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Anatomical Features Related to the Locomotion of the Brown Bear (Ursus arctos) Zeugopodium

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The present study aimed to examine the bones and muscles of the Brown bear's (*Ursus arctos*) zeugopodium by macroscopic dissection and identification on 18 thoracic and pelvic limbs, from 5 male and 4 female bears. The features of the muscles and bony structures responsible for the rotation of the antebrachial bones and for the plantar flexion with the eversion of the autopodium in relation to the adaptive mechanisms of the limb to the environment of the Brown bear were investigated. The obtained results were analyzed and compared with the pentadactyl extremity of the dog, cat, rabbit, and human to highlight the specific adaptation of the limbs in the Brown bear. Understanding the locomotion of the limbs is important for veterinary neurology, orthopedics, and traumatology, where the specific adaptation ability should be considered for a better diagnosis and correct treatment.

Key words: Brown bear, supination, pronation, radius, zeugopodium, *m. soleus*

Introduction

As part of the suborder Caniformia of the order Carnivora, the Brown bear has some features of the Canidae family and has been compared to both the dog [14, 26] and the cat [26], but also to the human [9]. In recent years, some morpho-functional and histological studies of the stomach and adrenal glands of the Brown bear have been performed [22, 23]. In our previous research Brown bear arteries, veins, and nerves of the zeugopodium were examined and compared with the dog, cat, and human [20, 21]. Devis 1941 established a similarity between the blood vessels of the thoracic limb of the Red panda (*Ailurus fulgens*) and ursids, while a study on the Spectacled bear (*Tremarctos ornatus*) and Himalayan bear (*Ursus thibetanus*) showed the most appropriate site for blood collecting from the cephalic vein [8, 18]. From an anatomical point of view, the skeletal system of the bear has been widely researched [10, 11, 15, 19]. Sasaki et al. [24] studied the pelvic limb muscles of the Malayan Sun bear

(*Helarctos malayanus*), Polar bear (*Ursus maritimus*), Brown bear, and Giant panda (*Ailuropoda melanoleuca*) concerning their climbing abilities. Amaike et al., 2021 compared the forearm skeletal mobility of Himalayan, Brown, and Polar bears [1]. From the information obtained could be concluded that supination is the movement that is often implemented by the bear. The limited data on the development and function of the musculature related to it drove the authors to study the musculature of the zeugopodium. In the present study the bone structures, the muscles, and their function in the Brown bear were compared with the available data in the literature for the dog, cat, rabbit, and human [1, 2, 5, 6, 7, 11, 13, 28].

Material and Methods

All bear cadavers in the present research are animals from the "Dancing Bear Park" in Belitsa, Bulgaria, who died naturally or were euthanized for medical reasons. The limbs of nine bears were included in the study – 5 male and 4 female, between 30-40 years of age. The skin in the distal part of the limbs was carefully removed. The muscles and their insertion tendons in the regions of interest were dissected and photographed with Lumix DC FZ82 (Panasonic®, Japan). The bones from the same cadavers were prepared by boiling water method with subsequent immersion in diluted with purified water to 15% Hydrogen peroxide (30% Valerus®, Bulgaria) for 24 hours. So prepared bones of the zeugopodium were analyzed and photographed. All terms of the anatomical structures are consistent with Nomina Anatomica Veterinaria [28] and the illustrated nomenclature [5].

Results and Discussion

Craniolaterally on the antebrachium in the Brown bear below *v. cephalica* the strong *m. brachiradialis* was identified, which ends in the distal quarter along the medial edge of the radius, above *proc. styloideus medialis*. Laterally and caudally to it were located the divided in two *m. extensor carpi radialis longus* and *brevis*, as the long ended at the base of the second metacarpal bone, and the short on the third (**Fig. 1A, B; Fig. 2A, B**). Beneath the radial carpal extensors and the common digital extensor, the strong and covered by shiny tendinous sheet *m. supinator* was identified, the insertion of which reached the distal quarter of the radius (**Fig. 2B**). Next to its insertion from the two antebrachial bones started the *m. abductor digiti I [pollicis] longus*, which ended at the base of the first metacarpal bone (**Fig. 1A, B; Fig. 2A, B**). According to Amaike et al. 2021, the ranges of rotation of the radius around the ulna are 74.3° - 80.6° in young Asiatic black bears, and 71° - 80° in adults, while in young Brown bears - 70° - 78.5°, and adult 36.2° - 54.0°. The Polar bear has the most limited movements of about 39.3°. The rotation in dogs is from 20° to 50° and in the cat is over 100° [27]. Belu et al., 2012 established that in humans the angle of rotation is 180°, in dogs is 20°, and in cats 80°. In rabbits, the two bones are strongly curved and fixed together by a fibrous interosseous connection (*syndesmosis*) [6]. Amaike et al. 2021 discuss that there is no significant difference between the studied bear species in bringing food to the mouth, but the difference comes from the natural habitat and food-finding techniques.

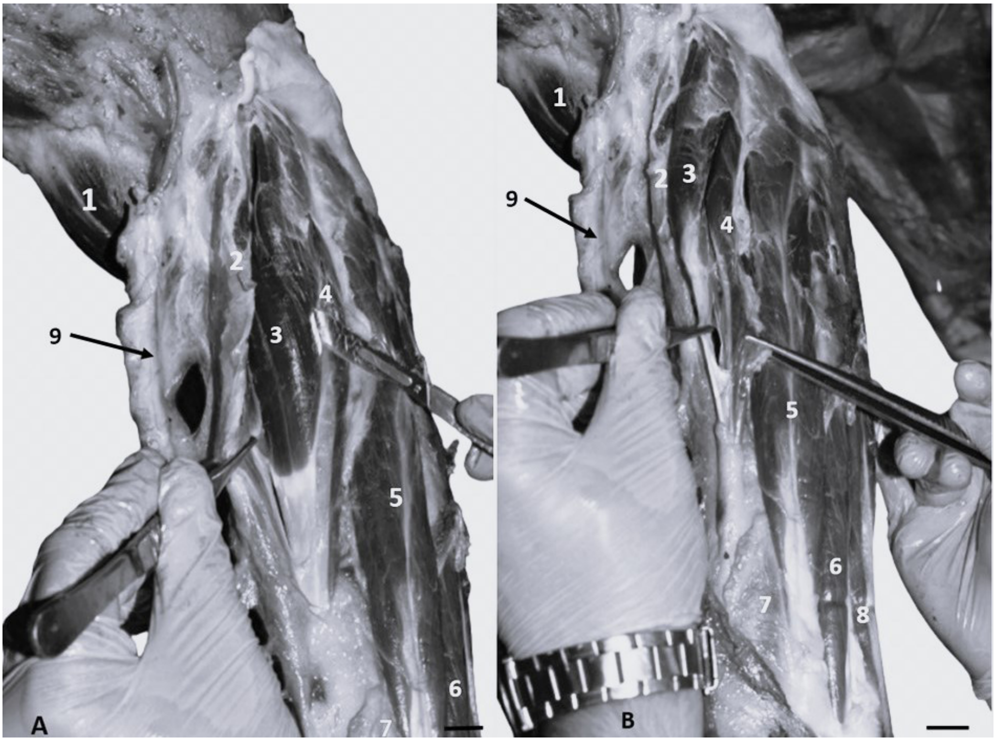

Fig. 1. Craniolateral muscles of the forearm of the Brown bear. **1.** *m. biceps brachii*; **2.** *m. brachioradialis*; **3.** *m. extensor carpi radialis longus*; **4.** *m. extensor carpi radialis brevis*; **5.** *m. extensor digitorum communis*; **6.** *m. extensor digitorum lateralis*; **7.** *m. abductor digiti primi [pollicis] longus*; **8.** *m. extensor carpi ulnaris [m. ulnaris lateralis]*; **9.** *v. cephalica*; Bar = 2 cm.

The Asiatic black bear is smaller, and its habit is associated with tree climbing at all ages like the Brown bear at a young age, which is accomplished with supination of the forelimbs thus hugging the trees. This ability in Polar and adult Brown bears is lost as they increase in weight and size with the onset of puberty, as the weighting is associated with the colder climate in their habitat [1] and with the reproductive rates in female Brown bears [4, 12]. Inward rotation (pronation) is believed to be limited, occurring when landing from ice floes on snow, other terrain, or water [1]. Bears are good swimmers, but they swim like dogs, which does not include the supination and pronation movement [1]. The rotational movements are also assisted by the carpal bones, being limited in *art. radiocarpea* in humans [2] and situated between the radius and the intermedioradial carpal bone in the bear. This carpal bone moves with the radius during forearm pronation/supination. The carpal joint also allows extension/flexion and abduction/adduction of the thoracic limb at the wrist [17].

From the dissections and analysis conducted by the present study, the authors can point out that the supination is accomplished by several muscles – *m. brachioradialis, m. extensor carpi radialis longus et brevis, m. supinator* and *m. abductor digiti primi [policis] longus*. The brachioradial muscle, which performs semi-pronation and semi-supination in humans [2, 16], is also well developed in the Brown bear with a more distal insertion compared to the dog. It is always present in the cat [5, 27, 28], in 39%

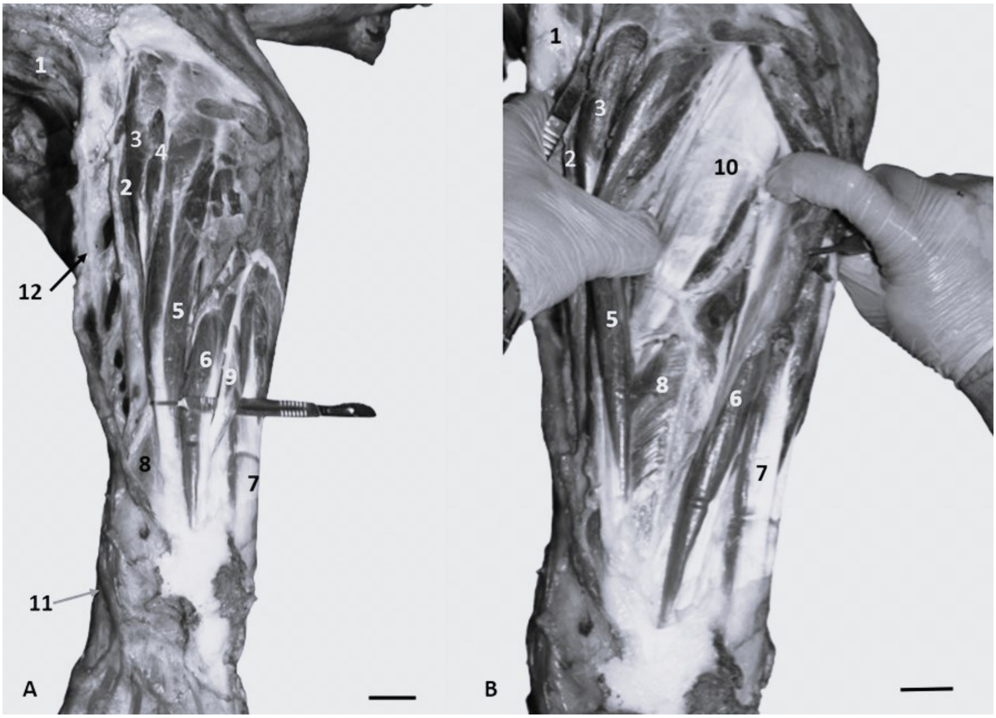

Fig. 2. Superficial (A) and deep (B) craniolateral muscles of forearm of the Brown bear. **1.** *m. biceps brachii*; **2.** *m. brachioradialis*; **3.** *m. extensor carpi radialis longus*; **4.** *m. extensor carpi radialis brevis*; **5.** *m. extensor digitorum communis*; **6.** *m. extensor digitorum lateralis*; **7.** *m. extensor carpi ulnaris [m. ulnaris lateralis]*; **8.** *m. abductor digiti primi [pollicis] longus*; **9.** *m. extensor digiti [pollicis] primi et secundi*; **10.** *m. supinator*; **11.** *v. cephalica accessoria*; **12.** *v. cephalica*. Bar = 2 cm.

of the dogs [13], and absent in the rabbit [7]. *Mm. extensor carpi radialis longus et brevis* are completely separated, they extend and abduct the wrist in humans [2], which is also observed in the Brown bear and cat, while in the dog and rabbit the muscles are partially fused in the region of their bellies and separate only in their insertions [5, 7, 13, 27, 28]. *M. supinator* is limited to the proximal one-quarter of the radius in the dog, to the middle in the cat, and distal in the bears we studied, while in the rabbit the muscle is absent [2, 5, 7, 13, 27, 28]. *M. abductor digiti primi [policis] longus* is well-developed in humans [2] and especially in the Brown bear, where was found attached just next to the insertion of *m. supinator*. In the bear and the cat, the abduction of the wrist is carried out in *art. radiocarpea* and first digit in combination with preceding supination, while in dogs and rabbits, these movements are limited [2, 5, 7, 13, 27, 28]. *M. biceps brachii* is also included in the supination in bears, cats, and humans [2, 6, 27]. Pronation is carried out by only two muscles - *m. pronator teres* and *m. pronator quadratus* [2]. In the Brown bear was found *m. pronator teres*, with a short belly and a long tendon that attaches to the medial edge at the distal third of the radius, approaching the insertion of *m. supinator* (**Fig. 3A, B**). The pronator teres muscle is stronger and longer in the cat compared to the dog [13, 27], where is shorter and functions primarily as a flexor of the elbow joint [13], while in the rabbit is even weaker and rudimentary [7]. This muscle is the largest in humans and consists of the humeral and ulnar head

[2]. *M. pronator quadratus* lies medially on the interosseous antebrachial membrane between the bodies of the radius and ulna. In the Brown bear, as in the cat, the muscle was found covered by a shiny tendon sheath which makes it stronger, being situated distally between the two bones of the forearm [13, 27, 28]. From our observations the small number of muscles performing pronation as a type of movement, although limited, is in great percentage in the cat and young Brown bear.

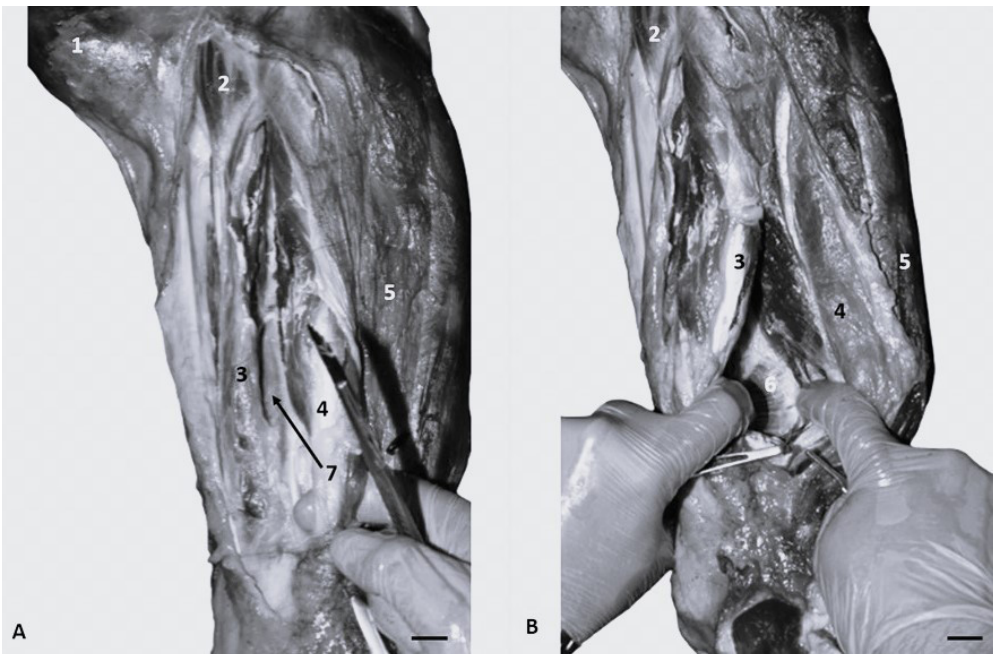

Fig. 3. Superficial (A) and deep (B) caudal muscles of the forearm of the Brown bear, medial view. **1**. *m. biceps brachii*; **2.** *m. pronator teres*; **3.** *m. flexor carpi radialis*; **4.** *m. flexor digitorum superficialis*; **5.** *m. flexor carpi ulnaris*; **6.** *m. pronator quadratus*; **7.** *v. mediana*. Bar = 2 cm.

Proximal rotation of the radius and ulna occurs in-between *cirumferntia atiucularis* of the head of the radius located in *incisura radialis* between the two *proc. coronoideus lateralis et medialis* of the ulna, shown in **Fig. 4A, B, C**, in confirmation of what was established by other authors [6, 11]. The distal rotation is between *cirumferntia artucularis* of the head of the ulna and *incisura ulnaris* of the radius [6, 11], relevant to the preceding abduction of the wrist and finger and supination [2]. In the young to adult Brown bear, the rotation is 36°-78° [1], which is due to the interrupted *cirumferntia articularis* of the radius [1]. This discontinuity was confirmed (**Fig. 4A**), whereas in humans and cats, the radial head is completely round without discontinuity [6, 11], in the dog it is half-complete, and in the rabbit, is presented by two-faceted rudimentary articular surfaces [6, 7, 11]. The greater degree of rotation of the radius in the cat compared to the Brown bear could be explained, in addition to the round *circumferentia articularis*, with the significantly lighter weight, as well as the constant climbing, which is part of their behavior and habit [1, 6, 11].

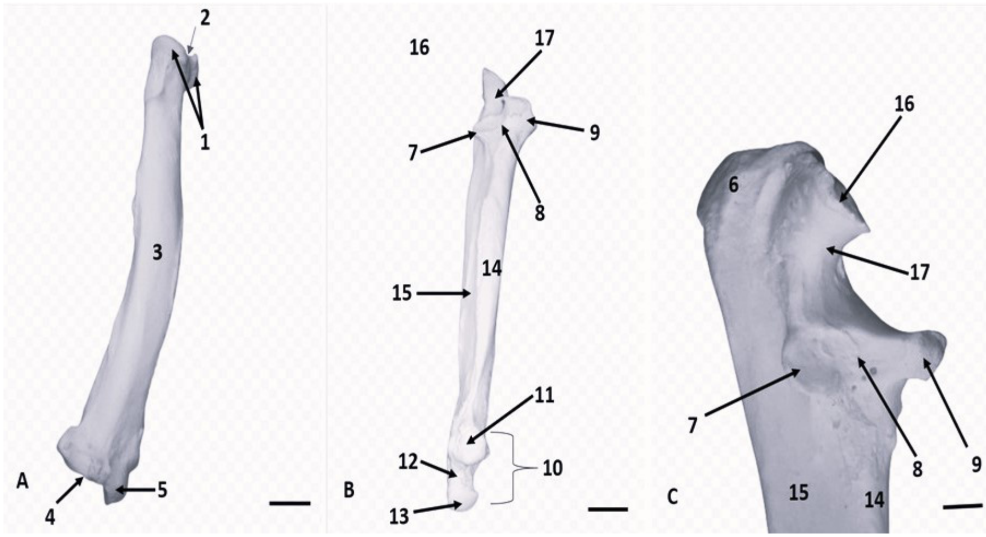

Fig. 4. Bones of the antebrachium in the Brown bear: Radius (A) cranial view; Ulna (B), cranial view; Ulna (C) proximal end, craniolateral view. **1.** *caput radii, circumferentia articularis;* **2.** notch which interrupted *circumferentia articularis*; **3.** *corpus radii*, *facies cranialis*; **4.** *trochlea radii*; **5.** *proc. styloideus medialis*; **6.** *tuber olecrani*; **7.** *proc. coronoideus medialis*; **8.** *incisura radialis*; **9.** *proc. coronoideus medialis*; **10.** *caput ulnae*; **11.** *cirumferentia articularis*; **12.** *proc. styloideus lateralis*; **13.** *facies articularis carpea*; **14.** *facies cranialis, corpus ulnae*; **15.** *facies lateralis*, *corpus ulnae*; **16.** *proc. anconeus*; **17.** *incisura trochlearis*. Bar = 3,1 cm

In **Figure 5A** are observed *m. fibularis [peroneus] longus* and *m. fibularis [peroneus] brevis*, *m. extensor digitalis lateralis* and *m. flexor digitorum lateralis* in the Brown bear. The first two muscles perform plantar flexion with eversion of the foot in humans [2, 16].

They are developed in dogs and cats [5, 28], and in rabbits an additional fourth, *m. fibularis [peroneus] quartus* is presented [7]. In all species, the inversion of the autopodium takes place during bouncing from a place [2, 7, 13, 16, 27]. In the Malayan Sun bear and Giant panda, a larger muscle belly with a short terminal tendon of *m. tibialis cranialis* has been demonstrated and more distal insertion of *m. popliteus* compared to Brown and Polar bears, which is an adaptive mechanism related to climbing and hugging stems with the pelvic limbs [24]. Accordingly, the loss of this ability in Brown and Polar bears has been observed due to the development of larger weight and size [1, 24]. Hugging the trunks is accomplished by turning the autopodium, by the identified muscles of the peroneus group in young Brown bears [1]. In all the bears studied, we observed a strong *m. soleus* [**Fig. 5B**], which started from the head of the fibula and ended in *tendo calcanei* and together with the lateral and medial head of *m. gastrocnemius* thus forming *m. triceps surae* (**Fig. 5B**). *M. soleus* is well developed in humans [2, 16], cats, and rabbits [5, 7, 28], but absent in dogs [5, 13, 28]. This muscle is responsible for the plantar flexion of the foot [2, 16], which in humans is associated with activities such as stepping on the gas pedal, standing on tiptoes, cycling, and dancing, most responsible for pushing off from the ground [16].

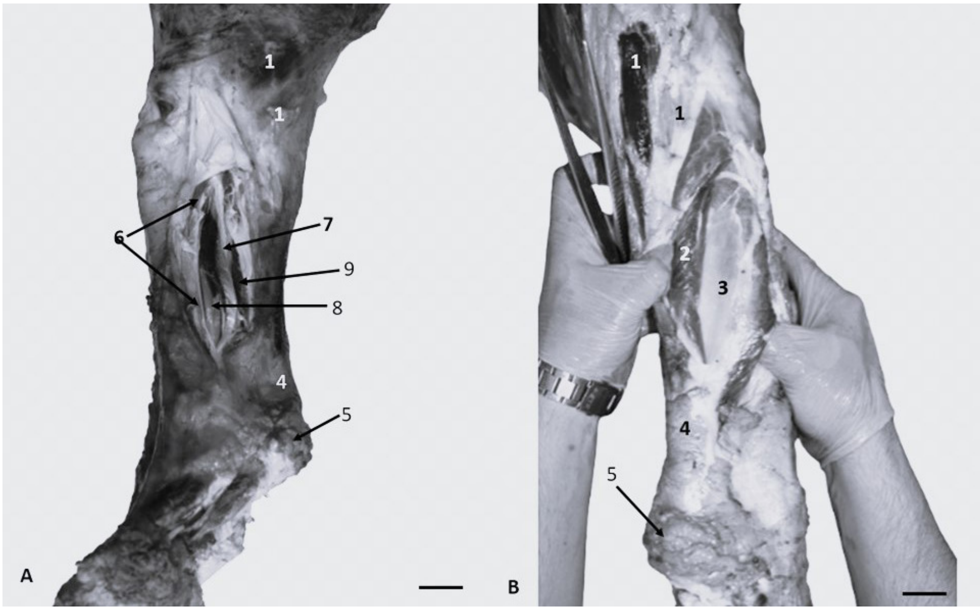

Fig. 5. Craniolateral (A) and caudal muscles (B) zeugopodium on the pelvic limb of the Brown bear. 1. m. biceps femoris; 2. m. gastrocnemius, caput laterale; 3. m. soleus; 4. tendo calacaneus communis; 5. tuber calcanei; 6. m. fibularis (peroneus) longus; 7. m. extensor digitorum lateralis; 8. m. fibularis (peroneus) brevis; 9. m. flexor digitorum lateralis. Bar = 2 cm.

This also explains its strong representation in cats related to high jumping, as well as in rabbits to push off the ground to jump while running [2, 7, 16, 28]. The well-developed muscle in the Brown bear could be associated, in our opinion, with standing on the tip of the toes of the pelvic limbs to reach a high fruit or honeycomb. Dogs lack *m. soleus*, so the primary extensor of the tarsal joint is *m. gastrocnemius* with its two heads. This provides stability when standing and generates propulsive forces during movement in walking, trotting, and galloping [13]. Also, high jumping from a place is not typical for this type of animal.

The tibia of the Brown bear is similar to the human but it is distinguished by deeper concavity of cochlea tibiae *cochlea tibiae* [11], which is confirmed by the present study (**Fig. 6A, B**). In 44% of the adult bears the tibia and the fibula were ossified between the lateral condyle of the tibia, *facies articularis fibularis*, and the head of the fibula, *facies articularis capitis fibulae* in *articulatio tibiofibulris proximalis* [5, 28]. We established a predominant ossification in the male compared to the female Brown bears. Three of the five researched male bears (60%) had fusion on both legs, one on the left only, and one without any. From the four female bears one (25%) was presented with ossification on the right only. It could be assumed that the larger build of the male bears could lead to overloading of this joint, which is also the cause of chronic arthritis of the upper tibiofibular joint in humans [3]. At *articulatio tibiofibulris distalis* [5, 28] no ossification in any of the bears studied was established, neither on the left nor on the right leg.

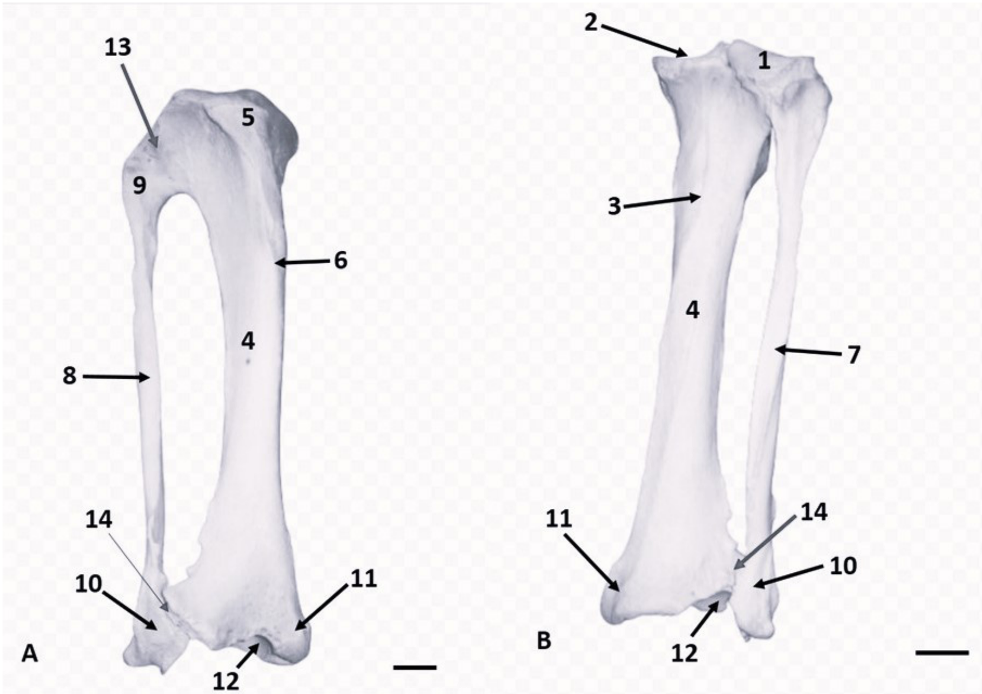

Fig. 6. Crural bones of the Brown bear: Cranial (A) and caudal (B) view. 1. condylus lateralis; 2. condylus medialis; 3. linea m. poplitei; 4. corpus tibiae; 5. tuberosits tibae; 6. margo cranialis; 7. facies caudalis, corpus fibulae; 8. facies cranialis, corpus fibulae; 9. caput fibulae; 10. malleolus lateralis; 11. malleolus medialis; 12. cochlea tibiae; 13. ossified art. tibiofibularis proximalis; 14. art. tibiofibularis distalis: Bar = 2,4 cm.

Conclusion

The rotation of the radius for which the supinator muscles are primarily responsible is greatest in the domestic cat, compared to the Brown bear, and least in the dog. The inability to climb by grasping and hugging would point to a pathology in the innervation (lesion of the *n. musculocutaneous* or *n. radialis*) or rupture of some of the muscles responsible for the supination, also a distortion of the radiocarpal joint might be considered.

The presence of *m. soleus* in the Brown bear, cat and rabbit is associated with plantar flexion necessary for pushing off the ground, and failure to do so during jumping from a place in a cat or during running in a rabbit would point to a lesion of *n. tibialis* or rupture of *m. soleus*.

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