

HIND LEG MYOLOGY OF THE MAASTRICHTIAN (LATEST CRETACEOUS) EUORNITHISCHIAN DINOSAUR *Zalmoxes shquiperorum* FROM THE HAȚEG BASIN, ROMANIA: PRELIMINARY DATA

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Abstract. The musculature of the pelvic girdle and hind leg of *Zalmoxes shquiperorum* (Dinosauria: Euornithischia: Iguanodontia) from the Uppermost Cretaceous (Maastrichtian) deposits of the Hațeg Basin is reconstructed. Corroborative evidence is sought on the osteological remains in the form of scars and correlated with muscle impressions of extant birds such as *Gallus*. The present work is the first undertaken towards the restoration of the musculature of a dwarf dinosaur taxon and is the first part in a much broader attempt at understanding, if any myological changes have taken place as a result of these taxa being subjected to the island rule. No attempt as yet is made to discuss and compare the identified muscle scars with those of other ornithischians or to critically compare the varying interpretations held by other authors with regard to the particular muscles whose origins and insertions are to be found on the hind leg elements of ornithischian dinosaurs.

Keywords: *Zalmoxes*, hind leg skeleton, muscle scars, ornithopoda, Latest Cretaceous, Romania.

Rezumat. Studiul musculaturii membrului posterior la dinozaurul euornithischian *Zalmoxes shquiperorum* din Cretacicul terminal (Maastrichtian) al Bazinului Hațeg, România: date preliminare. Musculatura centurii pelviene și a membrului inferior la *Zalmoxes shquiperorum* (Dinosauria: Euornithischia: Iguanodontia) din depozitele Cretacicului terminal (Maastrichtian) al Bazinului Hațeg este reconstituită cu această ocazie. Dovezi coroborative sunt reperate pe resturile osteologice sub forma impresiunilor/cicatricelor musculare și corelate cu impresiunile musculare observate la păsările actuale precum genul *Gallus*. Prezenta lucrare este prima care are ca scop reconstituirea musculaturii unui taxon de dinozaur pitic și este prima parte a unei încercări mai ample de a înțelege dacă au avut loc schimbări miologice în cadrul taxonilor supuși nanismului insular. Momentan nu se face nici o încercare de a discuta și compara impresiunile musculare identificate cu cele prezentate și descrise la alte genuri de dinozauri ornithischieni sau de a compara în detaliu diversele interpretări susținute de alți autori cu privire la diverșii mușchi și inserțiile identificate pe elementele membrului inferior al dinozaurilor ornithischieni.

Cuvinte cheie: *Zalmoxes*, scheletul membrului inferior, impresiuni musculare, Cretacic terminal, România.

INTRODUCTION

Although anatomical and systematic studies have been undertaken on the Hațeg ornithischian dinosaur fauna (NOPCSA, 1900, 1903, 1915; WEISHAMPEL et al., 2003; DALLAVECCHIA, 2006; GODEFROIT et al., 2009; BENTON et al., 2010), rather few have attempted to discern and reconstruct the underlying musculature despite ample material, usually preserved well enough to identify the associated muscle scars. Among the works dealing with the genus *Zalmoxes*, only WEISHAMPEL et al. (2003) and GODEFROIT et al. (2009) have made any serious attempt at discerning and mentioning muscle attachment scars on the studied specimens. A total of 28 muscle scars have been identified on the studied material, 4 of which being tentatively assigned.

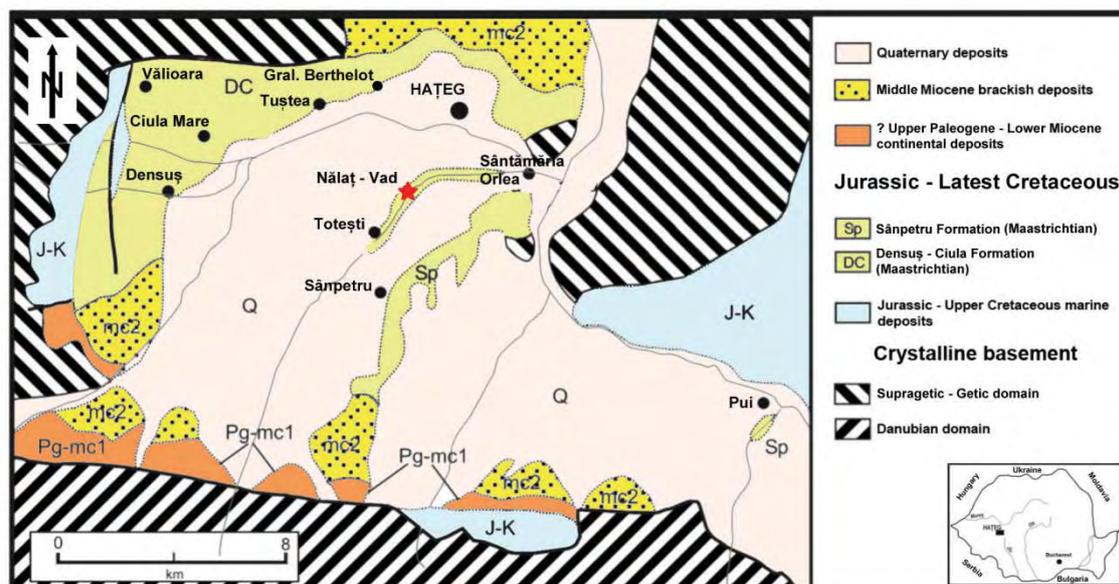


Figure 1. Geological map of the Hațeg Basin illustrating the location of the main classical Maastrichtian dinosaur localities and the location of Nălaț-Vad site (red star); modified after GRIGORESCU et al. (2010) and CSIKI et al. (2010).

GEOLOGICAL SETTING

Discovered at the beginning of 2001 by a Romanian-Belgian field work team (the Babeş-Bolyai University Cluj-Napoca and the Royal Institute of Natural Sciences Brussels), Nălaţ-Vad is a locality notably rich in dinosaur teeth and bones, but also in dinosaur and other reptile and bird eggs and (?) egg nests. The geology and stratigraphy of this locality has been thoroughly treated in previous studies (SMITH et al., 2002; PANAIOTU & PANAIOTU, 2002, 2010; GODEFROIT et al., 2009) so that only a brief review shall be given below. It is situated in the bedding of the Râul Mare River between the villages of Nălaţ and Vad (a former single locality, Nălaţ-Vad; Fig. 1). The river water flow almost always covers the entire exposure leading to difficult excavation conditions. The dipping of the layers (N40E75) also is raising problems in that the excavations need to extend deeper into the sediment and water. The outcropping sediments belong to the Sânpetru Formation (GRIGORESCU, 1992). Palynological and paleomagnetic studies suggest that this formation is Early Maastrichtian (ANTONESCU et al., 1973; VAN ITTERBEECK et al., 2004, 2005; PANAIOTU & PANAIOTU, 2002, 2010).

MATERIALS AND METHODS

All the material is curated at the Vertebrate Palaeontology Laboratory of the Babeş-Bolyai University in Cluj-Napoca (abbreviated as UBBNVZ: NV signifies the abbreviation for Nălaţ-Vad, the site where the fossils are originating from and Z is the abbreviation for *Zalmoxes*).

This study has used as its prime focus, the material described by GODEFROIT et al. (2009) from Nălaţ-Vad site, specimen UBB (NVZ1) representing an associated almost complete *Zalmoxes shquiperorum* WEISHAMPEL, JIANU, CSIKI & NORMAN (2003) skeleton, the numbers after the primary designation representing the sequence in which they were recovered. NVZ represents isolated osteological remains of *Zalmoxes* from Nălaţ-Vad site. In an attempt to provide as complete a description as possible, the above mentioned material was supplemented with a new specimen recently discovered at Nălaţ-Vad. Despite the fact that this new specimen (UBB NVZ4) is of a juvenile, the remarkable degree of preservation, wherein the skeleton is essentially complete, has allowed us to augment this work with a description of an articulated Pes, in as far as the current level of preparation of the specimen permits. The studied elements were prepared by the acid etching technique, augmented by mechanical preparation to speed up the process. Photographs of the studied specimens were taken with a Canon EOS 500D camera and an 50mm f1.8 lens and processed in Photoshop to sharpen the bone texture and also to create the accompanying line drawings.

EXPLANATION OF FIGURE LETTERINGS

acet. – acetabulum

c. fib. – fibular head (*caput fibulae* sensu GHETIE, 1976)

cn. c. – cnemial crest

cond. int. – internal condyle

cond. lat. – lateral condyle

cond. med. – medial condyle

fos. intercond – intercondylar fossa

fos. pr. act. – preacetabular fossa

fos. pop. – popliteal fossa

gr. int. – internal groove

il. p. – iliac peduncle

lam. sup. act. – supracetabular lamina/shelf

lig. col. – collateral ligament (*ligamentum collaterale* sensu GHETIE, 1976)

m. add. f. – *musculus adductor femoris*

m. cf. b. – *musculus caudifemoralis brevis*

m. cf. l. – *musculus caudifemoralis longus*

m. e. d. I. – *musculus extensor digitorum longus* (sensu GHETIE, 1976)

m. e. d. III. b. – *musculus extensor digitorum III brevis* (sensu GHETIE, 1976)

m. f. d. b. – *musculus flexor digitorum brevis*

m. f. d. l. – *musculus flexor digitorum longus*

m. f. d. p. – *musculus flexor digitorum profundus* (sensu GHETIE, 1976)

m. f. t. e. – *musculus flexor tibialis externus*

m. f. t. i. – *musculus flexor tibialis internus*

m. gc. – *musculus gastrocnemius*

m. ilc. – *musculus iliocaudalis*

m. ilfib. – *musculus iliofibularis*

m. iltib. – *musculus iliotibialis*

m. isc. – *musculus ischiocaudalis*

m. istr. – *musculus ischiotrochantericus*

m. p. l. – *musculus peroneuslongus*

m. pif. e. – *musculus puboischiofemoralis externus*

m. pif. i. 1. – *musculus puboischiofemoralis internus 1 (pars medialis)*

m. pif. i. 2. – *musculus puboischiofemoralis internus 2 (pars dorsalis)*

m. tib. a. – *musculus tibialis anterior*

pop. gr. – popliteal groove

proc. pr. act. – preacetabular process

proc. pub. – pubic process

proc. ps. act. – postacetabular process

proc. isch. – ischial process

pub. p. – pubic peduncle

t. fem. ten. – tendon of *musculus triceps femoris*

tr. ant. – anterior trochanter

tr. m. – major trochanter

tr. IV – fourth trochanter

tib. lig. – tibial ligament

TYPES OF MUSCLE SCARS

As noted by DILKES (2000), the restoration of the musculature of extinct vertebrates usually follows two trends of study/deduction. Firstly, the features on the surface of bone which can be related to muscle scars are identified. These osteologic features include rugose areas and/or prominent projections such as the fourth trochanter which exhibit some relationship with the attachment of the muscles. At times, ridges of varying sizes may be present which demarcate the boundaries of muscle attachments in otherwise featureless areas of bones. Secondly, the restorations are made of muscles for which there are no corresponding features on the bone by comparing the studied extinct taxon with an extant taxon. In case of dinosaurs, the extant models were either birds or crocodiles depending on the author and the predominant evolutionary model used at the time.

Given the problems inherent with using either the crocodylian model or the bird model for myological restorations, we have limited the scope of the present work to simply describing the appearance and location of the scars we have identified. The terminology used is that employed by DILKES (2000), completed with few terms from GHETIE (1976).

Despite the fact that we have not attempted to discuss at this time the different interpretations of the pelvic and hind leg musculature of ornithischian dinosaurs, it is our belief that given the phylogenetic proximity and functional similarities, the bird muscle pattern most closely resembles the features observed on the osteologic material.

In the studied material, muscle scars occur as either more or less developed parallel/vermiform ridges, either on the extremities, on the bone shaft or on prominent structures such as the fourth trochanter. These ridges are most visible on the supracetabular shelf of the ilium where they have a vermiform pattern and create a much roughened surface. Additional sites of muscle attachment may be represented by small, submillimeter pits, which usually have a radiating pattern from the centre of the insertion area as observed on the fibula. Still others may be observed as small ridges demarcating a depressed area of insertion such as those observed on the tibia and femur.

1. Ilium (UBB NVZ1-17, Fig. 2)

The ilium of *Zalmoxes* is a large bony structure with an "S" shaped outline in dorsal view. The lateral side forms an angle of about 30 degrees from the horizontal and bears numerous muscle scars. The preacetabular process is long and curved, with a pronounced dorsoventral flattening. The preacetabular process is long and dorsoventrally flattened and has a pronounced longitudinal groove bordered dorsally by a well-developed ridge running the whole length of the medial side. Caudal to the preacetabular process, the preacetabular notch is very deep and has a triangular outline.

The acetabulum is a well-developed semicircular area, with a crescent shaped articular surface, whose convex side faces medially. It is limited laterally from the cranial tip of the ischial peduncle to the pubic peduncle by a continuous ridge.

Cranially, the acetabulum is bordered by the well-developed pubic peduncle which is oriented cranioventrally at 45 degrees. Caudally, the acetabulum is bordered by a large ischial peduncle.

Dorsally, the ilium flattens and develops a very pronounced supra-acetabular shelf with a nearly semicircular lateral outline when viewed from the dorsal side. The postacetabular process is well-developed and robust. Its dorsal margin is laterally expanded and in continuation with the supra-acetabular shelf. The lateral side of the postacetabular process bears very distinct muscle scars indicative of the well-developed pelvic musculature of the area.

1.1. Musculature of the Ilium

1.1.1. *Musculus iliotibialis*. Ridges for the origin of this muscle appear on the entire lateromedial edge of the ilium, most conspicuously on the caudal half where they can be as high as 2mm. The lateral surface of the preacetabular process bears small longitudinal ridges forming a network which has been interpreted as the origin of the iliotibialis muscle (ROMER, 1927; GALTON, 1969; NORMAN, 1980, 1986; DILKES, 2000). A prominent ridge on the preacetabular process has been interpreted as evidence for the separation of the iliotibialis muscle into two distinct regions, the *tibialis cranialis* muscle and the *tibialis caudalis* muscle. This view is held by ROMER (1927) for the hypsilophodontid *Thescelosaurus* and by NORMAN (1986) for the iguanodontid *Iguanodon*.

1.1.2. *Musculus iliofibularis*. The origin of this muscle appears on the dorsal margin of the ilium as very well developed slightly sigmoid ridges trended dorsoventrally. The second origin for this muscle is on the ventral ridge of the postacetabular process where it is marked by a prominent depression bearing extensive vermiform scarring.

1.1.3. *Musculus caudifemoralis (pars brevis)*. The origin of this muscle is represented as a smooth area on the ventral side of the postacetabular process, mostly visible laterally. This area is situated craniocaudal to the ischial peduncle. This area has been regarded as the origin for the *caudifemoralis brevis* muscle (ROMER, 1927; GALTON, 1969; SANTA LUCA, 1980, 1984; NORMAN, 1980, 1986; DILKES, 2000).

1.1.4. *Musculus puboischiofemoralis internus (pars medialis)*. The origin of this muscle is on the ventral side of the preacetabular process, dorsocranial to the acetabulum. The site of origin is mostly smooth but it bears some faint ridges running craniocaudally. There is the possibility that this muscle in *Zalmoxes* also extended onto the dorsal side of the pubic peduncle and occupied most of the space of the preacetabular notch. The dorsal side of the pubic peduncle is marked with distinct ridges. The pubic peduncle is divided dorsoventrally by a lateral ridge which could have served as a border for the origin of the *puboischiofemoralis internus* muscle.

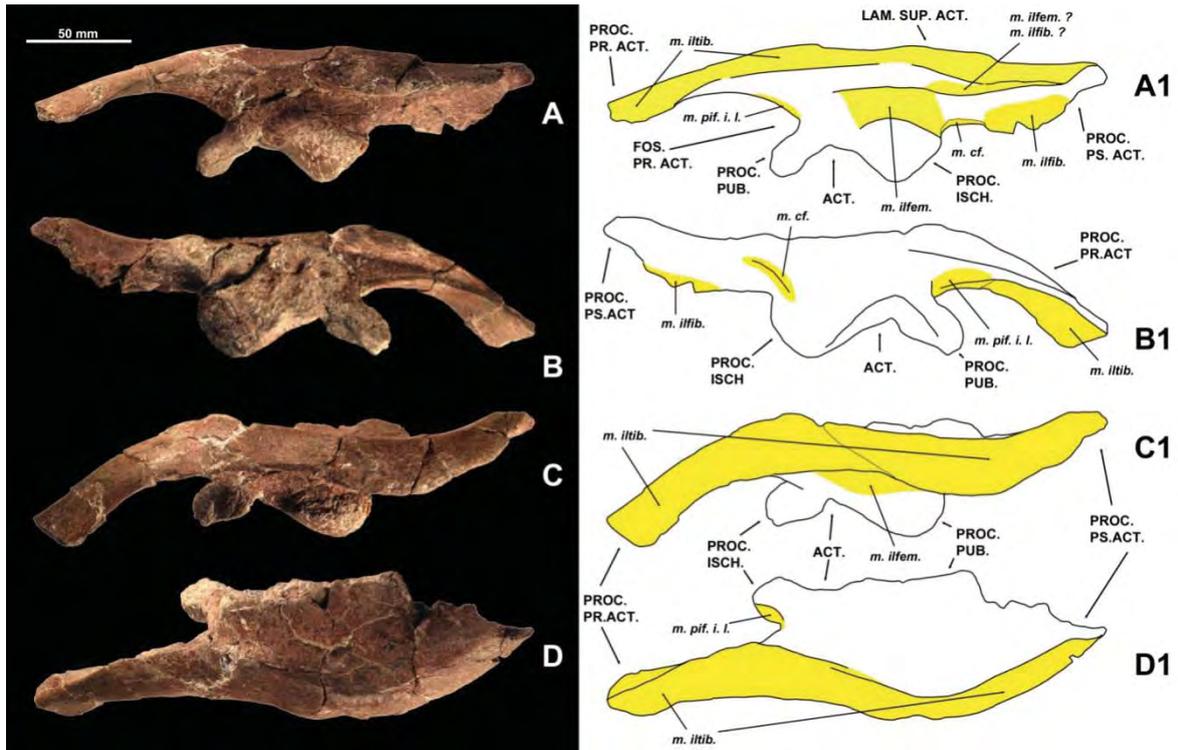


Figure 2. Left ilium of *Z. shquiperorum* and associated muscle scars in lateral (A, A1), medial (B, B1), dorsal (C, C1) and oblique dorsal (D, D1) views.

2. Ischium (UBB NVZ1-18, Fig. 3)

The iliac peduncle is very well-developed and has a slightly depressed elliptical cranial surface visible in lateral view, which contacts the globulous ischial peduncle of the ilium. This surface is formed by the caudal half of the peduncle and runs for its entire length.

The pubic peduncle is slender and elongate, its dorsal side bearing a shallow semicircular area which forms the posteroventral margin of the acetabulum.

The ischial shaft is mediolaterally flattened and its distal half is strongly ventrally curved and also near its distal end slightly laterally curved, terminating with a prominent distal flaring.

The medial side is flat and bears numerous small striations indicative of a ligamentous attachment as interpreted by DILKES (2000).

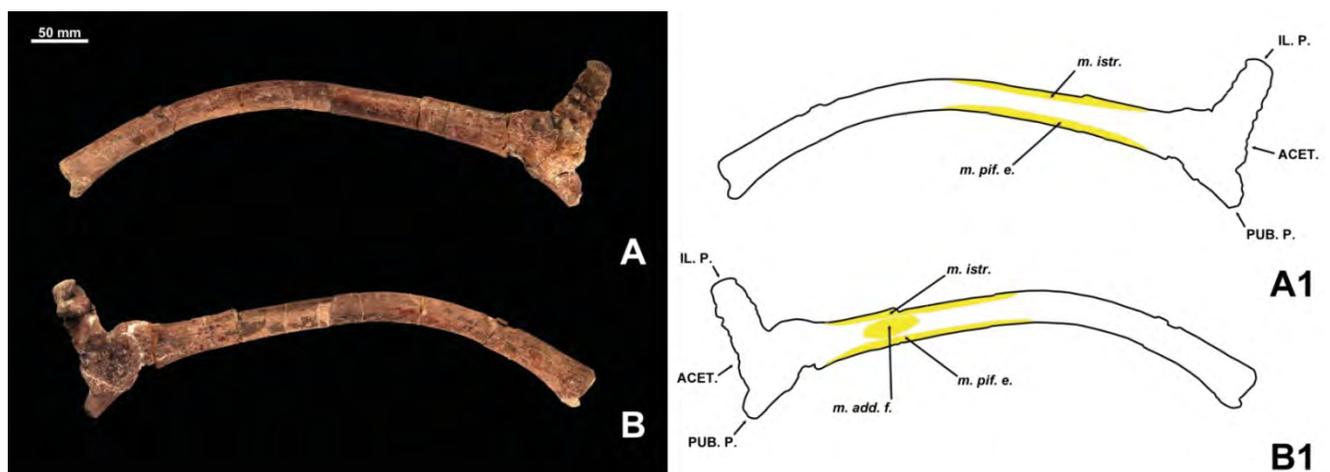


Figure 3. Left ischium of *Z. shquiperorum* in lateral (A, A1) and medial (B, B1) views.

3. Femur (UBB NVZ9, Fig. 4)

The femur bears a strongly arched lateral profile in anterior view, nearly straight in lateral view. Massive, hemispherical femoral head, set off from the long axis of the shaft by a long neck. The greater trochanter is regularly rounded and slightly below the level of the femoral head.

The anterior trochanter is separated from the greater trochanter by a vertical cleft. The external surface bears numerous striations marking the insertion of the *iliofemoralis* muscle. The lateral side of the greater trochanter shows a wide depressed area, limited cranially by the anterior trochanter and caudalventrally by a well-developed ridge with a smooth surface. This depressed area bears numerous small striations which served as the insertion for the *iliotrochantericus* muscle.

The fourth trochanter is located at the middle of the femoral shaft. The lateral condyle extends further than the medial condyle and its posterolateral surface forms a long and shallow vertical groove.

3. 1. Musculature of the femur

3.1.1. *Musculus iliofemoralis*. The insertion of this muscle is in the shallow depression of the greater trochanter and is visible in lateral view as numerous small ridges and submillimeter pits.

3.1.2. *Musculus ischiotrochantericus*. The insertion is visible in lateral view as a well-developed ridge ventral to the greater trochanter with a mostly smooth surface covered with small, shallow pits.

3.1.3. *Musculus puboischiofemoralis internus 1 (pars medialis)*. The insertion is on the medial side of the femur, ventral to the femoral neck and is represented by a shallow teardrop shaped depression with numerous submillimeter pits.

3.1.4. *Musculus puboischiofemoralis internus 2 (pars dorsalis)*. The insertion is on the anterior trochanter and is marked by small longitudinal ridges and a shallow depressed area at the base of the anterior trochanter in lateral view.

3.1.5. *Musculus caudifemoralis longus*. The insertion is on the upper part of the fourth trochanter in medial view and in the studied specimen it is represented by well-developed ridges parallel to the long axis of the femur.

3.1.6. *Musculus caudifemoralis brevis*. The insertion is on the lower part of the fourth trochanter in medial view and unambiguously in the centre of the trochanter; in lateral view although it probably extended over the entire surface. In some specimens, the scars are composed of longitudinal ridges parallel to the long axis of the femur, although there seems to be considerable variation as some specimens show only a smooth surface on either side of the trochanter.

3.1.7. *Musculus femorotibialis externus*. The origin of this muscle is located on the lower third of the femur in lateral view and is represented by a shallow elliptical depression oriented to the long axis of the femur, bearing weakly developed ridges in its central part and submillimeter pits at its periphery.

4. Tibia (UBB NVZ3 – left tibia, Fig. 5)

The general outline of the bone is relatively straight with a posterolateral angle forming a prominent internal condyle overhanging the tibial shaft. The internal condyle is separated by a shallow popliteal groove from the smaller lateral condyle. The cnemial crest is less pronounced than in other derived ornithopods (GODEFROIT et al., 2009) and occupies the proximal fifth of the tibia's total length. The anteroproximal surface of the cnemial crest forms a wide anterior groove. The tibial shaft is long and slender, slightly bowed laterally with an ovoid cross section. Below the end of the cnemial crest, a rounded vertical ridge descends to the lateral edge of the lateral *malleolus*. On the distal end of the tibia, the external *malleolus* is very pronounced distally. The internal *malleolus* is more pronounced medially and has an articular surface deflected medially towards the anterolateral side of the tibia.

4. 1. Musculature of the Tibia

4.1.1. *Musculus extensor digitorum longus*. Although the origin of this muscle is not unambiguously identified, in the studied specimens, slender ridges on the proximal caudal side of the tibia immediately below the cnemial ridge might be for the insertion of this muscle as interpreted by DILKES (2000).

4.1.2. *Musculus flexor tibialis internus*. The insertion of this muscle is located ventrolaterally to the internal condyle. Although the two parts of the muscle, the internal and external, cannot be separated, the insertion is marked by a slightly depressed area with faint longitudinal ridges, which is most clearly visible in caudal view.

4.1.3. *Musculus gastrocnemius & musculus peroneus longus*. The origin for these muscles is visible in medial and anterior views, immediately ventral to the cnemial crest and is marked by well-developed, straight longitudinal ridges. The two muscles cannot be differentiated in the studied specimens.

4.1.4. *Musculus tibialis anterior & tendon for musculus triceps femoris*. The origin of this muscle occupies the whole proximal part of the tibia in medial view and is bordered dorsally by a well-developed ridge. The area bears weak longitudinal ridges on its entire surface.

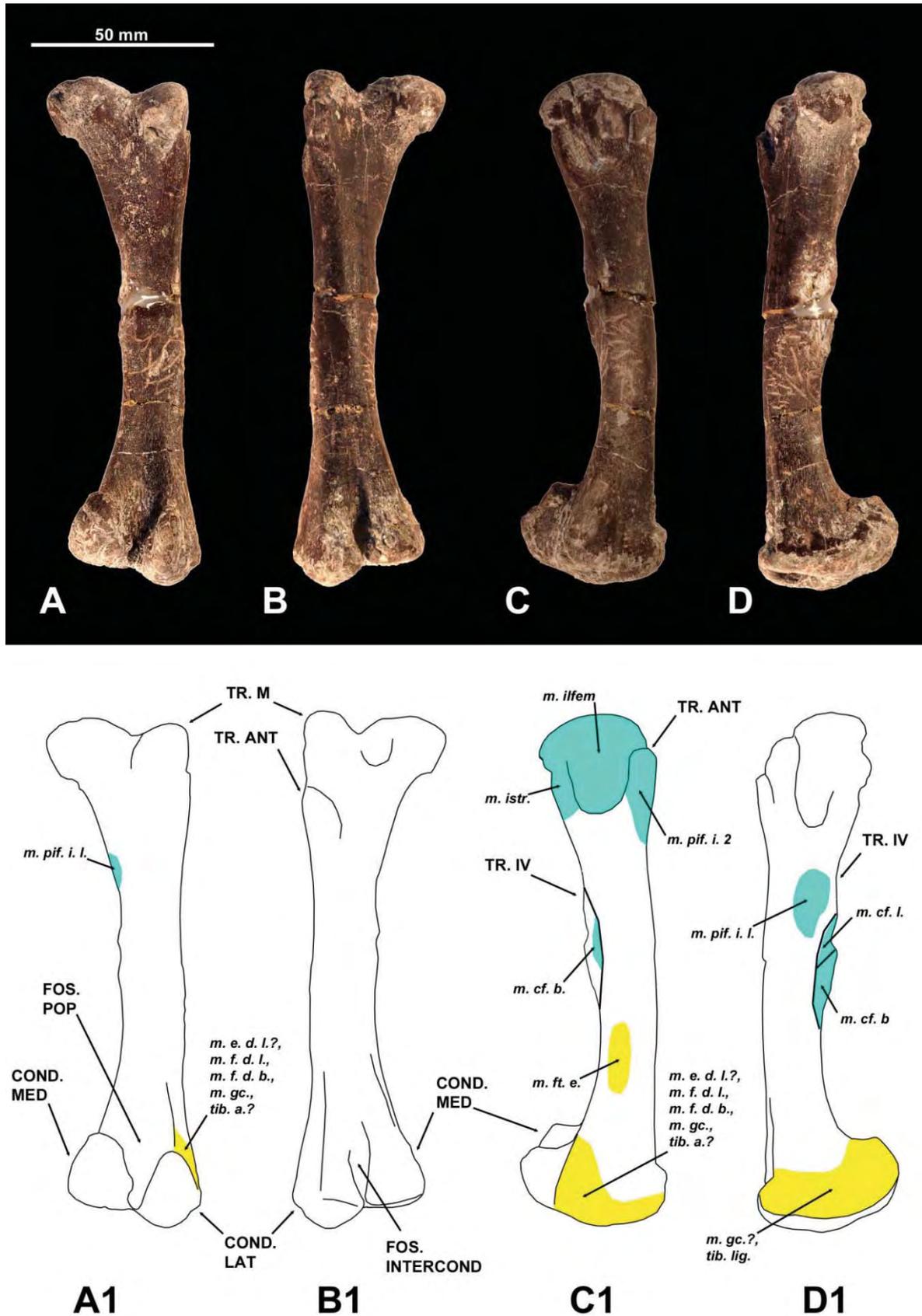


Figure 4. Right femur of *Z. shquiperorum* in caudal (A, A1), cranial (B, B1), lateral (C, C1) and medial (D, D1) views. Insertion areas for muscles are in blue, origin areas for muscles are in yellow.

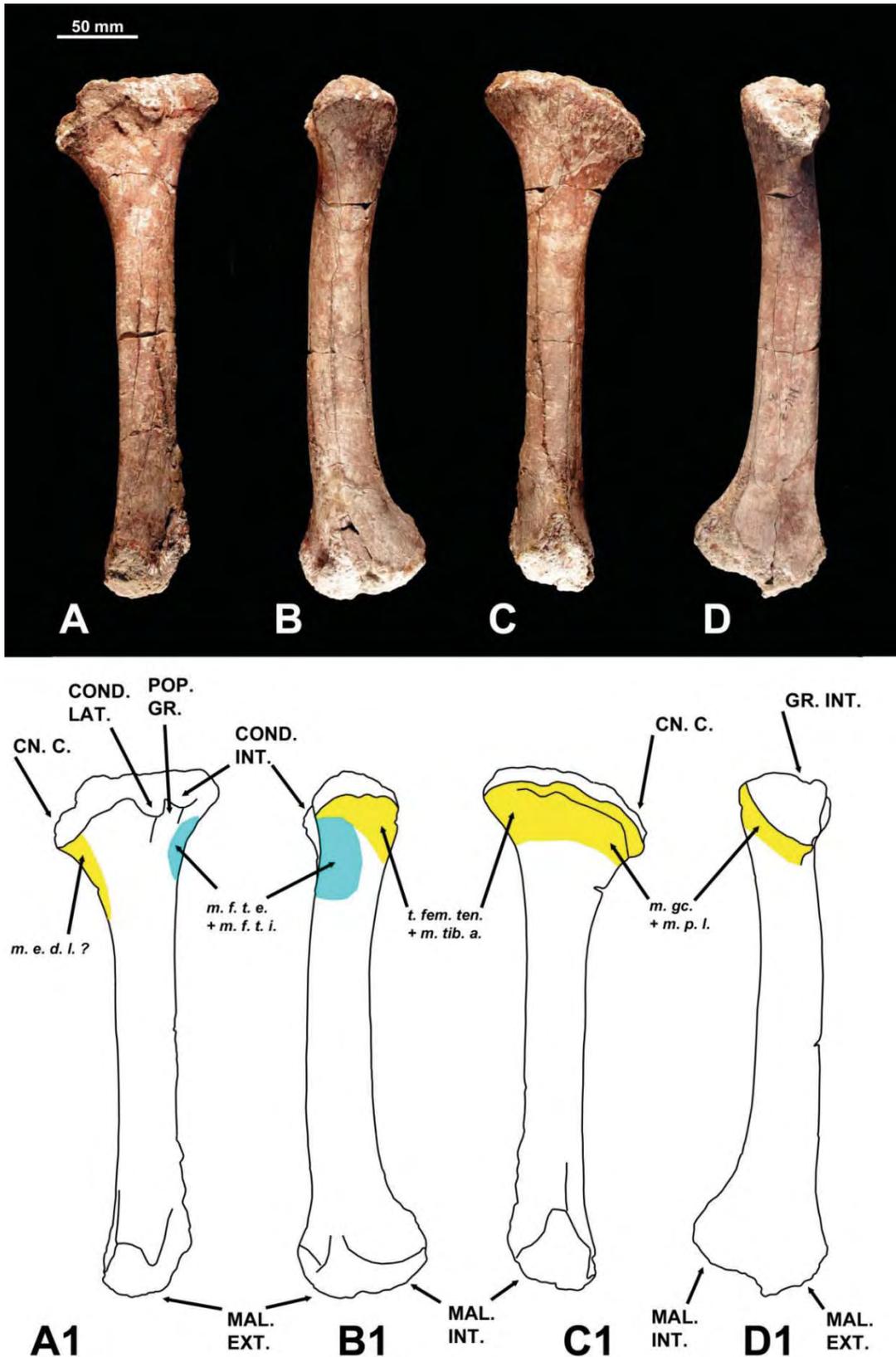


Figure 5. Left tibia of *Z. shquiperorum* in lateral (A, A1), posterior (B, B1), medial (C, C1) and anterior (D, D1) views. Insertion areas for muscles are in blue, origin areas are in yellow.

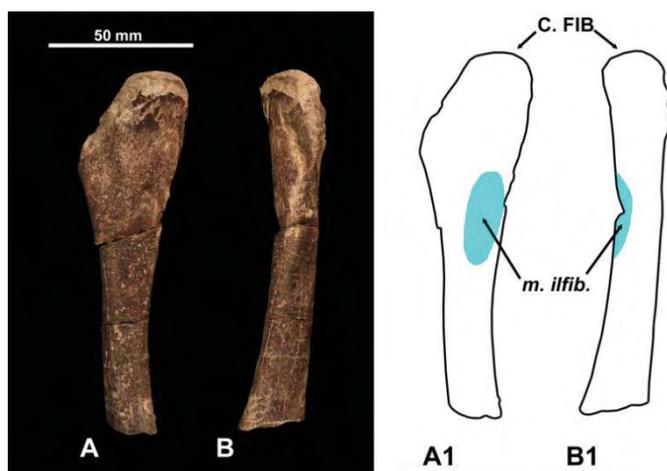


Figure 6. Right fibula of *Z. shquiperorum* in medial (A, A1) and lateral (B, B1) views.

5. Fibula (UBB NVZ2-11 – right fibula, Fig. 6)

The single specimen available for study consists of a proximal end of a right fibula. It is slender in outline, with a generally straight profile and a slightly concave medial surface for the attachment to the tibia.

5.1. Musculature of the fibula

5.1.1. *Musculus iliofibularis*. The insertion for this muscle is visible in medial view as a shallow depression with a flat floor ornamented by striations near its periphery and small submillimeter pits at the centre.

6. Pes (UBB NVZ4 - right pes, Fig. 7)

Only the proximal and distal phalanges, pedal unguals were available for study (UBB NVZ unnumbered) as the remainder of the specimen is still in the process of preparation. The identification of the individual elements was based upon ZHENG et al. (2011). Variation of the colouring among the various elements in Fig. 7 is due to different lighting conditions necessary for photographing the specimens at high magnifications. The specimen belonged to a complete juvenile disarticulated individual in a very good state of preservation. The proximal phalanges lack a well-developed dorsal process. The dorsal surface is nearly straight to slightly concave, whereas the ventral side is strongly concave. The proximal anterior surface is larger than the distal, unequally divided by a median ridge, the articular surface being displaced at a shallow angle. The distal articular surface is developed into two lobes of equal size and extends onto the ventral and dorsal surfaces. Laterally, there are well developed depressions for the insertion of the lateral interphalangeal ligaments immediately caudal to the distal articular surface.

The distal phalanges have the same morphology as that of the preceding elements with the exception that the proximal and distal articular surfaces are of equal size and the angle at which the dorsal articular surface is divided by the median ridge is more acute than that encountered in the medials.

The unguals are long, narrow, dorsoventrally flattened and slightly arched with a pointed or rounded tip. The dorsal side is strongly convex medially, abruptly tapering laterally into two rugose extensions converging at the tip. The ventral side is nearly straight or slightly convex.

6.1. Musculature of the pes

6.1.1. *Musculus flexor digitorum brevis*. The insertion of this muscle is visible on the plantar surface of the phalanges, occupying the central concavity. This concavity has very deep circular pits.

6.1.2. *Musculus flexor digitorum longus*. The insertion of this muscle is visible on the plantar surface of the ungual phalanges and is marked by numerous pits giving the area a spongy appearance.

6.1.3. *Musculus extensor digitalis III brevis*. The insertion is visible in dorsal view on the ungual phalanges as a series of elongated pits/ridges around the proximal articular surface. The pits/ridges are arranged in several parallel bands on the dorsal surface.

6.1.4. *Ligamentum collaterale*. The insertion of this ligament is represented by deep pits on the anterolateral sides of the phalanges.

6.1.5. *Tendo musculus flexor perforantis digitorum profundi*. The insertion of this tendon is visible on the proximal posterolateral sides of the ungula phalanges as shallow depressions ornamented with small longitudinal ridges.

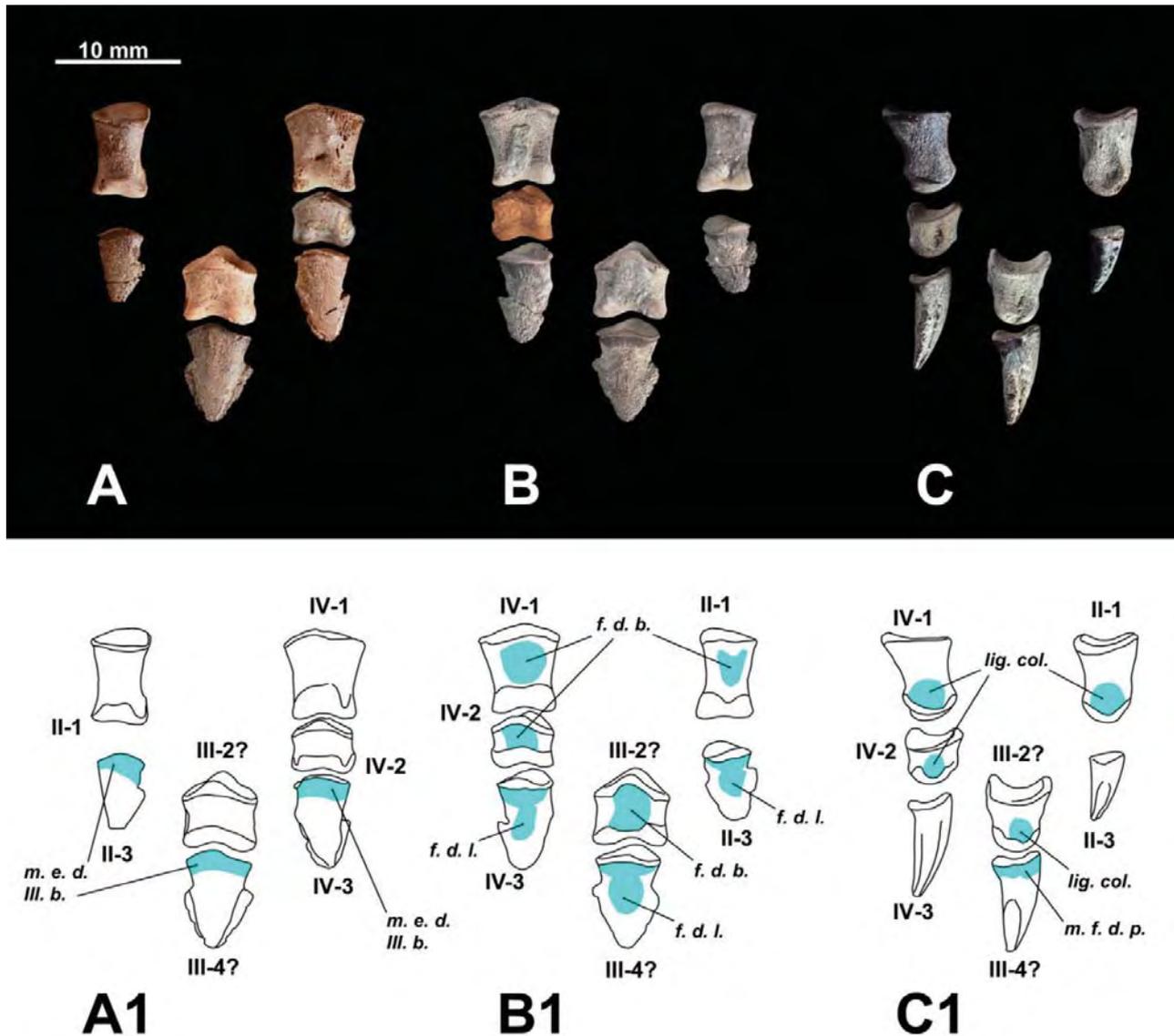


Figure 7. ?Right pes of *Z. shqiperorum* in dorsal (A, A1), plantar (B, B1) and lateral (C, C1) views.

DISCUSSIONS

Based on the above identified muscle scars, several, albeit tentative comparisons can be made with other ornithischian dinosaurs. Unfortunately, any conclusions with regard to the running ability of studied taxon can only be of the most superficial nature due to the fact that so far no adult specimen has preserved the complete hind leg and even those where the femur and tibia are associated, the individual bones are fragmentary. The most striking difference observed is the size of the muscle scar for the *m. iliotibialis*, which is much more pronounced than that observed in other ornithischians such as *Gilmoresaurus*. Whereas in *Gilmoresaurus* and *Iguanodon*, the scar is made up of very fine ridges extending from the preacetabular process onto the supra-acetabular lamina/shelf (PRIETO-MARQUEZ & NORELL, 2010), the insertion for the same muscle in *Zalmoxes* is made up of very coarse and well developed sigmoidal ridges giving the dorsal border of the ilium a very roughened aspect.

This apparently hypertrophied origin for the *m. iliotibialis* we interpret as the result of the severe reduction of body size encountered in this genus and not in direct proportion to the size of the originating muscle.

The insertion scar for the *m. adductor femoralis* presents the opposite problem as its location cannot be made out clearly in any of the studied specimens, a situation contrary to the usual strong scar encountered in other taxa such as *Iguanodon* (NORMAN, 1986).

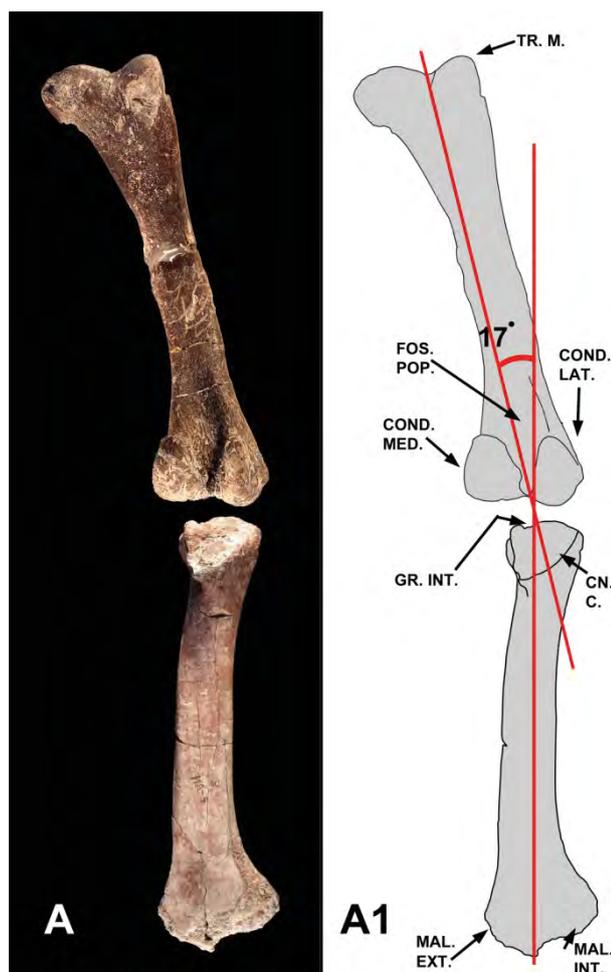


Figure 8. Articated reconstruction (A) and explanatory drawing (A1) of the femur and tibia of *Z. shquiperorum* caudal view illustrating the carrying angle of the femur in a resting position.

With respect to the posture of *Zalmoxes*, we have attempted to discern the angle between the femur and tibia by orienting the distal femoral articulation in such a way to make it parallel with the proximal tibial facet. This approach results in a carrying angle of about 17 degrees medial inclination of the femur with respect to the tibia (Fig. 8).

Regarding the *m. caudofemoralis brevis* and *longus*, it would appear that given the size of the fourth trochanter, these muscles were somewhat reduced, a situation which is peculiar when taking into account the bowed outline of the femur characteristic of more agile bipedal dinosaurs such as the primitive ornithomimid *Lesothosaurus* or the theropod *Velociraptor* (BATES et al., 2012). Also, the bowing of the femur is much more similar to that encountered in *Lesothosaurus* than observed in *Hadrosaurus*, *Iguanodon* or *Olorotitan* (GODEFROIT et al., 2011), where the proximal part is straight, only bowing distally from the level of the fourth trochanter. It is quite probable that agile, exclusively bipedal taxa developed this bowing of the femur in order to maintain a more perpendicular angle of the tibia with respect to the ground when the leg is maximally extended during running and distribute the impact of the step more evenly across the femoro-tibial articulation. What is peculiar about the general aspect of the femur, the size of the fourth trochanter and associated insertion areas is the fact that the trochanter is positioned at midshaft implying an animal which was not capable of high speed running except perhaps in short bursts. In bipedal dinosaurian taxa known for their running abilities, the fourth trochanter is located closer to the level of the femoral head, where a lesser degree of extension of the *m. caudofemoralis* would have resulted in a greater angle of movement of the femur.

In Fig. 9 we present a tentative reconstruction of the gait of *Zalmoxes* from a rest position to full extension and flexion. The degree of freedom for the femorotibial articulation is deduced by the method employed by PAUL (1998) for Tyrannosaurids and Ornithomimids, where the relative orientation of the femoral condyles can be estimated by drawing a line through the proximal and distal points of the tibial medial condyle. From Fig. 9 we can determine that at the maximal flexion, the angle between the femur and the tibia would have been 90 degrees.

CONCLUSIONS

This study represents the first major attempt at documenting the myology of a dwarf ornithischian dinosaur. The muscle scars present on the lower appendicular skeleton of *Z. shquiperorum* have been identified with a high degree of confidence. Twenty five muscle scars have been described in both aspect and location on the studied bones.

The present study represents the first step towards the documentation of the allometric changes accompanying the severe reduction in body size of the dinosaur fauna from the Maastrichtian deposits of the Hațeg Basin.

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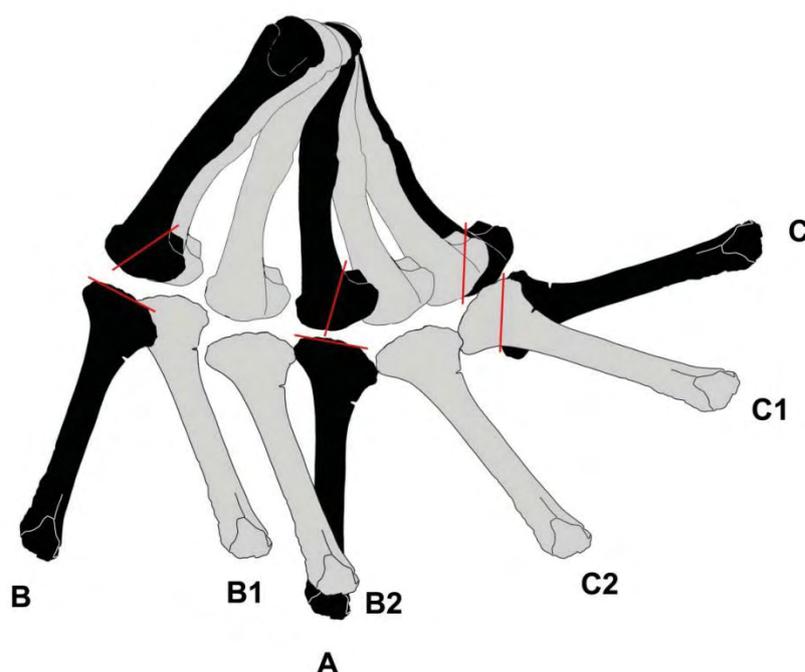


Figure 9. Hypothesized running sequence of *Z. shquiperorum* showing the degree of freedom of articulation between the femur and tibia from a resting position (A), to maximum extension (B) and maximum flexion (C).

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