Acta Scientiae Veterinariae, 2026. 54: 2023.

RESEARCH ARTICLE
Pub. 2023

ISSN 1679-9216

Tomographic and Radiographic Pelvimetry in the Brown-throated Sloth (*Bradypus variegatus*): a Morphometric Study

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ABSTRACT

***Background*: **The brown-throated sloth (*Bradypus variegatus*) is an arboreal xenarthran of Neotropical forests, exhibiting adaptations for suspensory locomotion. The pelvic girdle constitutes a fundamental structural element in mammals, serving as the primary interface for weight transfer between the axial skeleton and hindlimbs, contributing to locomotor mechanics. The pelvic morphology It is important to understand the birth outcomes, with the cephalopelvic disproportion representing a leading cause of dystocia in domestic and wildlife species. Pelvimetry, performed radiographically or tomographically, constitutes a technique that can be used to evaluate pelvic morphology, predict dystocia risk, and estimate biological parameters in domestic animals and species of wildlife. However, there are no published pelvimetric data for *B. variegatus*. This study was conducted to address this knowledge gap through pelvic tomographic and radiographic analysis of *B. variegatus*. The objectives were to morphometrically characterise the pelvic dimensions of the samples included in this study, classify pelvic typology, and investigate the correlations between pelvic dimensions and body size.

***Materials, Methods & Results*: **Nine frozen cadavers of *Bradypus variegatus* obtained from routine admissions to the Veterinary Hospital were used. The samples were classified into age/weight categories according to established criteria: stillborn (n = 2), infant (n = 5) and juvenile (n = 2). The sex distribution was 6 males, 1 female, and 2 undetermined (stillborns). Before imaging, each specimen was weighed and the length of the body was measured from the cranio-cervical transition point to the last caudal vertebra. A juvenile male underwent pelvic CT imaging and 8 cadavers underwent radiographic examination in ventro-dorsal and dorso-ventral projections. Ten pelvic diameters were measured digitally: superior bi-iliac diameter (DBIS), distance between iliac crests (DCI), middle bi-iliac diameter (DBIM), inferior bi-iliac diameter (DBII), distance between pubic symphysis tubercles (DTSP), distance between ischiatic tuberosities (DTI), right diagonal diameter (DDD), left diagonal diameter (DDE), sacro-pubic diameter (DSP), and distance between ischiatic spines (DEI). The pelvic inlet area (AEP) was calculated as (DBIM/2) × (DSP/2) × π. Statistical analyses were performed using BioEstat software version 5.3 (Instituto Mamirauá, Amazonas, Brazil).

***Discussion*: **This study provides the 1st quantitative pelvimetric data set for *Bradypus variegatus*. The main limitations include the modest sample size (n = 9) characteristic of rare wildlife anatomy studies, the absence of adult specimens preventing the characterisation of pelvic morphology of adult animals and the evaluation of sexual dimorphism. Progressive increases in DBIS, DBII, and AEP can support evidence-based treatment in rehabilitation settings. The mesatipelvic conformation suggests that dystocia investigations should prioritise foetal factors, positioning abnormalities, and maternal parity, although confirmation requires studies that incorporate adult females and observations of pregnancy. The dual-modality approach demonstrates that CT provides superior anatomical detail, while radiography yields linear measurements. These findings may be fundamental veterinarians in captive breeding programmes for this threatened species facing habitat fragmentation and anthropogenic threats. Future research priorities include expanding this data set to include adults of both sexes, validating measurements in vivo, and integrating pelvimetric data with pelvic limb myology and biomechanical for later application in reproductive health evaluation and species conservation.

Keywords: common sloth. computed tomography. pelvic morphometry. pelvic radiography. xenarthran morphology.

DOI: 10.22456/1679-9216.154072

Received: 9 March 2026 Accepted: 26 August 2026 Published: 12 September 2026

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INTRODUCTION

The brown-throated sloth (*Bradypus variegatus*) is an arboreal folivore of Neotropical forests with adaptations for a suspensory lifestyle. As a member of Xenarthra, it presents xenarthrous articulations and a low metabolic rate [6,11]. The pelvic girdle serves as the primary interface for weight transfer between the axial skeleton and hindlimbs, supports abdominal and pelvic viscera, and contributes to locomotor mechanics [3,5]. Pelvic morphology directly determines pregnancy outcomes, with cephalopelvic disproportion representing the leading cause of dystocia in domestic and wildlife species [8].

Pelvimetry, performed radiographically or tomographically, is an established technique for assessing pelvic morphology, predicting dystocia risk, and estimating biological parameters [7,14,15]. Computed tomography offers high-resolution three-dimensional data without bone superimposition [4,5]. Tomographic and radiographic studies have contributed essential knowledge in vertebrates, including sex determination in budgerigars [15], pelvic adaptations in gazelles [5], and baseline references in anteaters [9].

For threatened species such as *B. variegatus*, baseline anatomical data are essential for clinical care and captive breeding [10,16]. However, no pelvimetric data exist for this species, constraining clinical decision-making. Thus, this study aimed to morphometrically characterise the pelvic dimensions of *B. variegatus*, classify pelvic typology, and investigate correlations between pelvic dimensions and body size.

MATERIALS AND METHODS

Ethical statement and animals

The research was carried out according to the guidelines of the Brazilian National Council for the Control of Animal Experimentation (CONCEA). The approval was granted by the Animal Ethics and Welfare Committee of the University (Protocol No. 5943220321). All procedures were conducted on cadavers, thus eliminating pain, suffering, or distress for living animals.

Nine frozen cadavers of the brown-throated sloth (*Bradypus variegatus*) were used. Specimens were obtained from routine admissions to the Pará Veterinary Hospital of the Federal University (HV/UFPA), Brazil, establishing a defined geographical and taxonomic scope for this study. Cadavers were stored at temperatures between -2°C and -10°C until processing.

Specimen classification and biometric data

Specimens were classified into age/weight categories based on established criteria for the species (Table 1). Before imaging, each specimen was weighed using a precision scale. Body length (in cm) was measured with a mm tape from the cranio-cervical transition point to the last caudal vertebra. The cadavers are noted to have been preserved in glycerol, resulting in an estimated 40-50% reduction from their live weight.

Specimen preparation and imaging acquisition

The cadets were thawed in running water for approximately 2 h. For imaging, each specimen was positioned in dorsal recumbency on an examination table with the pelvic limbs abducted and tractioned caudally to align the pelvis parallel to the surface of the table.

Computed tomography (CT)

A single male cadaver (1.5 kg) underwent pelvic CT imaging using a 16-channel helical CT scanner, Syngo CT 2009E[1]. Acquisition parameters were: 110 kVp, 130 mA, scan time 62.66 s, delay 3 s, and a field of view (FoV) of 115 x 115 mm. Contiguous 5 mm axial slices were acquired and subsequently reconstructed to a 1 mm slice thickness using multiplanar reconstruction (MPR) in the sagittal and coronal planes for three-dimensional volume rendering.

Radiography

The remaining 8 cadavers were radiographicly examined using a computed radiography system, CR-30X, AGFA®[2]. Standard technique for bone structures was applied (50 kV, 100 mAs). Two orthogonal projections per sample were acquired: ventro-dorsal (VD) and dorso-ventral (DV).

Pelvimetric measurements

Digital measurements of pelvic diameters were performed directly on CT and radiographic images using integrated software tools (CAD and PACS systems, respectively). All measurements were recorded in cm.

The following pelvic diameters were measured, as illustrated in Figure 1:

The pelvic inlet area (AEP) was calculated from the DBIM and DSP using the formula for the ellipse area: AEP = (DBIM/2) x (DSP/2) x π.

Table 1. Classification criteria for *Bradypus variegatus* specimens.

Age/Weight Class	Weight Range (kg)	Key Characteristics
Stillborn	N/A	Animals born dead; sex determination through gonads is not possible.
Infant/Puppy	< 1.2 kg	Lacks characteristic pelage dimorphism.
Juvenile/Young	1.2 - 2.3 kg	Presents an initial sexual dimorphism in the coat.
Adult	2.3 - 5.5 kg	Exhibits clear sexual dimorphism in pelage.

N/A: Not applicable.

Table 2. Mean ± standard deviation of biometric and pelvimetric measurements for *Bradypus variegatus* cadavers by age/weight class.

Measurement	Stillborn (n=2)	Infant (n=5)	Juvenile (n=2)	*P*-value
Body Weight (kg)	0.41 ± 0.04^{a}	0.72 ± 0.11^{a}	1.46 ± 0.02^{b}	< 0.001
Body Length (cm)	14.05 ± 0.35^{a}	17.5 ± 1.2^{a}	23.89 ± 3.16^{b}	< 0.001
DBIS	1.0 ± 0.0^{a}	2.07 ± 0.25^{b}	2.95 ± 0.13^{c}	< 0.001
DCI	2.6 ± 0.14^{a}	3.87 ± 0.53^{a}	5.70 ± 0.56^{a}	0.062
DBIM	1.55 ± 0.07^{a}	2.75 ± 0.33^{a}	3.88 ± 0.18^{a}	0.051
DBII	1.6 ± 0.14^{a}	2.27 ± 0.22^{b}	3.42 ± 0.13^{c}	< 0.001
DTSP	0.86 ± 0.01^{a}	0.92 ± 0.01^{a}	1.36 ± 0.30^{a}	0.210
DTI	1.85 ± 0.07^{a}	2.87 ± 0.57^{a}	3.92 ± 0.07^{a}	0.087
DDD	1.5 ± 0.0^{a}	2.52 ± 0.09^{a}	3.75 ± 0.61^{a}	0.055
DDE	1.5 ± 0.0^{a}	2.55 ± 0.40^{a}	3.84 ± 0.37^{a}	0.059
DSP	2.0 ± 0.0^{a}	2.75 ± 0.58^{a}	3.70 ± 0.82^{a}	0.195
DEI	1.2 ± 0.14^{a}	1.77 ± 0.41^{ab}	2.24 ± 0.26^{b}	0.043
AEP (cm²)	2.43 ± 0.11^{a}	6.03 ± 1.88^{a}	11.34 ± 2.93^{b}	0.014

Different superscript letters within a row indicate statistically significant differences ($P < 0.05$) between the groups based on Tukey's post-hoc test. The *P*-value column shows the result of the overall ANOVA test for each variable. DBIS: Superior bi-iliac diameter; DCI: Distance between iliac crests; DBIM: Middle bi-iliac diameter; DBII: Inferior bi-iliac diameter; DTSP: Distance between pubic symphysis tubercles; DTI: Distance between ischiatic tuberosities; DDD/ DDE: Right/left diagonal diameter; DSP: Sacro-pubic diameter; DEI: Distance between ischiatic spines; AEP: Pelvic inlet area.

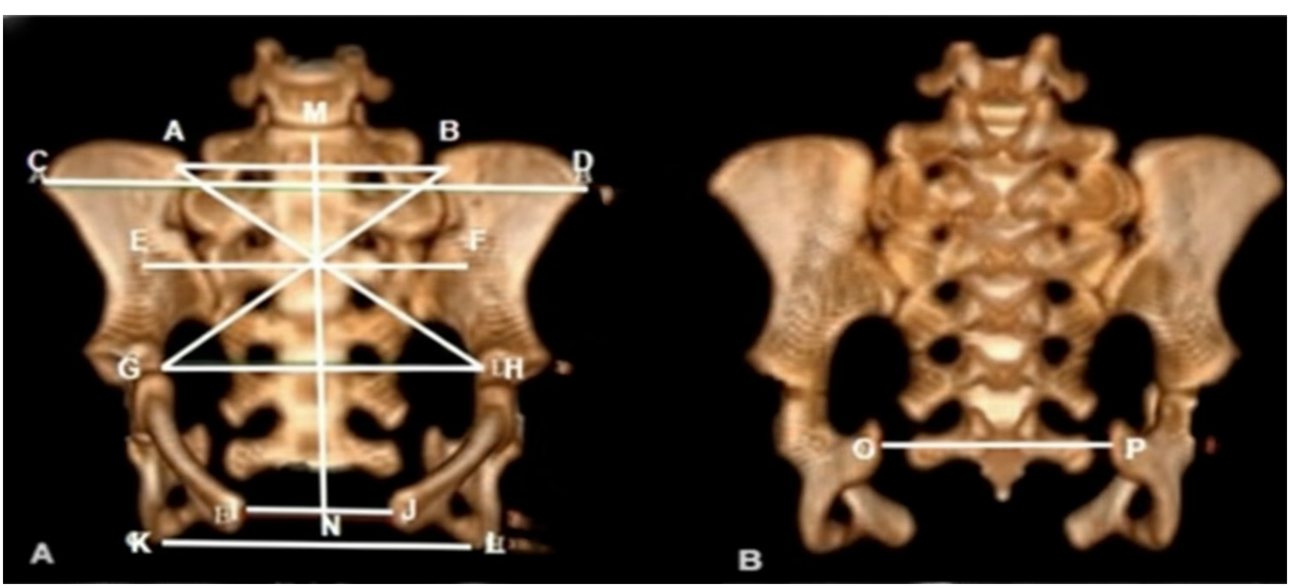

Figure 1. Tomographic image of the pelvis of Bradypus variegatus. A- Image of the pelvis in the ventrodorsal projection showing the measured pelvic perimeters. B- Image of the pelvis in the dorsoventral projection showing the measured pelvic perimeter. [DBIS: Superior bi-iliac diameter (Distance AB); DCI: Distance between the iliac crests (Distance CD); DBIM: Middle bi-iliac diameter (Distance EF); DBII: Inferior bi-iliac diameter (Distance GH); DTSP: Distance between the tubercles of the pubic symphysis (Distance IJ); DTI: Distance between the ischiatic tuberosities (Distance KL); DDD: Right diagonal diameter (Distance AH); DDE: Left diagonal diameter (Distance BG); DSP: Sacro-pubic diameter (Distance MN); DEI: Distance between the ischiatic spines (Distance OP)].

Statistical analysis

Statistical analysis were performed using BioEstat software version 5.3 (Instituto Ma-mirauá, Amazonas, Brazil). Pelvimetric values were compared across the 3 age/weight groups present in the sample: Stillborn, Infant, and Juvenile. Data normality was assessed. Analysis of variance (ANOVA) followed by Tukey's post-hoc test was used to examine differences in the means of pelvic measurements and biometric data (weight and length) among groups. Results are expressed as mean ± standard deviation. A P-value < 0.05 was considered statistically signifi-cant.

RESULTS

A total of 9 *Bradypus variegatus* cadavers were analyzed. Based on established age/weight criteria, the simple comprised 2 stillborns, 5 infants, and 2 juveniles. No adult specimens were present in the sample, as weights and pelage characteristics did not meet the adult class criteria. The sex distribution was 6 males, 1 female, and 2 undetermined (stillborns). Prior to imaging, biometric data were recorded: stillborns weighed 0.41 ± 0.04 kg with a body length of 14.05 ± 0.35 cm; infants weighed 0.72 ± 0.11 kg with a length of 17.5 ± 1.2 cm; and juveniles weighed 1.46 ± 0.02 kg with a length of 23.89 ± 3.16 cm. A 40-50% reduction from live weight was noted due to prior glycerol preservation.

Computed tomography (CT) provided better visualisation of the pelvic anatomy, producing high-resolution 3-dimensional reconstructions without bony superimposition. This allowed for a precise identification of all the osteological landmarks. In contrast, while radiographic (VD and DV) projections enabled pelvimetric measurements, inherent structural superimposition occasionally complicated the precise delineation of some features (Figure 2).

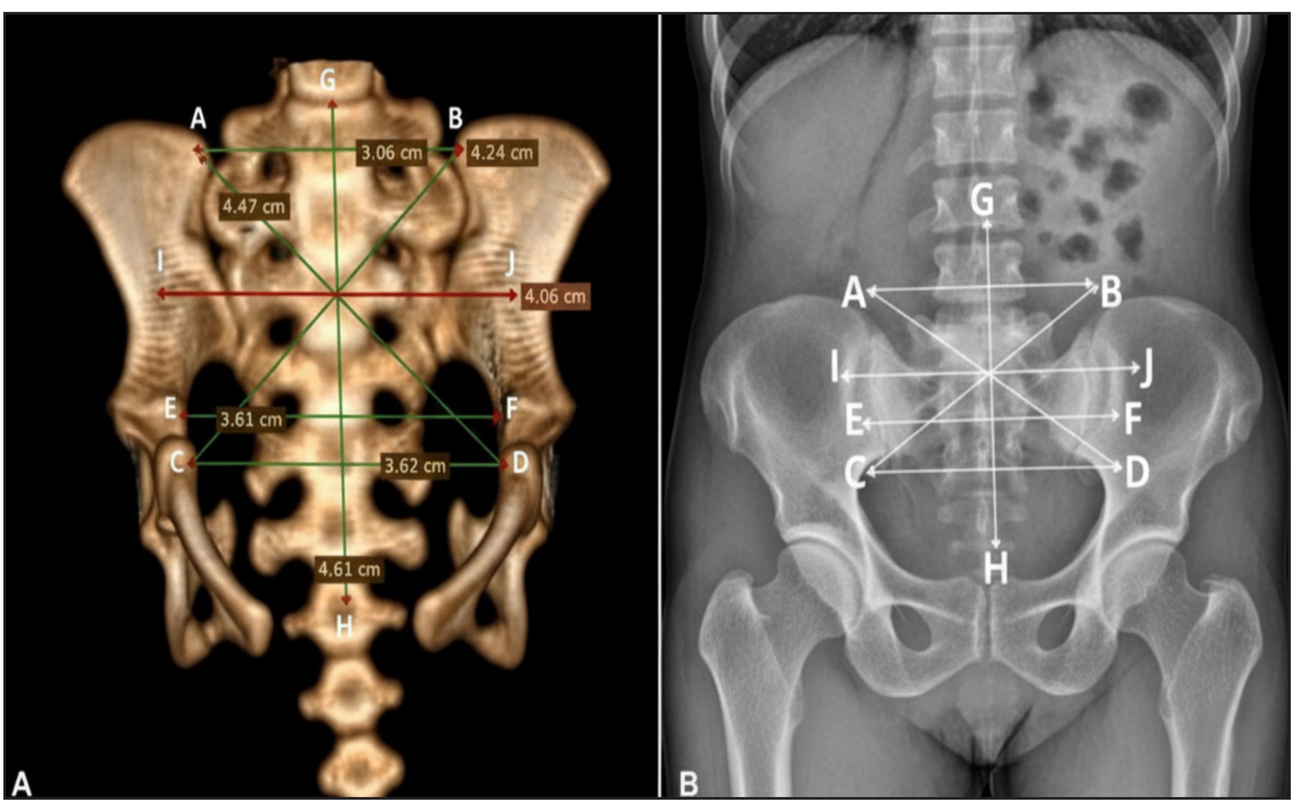

Figure 2. Tomographic (A) and radiographic (B) image of the pelvis of *Bradypus variegatus*, ventral view, demonstrating the clarity of the bony structures of the pelvis.

The pelvimetric data for all samples in the 3 age/weight classes are presented in Table 2. Statistical comparison revealed significant differences ($P < 0.05$) in body weight and length between juveniles and the other 2 groups (stillborns and infants). Regarding pelvic dimensions, significant growth was observed specifically in the transverse plane. The superior bi-iliac diameter (DBIS) and inferior bi-iliac diameter (DBII) showed significant, progressive increases from stillborns to infants to juveniles. The distance between the ischiatic spines (DEI) was significantly greater in juveniles compared to stillborns. In contrast, the sacro-pubic diameter (DSP) did not show significant variation among the groups. The pelvic inlet area (AEP) increased significantly from infants to juveniles.

Based on the comparative analysis of the middle bi-iliac diameter (DBIM) and the sacro-pubic diameter (DSP), which were not significantly different from each other within the juvenile group ($P > 0.05$), the pelvic conformation of B. variegatus was classified as mesatipelvic. This typology indicates a pelvis where the transverse (width) and conjugate (length) diameters are approximately equal.

Body weight and length showed moderate positive correlation with most transverse pel-vic measurements. In contrast, weak correlations were found between body measurements and the sacro-pubic diameter (DSP) as well as the distance between the pubic symphysis tubercles (DTSP). This indicates that pelvic growth in the craniocaudal dimension is not proportional to overall body development, whereas transverse pelvic growth is more closely associated with in-creases in body size.

DISCUSSION

The pelvimetric data in this study have direct applications in wildlife veterinary medicine. The pelvic dimensions, particularly the bi-iliac diameters (DBIS, DBII) and ischiatic spine distances (DEI), distinguish *Bradypus variegatus* from other xenarthrans and arboreal mammals [2,15]. Progressive increases in DBIS, DBII and pelvic inlet area (AEP) in the stillborn, infant, and juvenile groups provide a suitable date for pelvimetric study in this species.

The mesatipelvic pelvic conformation identified in *B. variegatus* differs from the dolicopellic pelvis common in many arboreal mammals [2,15]. This box-like pelvic inlet morphology suggests that cephalopelvic disproportion due to maternal pelvic constriction may not represent a primary dystocia risk in this species. Wildlife veterinarians managing breeding programmes or attending cases of dystocia in sloths need to know the pelvic anatomy of the species for gestation monitoring and peripartum management [8].

The pelvimetric analysis revealed transverse pelvic growth. The transverse diameters (DBIS, DBII, DEI) demonstrated progressive increases, while the sacro-pubic diameter (DSP) showed no variation. This growth prioritises pelvic width over length, aligning with the biomechanical requirements for suspensory locomotion [3,13]. The pelvic girdle serves as an anchor for specialised musculature to support weight rather than propulsion [3,12].

CT imaging proved essential for characterizing complex pelvic structures and validating measurement points. Radiography, while limited by structural superimposition, yielded linear measurements suitable for clinical applications. This dual-method approach, successfully employed in other species of wildlife, including gazelles and anteaters, offers real images of bone structures that can support future studies [5,9,14].

The findings must be interpreted within the context of several limitations. There were no adult samples available for analysis, which prevented the characterisation of pelvic morphometry in adult animals and the evaluation of pelvic dimorphism in relation to sex [2,7]. However, previous work demonstrated that cadavers preserved in *B. variegatus* maintain anatomical relationships suitable for studies [4], therefore, the relative proportions and pelvic measurements are valid to guide future studies.

Despite these limitations, the data provide practical data on the pelvis in juvenile sloths, a concept established in canine medicine [3]. The mesatipelvic conformation may suggest that dystocia investigations should prioritise foetal factors, positioning abnormalities, and maternal parity over pelvic constriction [8]; however, confirmation requires studies that incorporate adult females and observation of pregnancy.

Bradypus variegatus faces habitat fragmentation and anthropogenic threats throughout its range, and effective conservation requires species-specific anatomical knowledge for clinical care and population management [1,2]. This study contributes foundational data supporting veterinary interventions, rehabilitation protocols, and captive breeding programs [1,7]. Future research prior-ities include expanding this dataset to include adults of both sexes, establishing sex-specific norms, and validating measurements *in vivo* using imaging.

CONCLUSIONS

Based on these results, it was possible to describe in detail the bone structures of the limbs and pelvis of *Bradypus variegatus*, demonstrating the pronounced development of thoracic limbs com-pared to pelvic limbs, the absence of a clavicle (suggesting vestigially), and structural adaptations such as a rounded acetabulum and laterally wide pubis, fused carpal bones and elongated claws, which enhance stability and muscle attachment for arboreal mobility and life. These features align with the sloth's unique suspensory lifestyle and reflect evolutionary adaptations to its environment, contributing to broader discussions in evolutionary biology, biomechanics, and conservation. Limitations such as sample size and the absence of adult specimens warrant further investigation to deepen our understanding of these adaptations.

MANUFACTURERS

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Acknowledgements. The authors gratefully thank the team of video surgery, obstetrics and reproduction group (VOR), the National Council for Scientific and Technological Development (CNPq, Brazil), the Coordination for the Improvement of Higher Education Personnel (CAPES, Brazil) and the Research and Postgraduate Pro-Rector of Pará Federal University (Propesp/UFPA) for financial support in the study.

Ethical approval. The present study was conducted after the approval of the Animal Ethics and Welfare Committee of the Federal University of Pará (protocol No. 5943220321). The ethics principles of the European Commission for animal experiments involving animals (Directive 86/609EEC) were also followed.

Declaration of interest. The authors declare that there are no conflicts of interest associated with this research. The authors alone are responsible for the content and writing of the paper.

Artificial intelligence statement. The authors declare that artificial intelligence ChatGPT was used exclusively for linguistic correction, grammatical refinement, and reference standardization.

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