Medicina* 53:165–168. <https://doi.org/10.17221/1937-VETMED>
31. Goetz RH, Warren JV, Gauer OH, Patterson JL, Doyle JT, Keen EN, McGREGOR M, Tiller LM, Smith M, Mance E (1960) Circulation of the Giraffe. *Circulation Research* 8:1049–1058. <https://doi.org/10.1161/01.RES.8.5.1049>
32. Mitchell G, Maloney SK, Mitchell D, Keegan DJ (2006) The origin of mean arterial and jugular venous blood pressures in giraffes. *Journal of Experimental Biology* 209:2515–2524. <https://doi.org/10.1242/jeb.02277>
33. Goetz RH, Keen EN (1957) Some Aspects of the Cardiovascular System in the Giraffe. *Angiology* 8:542–564. <https://doi.org/10.1177/000331975700800609>
34. Østergaard KH, Bertelsen MF, Brøndum ET, Aalkjær C, Hasenkam JM, Smerup M, Wang T, Nyengaard JR, Baandrup U (2011) Pressure profile and morphology of the arteries along the giraffe limb. *J Comp Physiol B* 181:691–698. <https://doi.org/10.1007/s00360-010-0545-z>
35. Petersen KK, Hørlyck A, Østergaard KH, Andresen J, Broegger T, Skovgaard N, Telinius N, Laher I, Bertelsen MF, Grøndahl C, Smerup M, Secher NH, Brøndum E, Hasenkam JM, Wang T, Baandrup U, Aalkjaer C (2013) Protection against high intravascular pressure in giraffe legs. *American Journal of Physiology (Regulatory, Integrative and Comparative Physiology)* 305:R1021–R1030. <https://doi.org/10.1152/ajpregu.00025.2013>
36. Joly N, Lavocat A (1846) Recherches historiques, zoologiques, anatomiques et paléontologiques sur la girafe. *Memoirs de la Societe des Sciences Naturelle de Strasbourg* III:1–112
37. Murie J (1872) On the horns, viscera and muscles of the giraffe, with a record of the post-mortem examination of two specimens killed by a fire. *The Annals and Magazine of Natural History* 4:177–195. <https://doi.org/10.1080/00222937208696563>
38. Kühlnhorn F (1954) Ursprung und Insertion der wichtigsten Muskeln der Vorderextremität der Massagiraffe (*Giraffa camelopardalis tippelskirchi* Mtsch. 1898). *Anatomischer Anzeiger* 101:237–242
39. Gambaryan PP (1974) *How mammals run*. Wiley, New York, NY
40. Berry PSM, Bercovitch FB (2012) Darkening coat colour reveals life history and life expectancy of male Thornicroft's giraffes. *Journal of Zoology* 287:157–160. <https://doi.org/10.1111/j.1469-7998.2012.00904.x>
41. Hall-Martin AJ (1975) *Studies on the biology and productivity of the giraffe giraffa camelopardalis*. University of Pretoria
42. Dadone L (2018) Lameness Diagnosis and Management in Zoo Giraffe. In: *Fowler's Zoo and Wild Animal Medicine, Current Therapy*, 9th ed. Elsevier, p Chapter 88: 623-629
43. Lee V, Solounias N (2022) Osteological foot differences between giraffes from distinct geographical locations; a pilot study. *Zoologischer Anzeiger – A Journal of Comparative Zoology* 296:179–186. <https://doi.org/10.1016/j.jcz.2022.01.001>
44. Nickel R, Schummer A, Seiferle E (1986) *The Anatomy of the Domestic Animals - The Locomotor System of the Domestic Mammals*. Verlag Paul Parey, Berlin, Hamburg

45. Olds JE, Burrough ER, Wilberts BL, Riedesel EL (2015) Giraffe (*Giraffa camelopardalis reticulata*) arthropathy: post-mortem computed tomography, gross pathology and histopathologic findings. Salt Lake City, UT
46. Biewener AA (1983) Allometry of quadrupedal locomotion: the scaling of duty factor, bone curvature and limb orientation to body size. *The Journal of Experimental Biology* 105:147–171. <https://doi.org/10.1242/jeb.105.1.147>
47. Budras KD, Sack WO, Rock S, Horowitz A, Berg R (2009) *Anatomy of the horse*, 5th ed. Schlütersche, Hannover
48. Budras K-D, Habel RE (2003) *Bovine anatomy: an illustrated text*, 1st ed. Schlüter, Hannover
49. Damian A, Stan F, Crişan M, Dezdrobitu C, Ciama I, Irimescu I, Chirilean I, Gudea A (2012) Comparative studies of the thoracic appendicular skeleton in the giraffe and in the cow. *Lucrari Stiintifice - Universitatea de Stiinte Agricole a Banatului Timisoara, Medicina Veterinara* 45:5–12
50. Onwuama KT, Kigir ES, Jaji AZ, Salami SO (2021) Gross Anatomical Studies on the Fore Limb of the West African Giraffe (*Giraffa Camelopardalis peralta*). *Journal of Veterinary Anatomy* 14:13–23. <https://doi.org/10.21608/jva.2021.163578>
51. Jahan S (2020) *Anatomical and Morphometrical Study of the Bones of Forelimb of Giraffe (Giraffa camelopardalis)*. Chattogram Veterinary and Animal Sciences University
52. Dyce KM, Sack WO, Wensing CJG (2010) *Textbook of veterinary anatomy*, 4th ed. Saunders/Elsevier, St. Louis, MO
53. van Sittert SJ, Skinner JD, Mitchell G (2010) From fetus to adult - An allometric analysis of the giraffe vertebral column. *J Exp Zool* 314B:469–479. <https://doi.org/10.1002/jez.b.21353>
54. König HE, Liebich HG (2004) *Veterinary Anatomy of Domestic Mammals, Textbook and Colour Atlas*. Schattauer, Stuttgart
55. Evans HE, Miller ME (2013) *Miller's anatomy of the dog*, 4th ed. Elsevier, St. Louis, MO
56. Adams B, Crabtree P (2011) *Comparative Osteology: A laboratory and Field Guide of common North American Animals*, 1st ed. Academic press, Oxford
57. Yohe LR, Solounias N (2020) The five digits of the giraffe metatarsal. *Biological Journal of the Linnean Society* 131:699–705. <https://doi.org/10.1093/biolinnean/blaa136>
58. van Schalkwyk OL (2006) Bone density and Calcium and Phosphorus content of the giraffe (*Giraffa camelopardalis*) and African buffalo (*Syncerus caffer*) skeletons. *Journal of Zoology* 264:307–315. <https://doi.org/10.1017/S0952836905007247>
59. Mitchell G (2021) *How Giraffes Work*. Oxford University Press, New York, NY
60. Kimani JK, Mbuva RN, Kinyamu RM (1991) Sympathetic innervation of the hindlimb arterial system in the giraffe (*Giraffa camelopardalis*). *The Anatomical Record* 229:103–108. <https://doi.org/10.1002/ar.1092290111>
61. Amoroso EC, Edholm OG, Rewell RE (1947) Venous valves in the giraffe, okapi, camel, and ostrich. In: *Proceedings of the Zoological Society of London. Journal of Zoology, London*, pp 435–440
62. Hargens AR, Millard RW, Pettersson K, Johansen K (1987) Gravitational haemodynamics and oedema prevention in the giraffe. *Nature* 329:59–60. <https://doi.org/10.1038/329059a0>

63. Swadlow HA, Waxman SG (2012) Axonal conduction delays. *Scholarpedia* 7(6):1451. <https://doi.org/10.4249/scholarpedia.1451>
64. More HL, O'Connor SM, Brøndum E, Wang T, Bertelsen MF, Grøndahl C, Kastberg K, Hølyck A, Funder J, Donelan JM (2013) Sensorimotor responsiveness and resolution in the giraffe. *Journal of Experimental Biology* 216:1003–1011. <https://doi.org/10.1242/jeb.067231>
65. Kimani JK, Opole IO (1991) The structural organization and adrenergic innervation of the carotid arterial system of the giraffe (*Giraffa camelopardalis*). *The Anatomical Record* 230:369–377. <https://doi.org/10.1002/ar.1092300310>
66. Nilsson O, Böj S, Dahlström A, Hargens AR, Millard RW, Pettersson KS (1988) Sympathetic innervation of the cardiovascular system in the giraffe. *Blood Vessels* 25:299–307. <https://doi.org/10.1159/000158743>
67. Constantinescu GM (2018) *Illustrated Veterinary Anatomical Nomenclature*, 4th ed. Thieme, Stuttgart

HuVetA

ELECTRONIC LICENSE AGREEMENT AND COPYRIGHT DECLARATION*

Name: Barak Wolnerman

Contact information (e-mail): barak.wolner@gmail.com

Title of document (to be uploaded): Anatomical mapping of a Rothschild giraffe forelimb

Publication data of document: TDK

Number of files submitted: 1

By accepting the present agreement the author or copyright owner grants non-exclusive license to HuVetA over the above mentioned document (including its abstract) to be converted to copy protected PDF format without changing its content, in order to archive, reproduce, and make accessible under the conditions specified below.

The author agrees that HuVetA may store more than one copy (accessible only to HuVetA administrators) of the licensed document exclusively for purposes of secure storage and backup, if necessary.

You state that the submission is your original work, and that you have the right to grant the rights contained in this license. You also state that your submission does not, to the best of your knowledge, infringe upon anyone's copyright. If the document has parts which you are not the copyright owner of, you have to indicate that you have obtained unrestricted permission from the copyright owner to grant the rights required by this Agreement, and that any such third-party owned material is clearly identified and acknowledged within the text of the licensed document.

The copyright owner defines the scope of access to the document stored in HuVetA as follows (**mark the appropriate box with an X**):

- I grant unlimited online access,
- I grant access only through the intranet (IP range) of the University of Veterinary Medicine,
- I grant access only on one dedicated computer at the Ferenc Hutýra Library,
- I grant unlimited online access only to the bibliographic data and abstract of the document.

Please, define the **in-house accessibility of the document** by marking the below box with an **X**:

I grant in-house access (namely, reading the hard copy version of the document) at the Library.

If the preparation of the document to be uploaded was supported or sponsored by a firm or an organization, you also declare that you are entitled to sign the present Agreement concerning the document.

The operators of HuVetA do not assume any legal liability or responsibility towards the author/copyright holder/organizations in case somebody uses the material legally uploaded to HuVetA in a way that is unlawful.

Date: Budapest, 17.09.2022



Author/copyright owner
signature

HuVetA Magyar Állatorvos-tudományi Archívum – Hungarian Veterinary Archive is an online veterinary repository operated by the Ferenc Hutjra Library, Archives and Museum. It is an electronic knowledge base which aims to collect, organize, store documents regarding Hungarian veterinary science and history, and make them searchable and accessible in line with current legal requirements and regulations.

HuVetA relies on the latest technology in order to provide easy searchability (by search engines, as well) and access to the full text document, whenever possible.

Based on the above, HuVetA aims to:

- *increase awareness of Hungarian veterinary science not only in Hungary, but also internationally;*
- *increase citation numbers of publications authored by Hungarian veterinarians, thus improve the impact factor of Hungarian veterinary journals;*
- *present the knowledge base of the University of Veterinary Medicine Budapest and its partners in a focussed way in order to improve the prestige of the Hungarian veterinary profession, and the competitiveness of the organizations in question;*
- *facilitate professional relations and collaboration;*
- *support open access.*

DECLARATION REGARDING TDK RESEARCH PAPER-THESIS EQUIVALENCE

I hereby declare the thesis entitled “*Anatomical mapping of a Rothschild’s giraffe forelimb*” is identical in terms of content and formal requirements to the TDK research paper submitted in 2022.

Date: 18.10.2023



.....
(Name of student)



Thesis progress report for veterinary students

Name of student: *Barak Wolnerman*

Neptun code of the student: *E7SCKN*

Name and title of the supervisor: *Dr. Kondor Milán - Research fellow*

Department: *Department of Anatomy and Histology*

Thesis title: *Anatomical mapping of a Rothschild's giraffe forelimb*

.....

Consultation – 1st semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2022	6	13	MEETING – IDEA DISCUSSION	<i>[Signature]</i>
2.	2022	6	21	MEETING – FOLLOW UP ON LITERATURE REVIEW FINDINGS	<i>[Signature]</i>
3.	2022	6	30	CARCASS DISSECTION	<i>[Signature]</i>
4.	2022	8	9	EMAIL CORRESPONDENCE REGARDING IMAGES FROM DISSECTION	<i>[Signature]</i>
5.					<i>[Signature]</i>

Grade achieved at the end of the first semester: *5*

Consultation – 2nd semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2022	9	22	EMAIL CORRESPONDENCE REGARDING ABSTRACT	<i>[Signature]</i>
2.	2022	9	23	MEETING – ABSTRACT FINALIZATION	<i>[Signature]</i>
3.	2022	10	11	EMAIL CORRESPONDENCE REGARDING IMAGE LABELLING	<i>[Signature]</i>
4.	2022	10	14	MEETING – FINAL PROOFING OF TEXT AND CONTENT	<i>[Signature]</i>
5.					<i>[Signature]</i>

Grade achieved at the end of the second semester: *5*



The thesis meets the requirements of the Study and Examination Rules of the University and the Guide to Thesis Writing.

I accept the thesis and found suitable to defence,

dr. Gonda Katalin

signature of the supervisor

Signature of the student:

Signature of the secretary of the department:

Date of handing the thesis in: *2023. 11. 03.*

