Preliminary study on pelvic ossification in an ornithopod dinosaur from Ladruñán (Teruel, Spain)

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Abstract

This study presents an osteohistological analysis of a partially preserved ischium (MPZ 2025/06) from an iguanodontian dinosaur recovered in the Barremian levels of the Mirambel Formation (Teruel, Spain). The thin section reveals marked cortical remodelling and high compactness, comparable to another coeval specimen of similar ontogenetic stage (MPZ 2024/94). Despite morphological differences, both ischia show a similar distribution of tissue fronts, suggesting limited interspecific histovariability between them. The asymmetric microanatomy identified (ventromedial expansion of the medullary cavity and dorsolateral thickening of compact tissue) correlates with muscle distribution inferred from previous reconstructions. These features support a biomechanical origin for the extreme remodelling seen in the ischium and highlight the value of histology in testing locomotor hypotheses in ornithopods.

Introduction

Ornithopod dinosaurs are a notable case study in palaeohistology, as the abundance of specimens has enabled a reasonable understanding of their development (Woodward *et al*., 2015). However, questions remain, such as the origin of unusual appendicular microstructures possibly linked to ontogenetic and locomotor changes (Hübner, 2012). Due to intraskeletal histovariability, a broader approach is needed, including postcranial elements potentially influenced by biomechanical factors (Maidment *et al*., 2014). This study analyses an iguanodontian ischium and compares it with that of a previously studied specimen that showed high compactness and remodelling. The aim is to improve the understanding of the pelvic microanatomy and its biomechanics in Iguanodontia.

Geological Setting

The ischium analysed belongs to a partial skeleton recovered by the Aragosaurus research team in Pepe site, near the town of Ladruñán (northeastern Teruel Province, Spain). The Pepe site lies in the uppermost levels of the Barremian Mirambel Formation, in the Morella sub-basin (Maestrazgo Basin). This unit comprises lutites, sandstones and limestones corresponding to alluvial and shallow lacustrine facies (Gasca *et al*., 2017). The fossil-bearing layer occurs in the upper part of a terrigenous alluvial interval composed of reddish to purplish mudstones, interpreted as floodplain deposits.

Material and Methods

The material consists of an incomplete ischium attributed to Iguanodontia indet. The element (MPZ 2025/06) and its thin section (MPZ 2025/06-L1) are housed in the Museo de Ciencias Naturales de la Universidad de Zaragoza. The section was taken from the proximal ischial shaft, offset from the ossification centre, which limits the skeletochronological record but enables comparison with a previously studied specimen. The 70–100 µm section was prepared at the Servicio General de Apoyo a la Investigación (UNIZAR) following standard procedures (Cerda *et al*., 2020). It was examined using an Olympus BX53M petrographic microscope at IUCA-UNIZAR, with high-resolution images obtained via an Olympus DP27 camera and OLYMPUS *Stream Basic* software. A CT scan was performed using a Zeiss Metrotom 800 G3/225 kV system and *ZEISS METROTOM OS* software (4 merge, 2103 µA, 400 ms exposure, 3 mm Cu filter) to analyse ossification patterns along the proximal plate near the cut point. Images were processed to enhance porosity detection, and compactness was assessed using *Fiji* with the *BoneJ* plug-in. Histological terminology follows de Buffrénil and Quilhac (2021).

Results

Morphological description

MPZ 2025/06 is a left ischium that preserves part of the ischial shaft, the base of the obturator process, and a fragment of the iliac peduncle. It has a preserved anteroposterior length of 392 mm and a maximum dorsoventral height of 153 mm. The lateral surface is slightly concave dorsoventrally and convex anteroposteriorly. The medial surface is flat dorsoventrally and anteroposteriorly concave from the base of the obturator process towards the anterior part. The ischial shaft is straight, expands lateromedially, and progressively compresses dorsoventrally as it lengthens. The obturator process is narrow and quadrangular in shape. The iliac peduncle widens anteriorly at its dorsal margin, becoming much thicker and possessing a triangular cross-section.

Osteohistological description

The sample exhibits cortical thickening in the dorsolateral area and a ventromedial expansion of the medullary cavity (Fig. 1A). The cavity contains large resorption chambers that inhibit trabecular bone formation, although porosity decreases medially. In the dorsolateral area, some resorption clusters are unusually developed and separated from the cavity by a band of compact tissue. The cortical region is filled with Haversian tissue, including up to three generations of secondary osteons in the most remodelled areas (Fig. 1B). In contrast, the ventral subperiosteum preserves a small portion of extracellular matrix with a woven-parallel complex, simple canals, and primary osteons arranged longitudinally. Sharpey's fibres are present, along with two lines of arrested growth (LAG) and four more peripheral LAG clusters with narrower spacing. CT data show a similar ossification pattern throughout the bone, although the available resolution does not confirm whether Haversian development matches that observed in the thin section.

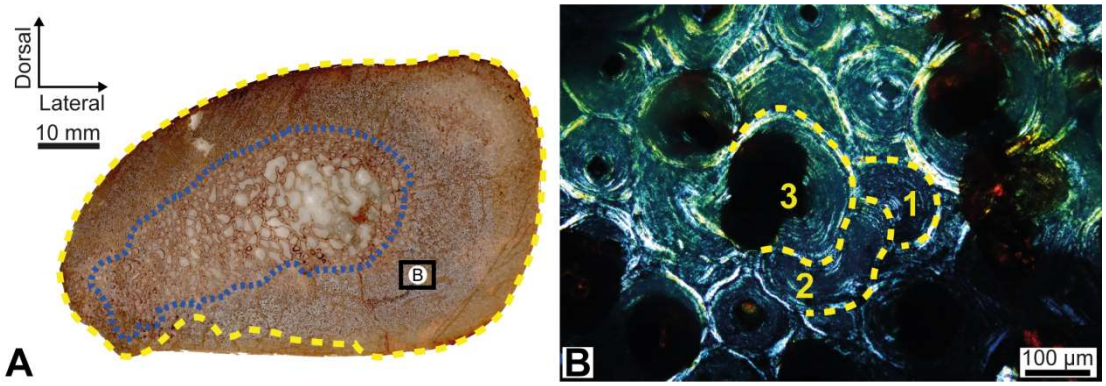

Figure 1. MPZ 2025/06-L1. A) Distribution of the medullary cavity and the resorption front (blue), and the Haversian substitution front (yellow). B) Magnification of the framed area in A under crossed Nicols: Haversian tissue with three generations of secondary osteons.

Discussion

Previous assessments based on two dorsal ribs indicate that the specimen was sexually mature but had not yet reached full skeletal maturity (Maíllo *et al*., 2023). The ischium shows extensive Haversian tissue, which could suggest an advanced ontogenetic stage. However, the preserved LAGs disperse similarly to those in the ribs, indicating that remodelling was driven by factors unrelated to late-stage skeletal maturity. Possible causes include biomechanical stress from active muscle insertions or changes in load distribution, both especially relevant in ornithopods transitioning between bipedal and quadrupedal locomotion (Maidment *et al*., 2014). The degree of remodelling and compactness in MPZ 2025/06 is comparable to that of another ischium (MPZ 2024/94-L1) from a coeval iguanodontian of similar ontogenetic stage, found at the nearby Azud Aliaga site (Aliaga, Teruel Province) (Maíllo *et al*., 2025) (Fig. 2). Despite differences in section morphology, both show a comparable distribution of tissue fronts, suggesting minimal interspecific variability in ischial histology.

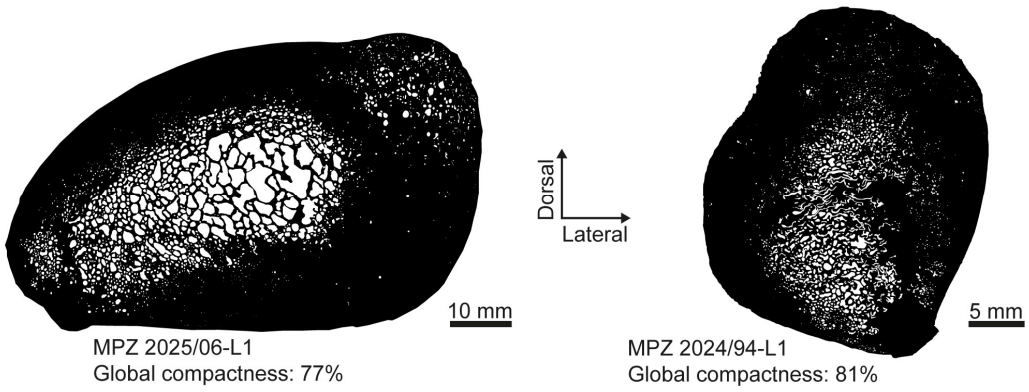

Figure 2. Distribution of compact tissue (black) and porosity (white) in each sample.

The tissue distribution in both specimens aligns with the muscular reconstruction proposed by Maidment *et al*. (2014) for the pelvic girdle and its influence on hindlimb moment arms in quadrupedal ornithopods. Both ischia show ventromedial expansion of the medullary cavity and narrowing of compact tissue in that area. This drift correlates with the lower medial rotator moment arms. Similarly, dorsolateral thickening of compact tissue and increased Haversian density in that region may reflect interaction with pelvic

abductors and the *femorotibialis internus*, which originates on the dorsal surface of the ischium. If so, its involvement at the proximal margin of the ischial shaft should be reflected in the proximal plate's microstructure, with denser Haversian tissue proximally that decreases distally as the bone extends away from the muscle. Although we lack CT scans of the ischial shaft to confirm if this ossification persists as the influence of muscle diminishes, available data show that the distribution of the medullary cavity and the compact tissue is maintained throughout the proximal plate. This may indicate either proximally focused remodelling, driven by stress of the above-mentioned muscles and the primary ossification centre (near the shaft-acetabulum junction), decreasing distally as their influence wanes; or a uniform remodelling along the shaft, maintained by a larger sustained loading and tail muscle input that helps distribute mass evenly. Distinguishing between these will require further histological sampling along the bone.

Conclusions

Our preliminary results suggest that the ischial microstructure of Early Cretaceous iguanodontids from the Maestrazgo Basin shows minimal interspecific variability. Its asymmetric microanatomy, marked by ventromedial expansion of the medullary cavity and dorsolateral thickening of compact bone, aligns with associated musculature and suggests that the remodelling is primarily driven by biomechanical factors. Histology thus provides a useful complement to myological analysis, allowing the testing of locomotor inferences. Considering these results, further histological sampling of ornithopod pelvic bones is key to better understanding their palaeoecology and development.

References

Buffrénil, V. de, Quilhac, A. (2021): Bone tissue types: a brief account of currently used categories. In: Buffrénil, V., de Ricqlès, A.J., Zylberberg, L., Padian, K. (eds.). Vertebrate skeletal histology and paleohistology. FL CRC Press, Boca Raton, 147-190.

Cerda, I.A., Pereyra, M.E., Garrone, M.C., Ponce, D., Navarro, T.G., González, R., Militello, M., Luna, C.A., Jannello, J.M. (2020): A basic guide for sampling and preparation of extant and fossil bones for histological studies. Publicación Electrónica de la Asociación Paleontológica Argentina, 20(1), 15-28.

Gasca, J.M., Moreno-Azanza, M., Bádenas, B., Díaz-Martínez, I., Castanera, D. Canudo, J. I., Aurell, M. (2017): Integrated overview of the vertebrate fossil record of the Ladruñán anticline (Spain): Evidence of a Barremian alluvial-lacustrine system in NE Iberia frequented by dinosaurs. Palaeogeography, Palaeoclimatology, Palaeoecology, 472, 192-202.

Hübner, T.R. (2012): Bone histology in *Dysalotosaurus lettowvorbecki* (Ornithischia: Iguanodontia)–variation, growth, and implications. PLoS ONE, 7 (1), e29958.

Maidment, S.C.R., Bates, K.T., Falkingham, P.L., VanBuren, C., Arbour, V., Barrett, P.M. (2014): Locomotion in ornithischian dinosaurs: an assessment using three-dimensional computational modelling. Biological Reviews, 89 (3), 588-617.

Maíllo, J., Hidalgo-Sanz, J., Gasca, J.M., Moreno-Azanza, M. (2023): Aproximación esqueletocronológica en costillas de dinosaurio ornitópodo del Barremiense de Ladruñán (Teruel, España). In: Ros-Franch, S., Paredes-Aliaga, M.V., Martínez-Pérez, C. (eds.). Libro de Resúmenes de las XXXVIII Jornadas SEP, Vol. 4. Palaeontological publications, Spain, 164.

Maíllo, J., Hidalgo-Sanz, J., Gasca, J.M., Canudo, J.I., Moreno-Azanza, M. (2025): Intraskeletal histovariability and skeletochronology in an ornithopod dinosaur from the Maestrazgo Basin (Teruel, Spain). Journal of Anatomy, 00, 1-22.

Woodward, H.N., Freedman Fowler, E.A., Farlow, J.O., Horner, J.R. (2015) *Maiasaura*, a model organism for extinct vertebrate population biology: a large sample statistical assessment of growth dynamics and survivorship. Paleobiology, 41 (4), 503-527.