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**Three-dimensional images methodology to morphometric evaluation of
Mangalarga Marchador horses**

Tiago Tolêdo Bittencourt e Alves
Magister Scientiae

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Dissertation submitted to the Animal
Science Graduate Program of the
Universidade Federal de Viçosa in partial
fulfillment of the requirements for the
degree of *Magister Scientiae*.

Adviser: Erica Beatriz Schultz

Co-adviser: Yame F. R. S. da Silva

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A Deus.

À minha família.

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ABSTRACT

ALVES, Tiago Tolêdo Bittencourt e, M.Sc., Universidade Federal de Viçosa, February, 2025. **Three-dimensional images methodology to morphometric evaluation of Mangalarga Marchador horses**. Adviser: Erica Beatriz Schultz. Co-adviser: Yame Fabres Robaina Sancler da Silva.

In equine science, we correlate biometric parameters with locomotion characteristics and sporting performance. Those are some tools that assist in the evaluation and selection breeding process. Traditionally, morphometric measurements are obtained manually, requiring evaluators and need to have contact with the animal. That methodology makes the process laborious, slow, and stressful. Furthermore, subjectivity may occur among evaluators, compromising the accuracy of data collection. The objective of this research was to establish a non-invasive, accurate, and easy-to-use methodology for reconstructing the 3D models and carrying out morphometric evaluation of horses. Fifty-two (52) Mangalarga Marchador horses were used to construct the 3D models, and the following ten measurements were taken: withers height (WH); hip height (HH); head length (HL); neck length (NL); back-loin length (BLL); croup length (CL); shoulder length (SL); body length (BL); head width (HW); and croup width (CW). Conventional and digital methods were used to take morphometric measures. Statistical analysis (Pearson Correlation and linear regression) are used to establish the correlation between the two methodologies to verify the accuracy and precision. The results showed high precision, with R^2 of 98,78% when taking the overall measurements. Some animal parts reached a moderate correlation (HaW, HaC, SL, BL, CW), and for the others, the precision was low. The methodology is robust and reliable but needs some improvements for better accuracy.

Keywords: Horse conformation; Digital; Animal production; Breed characterization

RESUMO

ALVES, Tiago Tolêdo Bittencourt e, M.Sc., Universidade Federal de Viçosa, fevereiro de 2025.

Metodologia de imagens tridimensionais para avaliação morfométrica de cavalos Mangalarga Marchador

. Orientadora: Erica Beatriz Schultz. Coorientadora: Yame Fabres Robaina Sancler da Silva.

Na equideocultura, parâmetros biométricos estão relacionados às características de locomoção e desempenho esportivo, auxiliando no processo de avaliação e seleção da raça. Tradicionalmente, a morfometria é realizada manualmente, requerendo que avaliadores tenham a necessidade de contato com o animal. Esta metodologia torna o processo trabalhoso, lento e estressante. Além disso, a subjetividade entre avaliadores pode comprometer o processo de coleta de dados. Com isto, este estudo teve por objetivo estabelecer uma metodologia não invasiva, precisa e de fácil utilização para a construção de modelo 3D para avaliação da morfometria de equinos. Cinquenta e dois cavalos da raça Mangalarga Marchador foram utilizados na construção dos modelos 3D e dez medidas foram realizadas por meio da metodologia convencional e 3D, sendo estas: Altura na cernelha (AC); Altura na garupa (AG); Comprimento da cabeça (CC); Comprimento do pescoço (CP); Comprimento do dorso-lombo (CD); Comprimento da garupa (CG); Comprimento da espádua (CE); Comprimento do corpo (CCO); Largura da cabeça (LC); Largura da garupa (LG). Os dados obtidos (convencionais e 3D) foram correlacionados por meio de correlação de Pearson e regressão linear à 5 % de significância. Houve alta precisão com R^2 de 98,78% quando considerados todas as medições. Considerando as partes dos animais, as medidas de AC, AG, CE, CCO e LG obtiveram correlação moderada, já as medidas restantes atingiram uma correlação baixa. Conclui-se que a metodologia mostrou-se confiável e robusta, mas necessita ainda de alguns ajustes para a melhoria da sua acurácia.

Palavras-chave: Conformação Equina; Digital; Produção Animal; Caracterização Racial

SUMÁRIO

1. Abstract	08
2. Implications	09
3. Introduction	10
4. Material and Methods	12
5. Results	18
6. Discussion	26
7. Ethics approval	28
8. Declaration of generative AI and AI-assisted technologies in the writing process	28
9. References	29
10. ANEXO 1	35

Three-dimensional images methodology to morphometric evaluation of Mangalarga Marchador horses

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Abstract

In equine science, biometric parameters are commonly correlated with locomotion traits and performance, serving as essential tools for evaluating and selecting animals in breeding programs. Traditionally, morphometric measurements are obtained manually, requiring direct contact between the evaluator and the animal. This method is often labor-intensive, time-consuming, and stressful for the animals, which can compromise data accuracy. To address these limitations, this study aimed to establish a non-invasive, accurate, and user-friendly methodology for three-dimensional (3D) reconstruction and morphometric evaluation of horses. A total of fifty-two Mangalarga Marchador horses were evaluated using both conventional (manual) and digital (3D image-based) methods. Ten morphometric traits were measured: withers height (WH), hip height (HH), head length (HL), neck length (NL), back-loin length (BLL), croup length (CL), shoulder length (SL), body length (BL), head width (HW), and croup width (CW). Measurements obtained by both methods were compared using Pearson

correlation and regression analysis. The results demonstrated high overall precision, with an R^2 of 98.78% for total measurement agreement. Manual measurements of WH, HH, SL, BL, and CW showed strong correlations ($r > 0.60$) and moderate precision (R^2 : 0.55–0.60) with the corresponding 3D data. In contrast, HL, BLL, NL, CL, and HW exhibited low correlations ($r < 0.30$) and limited precision (R^2 : 0.01–0.10). As a preliminary investigation, we conclude that the 3D imaging methodology shows strong potential for equine morphometric assessment. However, further refinement is necessary to improve accuracy for certain specific measurements.

Keywords: Horse conformation, Digital, Animal production, Breed characterization

Implications

Horse Breed morphological characterization is used to register the animal's pedigree. The Mangalarga Marchador horse has a breed pattern approved by the Brazilian Association of Mangalarga Marchador Horse Breeders. The manual measurement can be subjective and stressful for the animal and technicians. With the technological advances, we developed in this paper a new methodology for scanning horses. This methodology aims to measure the morphological characteristics of the Mangalarga Marchador horse quicker, more precisely, and safer for the animals and technicians. We developed an accurate and easy to use methodology with precision technologies to facilitate the management and measurement procedure in equine production systems.

Introduction

The Mangalarga Marchador is a popular horse breed in Brazil, contributing billions of dollars to the national economy and generating hundreds of jobs in recent years (Cabral et al., 2020). Although it originated in Brazil, the breed has spread worldwide. Its economically relevant characteristics are primarily related to morphology, which influences both performance and gait traits. The key morphological traits that define the breed include withers height, rump height, head length, neck length, back loin length, rump length, shoulder length, body length, head width, and hip width (Lage et al. 2009; Petry et al. 2012; Silva de Moura et al. 2020; Castro Sellani et al. 2020).

These morphometric traits are not only important for breed standards but also play a crucial role in understanding the functional abilities of the horse. Since the domestication of horses, conformation has been used to forecast performance and health. In this context, biometry focuses on studying animal body measurements. Structural attributes such as size, shape, and proportion directly influence biomechanics and are intrinsically linked to functional aptitude (Astiz 2009; Fonseca, 2018; Ricard et al. 2023). Research in this field is particularly relevant for establishing the relationship between physical conformation and movement quality (Giraudet et al., 2023). Accordingly, morphometric evaluation considers the relationships among body structures and the proportions of different body parts, as they relate to specific functional purposes such as riding, traction, or load bearing (Rezende et al. 2014; Lucena et al. 2016; Fonseca, 2018; Ricard et al. 2023; Kristjansson et al. 2013; Baena et al. 2022; de Castro Sellani et al. 2020; Silva de Moura et al. 2020).

For the Mangalarga Marchador horse, biometric measurements are essential for official registration with the Brazilian Association of Mangalarga Marchador Horse

Breeders (ABCCMM). To meet registration requirements, the horse's conformation must be verified and evaluated through specific morphometric measurements. Traditional tools such as measuring tapes, horse measuring sticks, and hypometers are commonly used for this purpose. Although these instruments are easy to handle, some animals exhibit adverse reactions due to physical contact. Additionally, the large number of required measurements makes the process time-consuming, stressful, and highly dependent on the evaluators. These factors can compromise measurement accuracy. Therefore, the adoption of Precision Livestock Farming (PLF) technologies is desirable to enhance both the efficiency and reliability of the evaluation process.

PLF is defined as the use of technology, such as sensors, to quickly and precisely monitor parameters of health, environment, production, reproduction, and welfare of individuals or animal groups (Goyal, Yadav, and Mukherjee 2024; Xiang and Wang 2023; Samperio et al. 2021). Among these technologies, three-dimensional (3D) image processing is an important and relevant technology that has been used for many objectives like weight prediction (Zhao et al. 2023; Mortensen, Lisouski, and Ahrendt 2016; Xavier et al. 2024) and morphological characteristics (Guo et al. 2019; Sellke et al. 2023; Hanot et al. 2021; Giraudet et al. 2023).

Research on morphometric prediction, particularly in equine applications using PLF, is growing, since studies employ diverse approaches, such as 2D and 3D measurements. This is because the demand for precise, economical, and efficient procedures for morphometric equine characterization is high considering animal welfare and measurement speed (Lage et al., 2009) in addition to enabling data storage for subsequent analysis. Pérez-Ruiz et al. (2020) evaluated five Pura Raza Española horses by comparing 17 zoometric measurements obtained manually and through a point cloud system using a 3D LiDAR laser sensor, achieving a precision of

97.23%. Freitag et al. (2021) demonstrated a high correlation between morphometric measurements obtained from 2D images and those taken manually in American Quarter Horses. More recently, Matsuura et al. (2024) demonstrated the potential of smartphone-based 3D scanning to reconstruct body shape and obtain precise measurements of riding horses.

Although significant progress has been made, the use of 3D imaging for equine morphometry remains limited, with no studies to date applying the technique to the Mangalarga Marchador breed. Furthermore, this represents the first study application of the Artec Leo 3D scanner in animal morphometric analysis. Therefore, the objective of this study was to evaluate the use of three-dimensional imaging for morphometric assessment of Mangalarga Marchador horses.

Material and methods

Animals and Localization

This study was developed in the Precision Animal Science Laboratory of the Federal University of Vicosa, Minas Gerais State, Brazil, CEUAP number 62/2024. The study used the morphological characteristics of 52 horses of the Mangalarga Marchador breed of 3 years or more, without distinction of gender.

The data were obtained in the Federal University of Viçosa with 20 horses and during the 40^a National Fair of Mangalarga Marchador Horse that occurred in 2023 at Belo Horizonte, Minas Gerais, with 32 horses.

Morphological Characteristic

The morphometric characteristics analyzed accord to ABCMM using both manual and digital methods were (Figure 1):

- Withers Height (WH) – Measurement from the ground to the highest point of the withers, located between the upper edges of the two scapulae;
- Hip Height (HH) – Measurement from the ground to the highest central point of the sacral region, between the internal angles of the iliac bones;
- Head Length (HL) – Distance from the proximal end of the head (poll) to the tip of the muzzle;
- Neck Length (NL) – Distance from the cranial end of the dorsal arch of the atlas to the middle third of the cranial edge of the scapula;
- Back-Loin Length (BLL) – Distance from the end of the withers to the iliac tuberosity;
- Croup Length (CL) – Distance from the point of the hip (tuber coxae) to the point of the buttock (tuber ischii);
- Shoulder Length (SL) – Distance from the dorsal edge of the scapular cartilage to the tip of the shoulder (greater tubercle of the humerus);
- Body Length (BL) – Distance from the point of the shoulder to the point of the buttock;
- Head Width (HW) – Distance between the lateral edges of the forehead at the level of the orbital arches;
- Croup Width (CW) – Distance between the outermost points of the right and left tuber coxae (hip bones). Croup Width (CW) – represents the distance between the right and left hip regions ends.

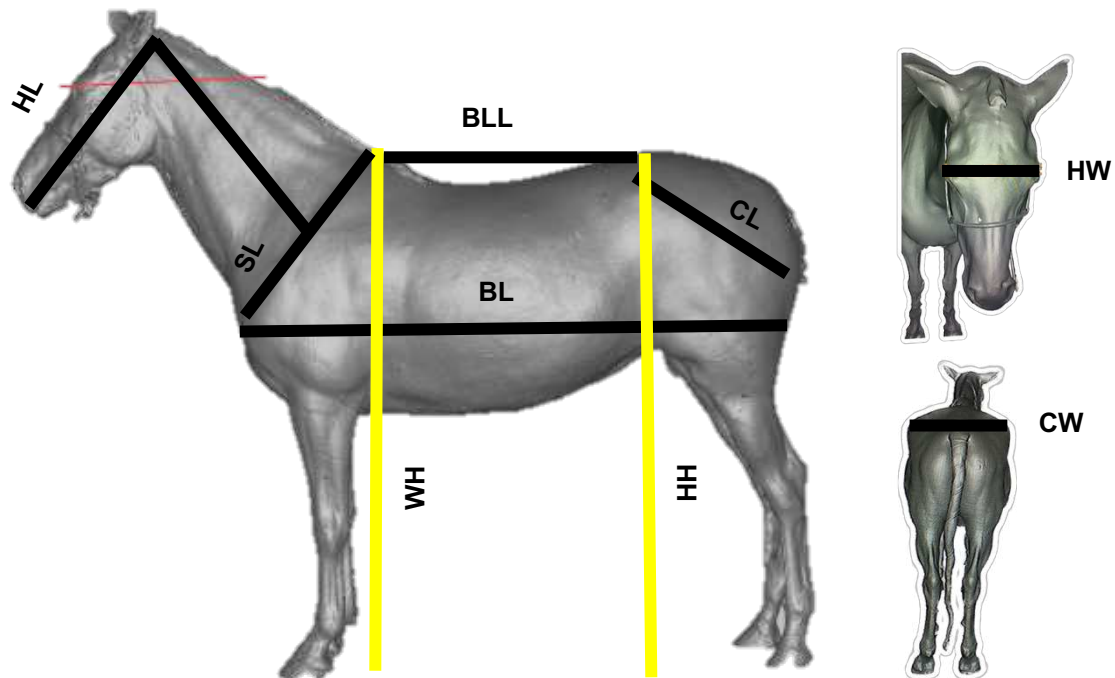


Figure 1: Represents the morphometric characteristics analyzed: Withers Height (WH); Hip Height (HH); Head Length (HL); Neck Length (NL); Back-loin Length (BLL); Croup Length (CL); Shoulder length (SL); Body Length (BL); Head Width (HW); Croup Width (CW). Source: The Authors

Collecting Data

Conventional measurements were obtained using a hypometer, with all data collected by the same trained professional (Figure 2a). During the procedure, the animal was restrained with a halter and kept stationary in a forced stance. The data collection area consisted of a flat, firm surface, and was marked to limit the animal's movement. This method requires physical contact between the hypometer and the animal at the designated anatomical regions to obtain measurements.



Figure 2: (a) Conventional Method, and (b) 3D Scanning Method

Immediately after the manual measurements, a three-dimensional scan was performed using the Artec Leo Professional Handheld 3D Scanner (Artec 3D®) (Figure 2b). The animals were properly restrained with a halter and positioned at a flat, firm, and calm location. During the image acquisition process, the camera was moved around the animal at an average distance of 1 meter, capturing all planes without any physical contact. On average, 2,400 frames were collected per animal, with each scanning session lasting approximately 5 minutes.

Image Processing

The Artec Studio 18 Professional program (Artec 3D ®) was used for processing. The processing was done in the following steps (The detailed commands used are listed in Appendix 1):

- Cleaning to select the frames of interest, where unnecessary artifacts were removed from the image, such as people passing in the background, leaving only the animal;
- Alignment with Global Registration of the frames, where all the frames collected and registered were automatically aligned in the program;
- Merging all the frames collected from the animal, forming a single three-dimensional model;
- Correction of the 3D model, in this phase possible flaws and holes in the model are identified and corrected; and
- Insertion of the texture of the animal's fur into the model, to make the 3D model closer to the animal being modelled.

Qualitative Analysis of 3D Models

The models were classified as good or bad. This was a visual analysis comparing the model with the real structure of the animal. A good model was one that was complete, with all the body parts, and a bad model was one that was incomplete and missing body parts (limbs, head, body).

We research whether it has descriptive difference for the color of the horses coats for obtained bad or good models. The coats were identified in light or dark colors and classified by the quality of the 3D model.

3D Models Measurements

To obtain the measurements of the animal body parts on the 3D model the software of Artec Studio 18 Professional (Artec 3D ®) was used. The software tool measured linear distance between two points manually defined, with only one

measurement per animal and characteristic. The planes used for the measurements were frontal plane to head width, upper plane to rump width and lateral planes left for all other measurements.

Statistical Analysis

The data obtained by conventional and 3D methodologies were processed and analyzed using the software R Studio. We performed correlation and linear regression analyses.

Pearson's correlation coefficient was estimated to explore the relationship between the traditional manual method and the 3D method. The correlations were classified as low (0.00 - 0.29), moderate (0.30 - 0.59), and high (0.60 - 0.99) (Callegari-Jacques, 2003).

A linear regression model was fitted using the least squares method. The regression model can be described as:

$$y = \alpha + \beta x$$

The performance of the regression models were assessed by the coefficient of determination (R^2), root mean squared error (RMSE) and mean absolute error (MAE) obtained with the equations 1, 2, and 3, respectively.

$$(1) \quad R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$$

(2)

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

(3)

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|$$

Where n is the number of samples, y_i is the manual value, \bar{y}_i is the average of the observations, \hat{y}_i is the 3D model value of its observation.

Results

Qualitative Analysis

The 3D models for representing the body shape presented differences in image quality, presenting good morphological characterization, Figure 3, and with gaps in different parts of the animal as observed in Figure 4.

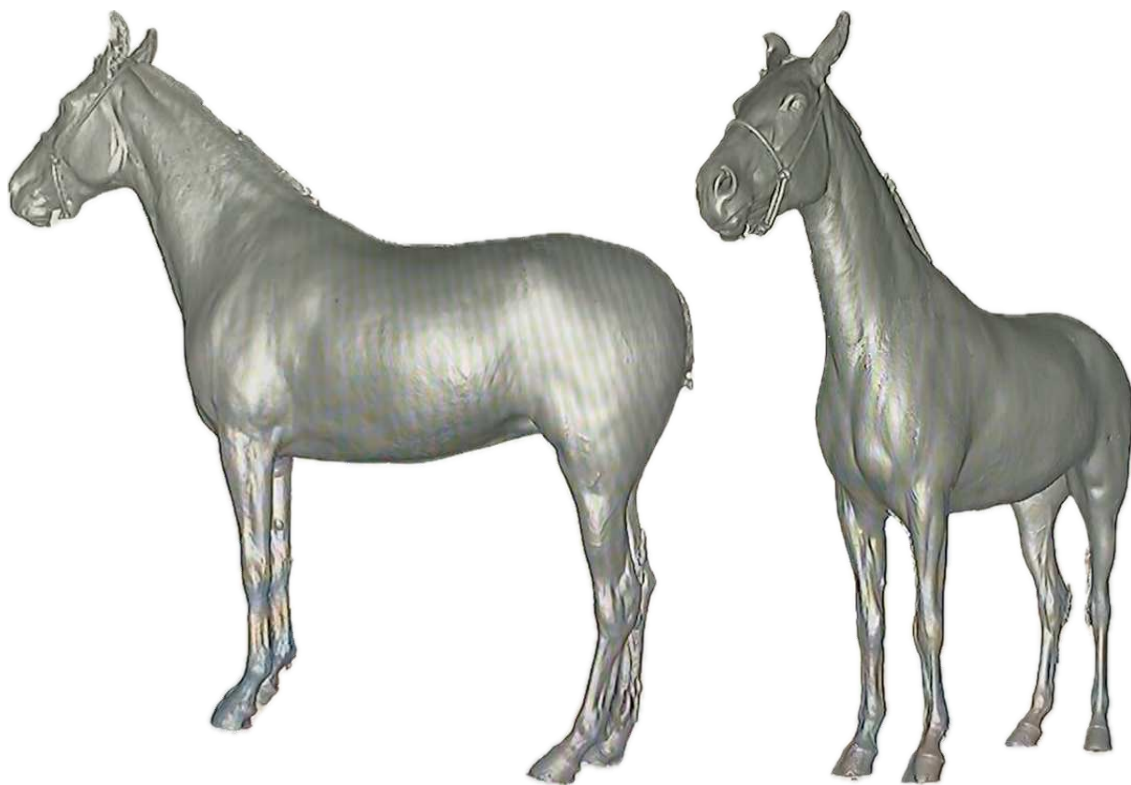


Figure 3: Representation of a qualitatively good three-dimensional Mangalarga Machador horse 3D model.

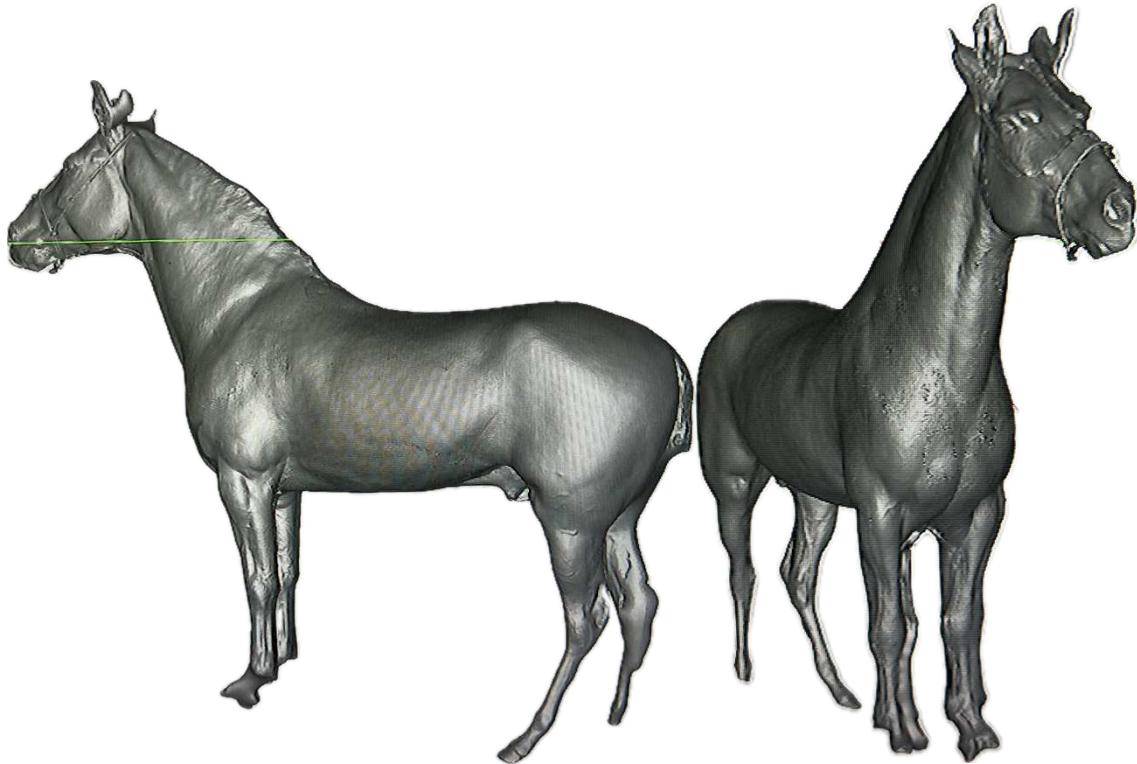
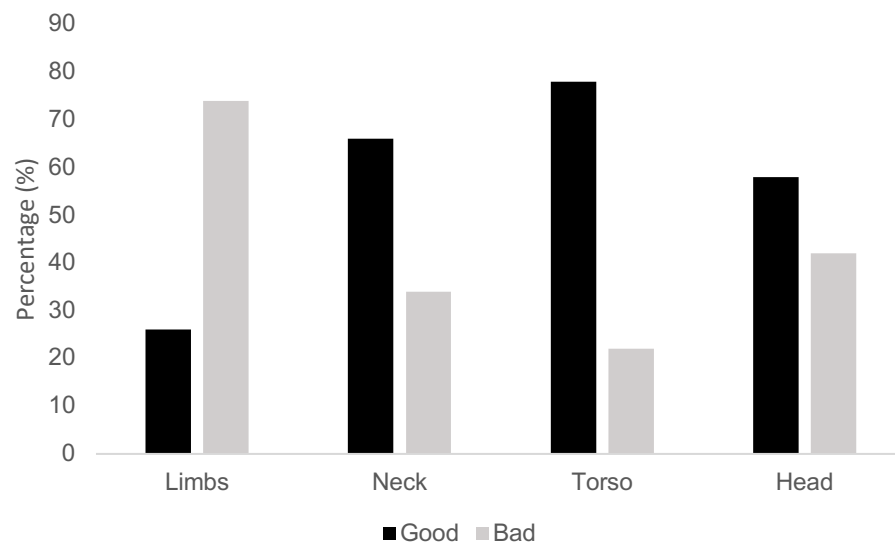


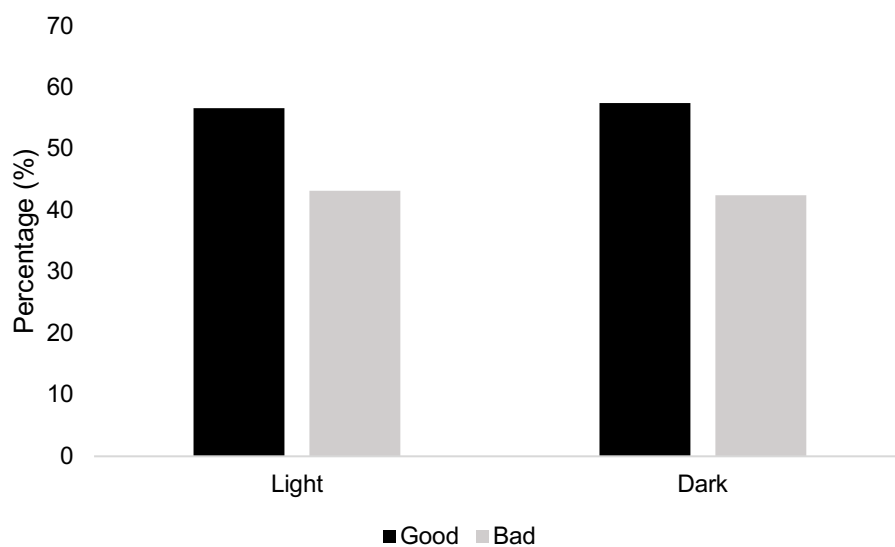
Figure 4: Representation of a qualitatively bad three-dimensional Mangalarga Machador horse 3D model.

There was a descriptive difference in the quality of the model in the different parts of the animal's body (Graph 1). The worst quality result of the 3D animal image obtained was related to the limbs at 74%, followed by the head at 42%, the neck at 34%, and the torso at 22%.



Graph 1: Descriptive analysis of the quality of the 3D model according to the animal's body parts.

For the color of the horses' coats, there was no descriptive difference in the quality of the 3D models for body shape, with 56.7% good, 43.3% poor for light coats and 57.5% good, 42.5% poor for dark coats (Graph 2).



Graph 2: Descriptive analysis of 3D model quality as a function of coat.

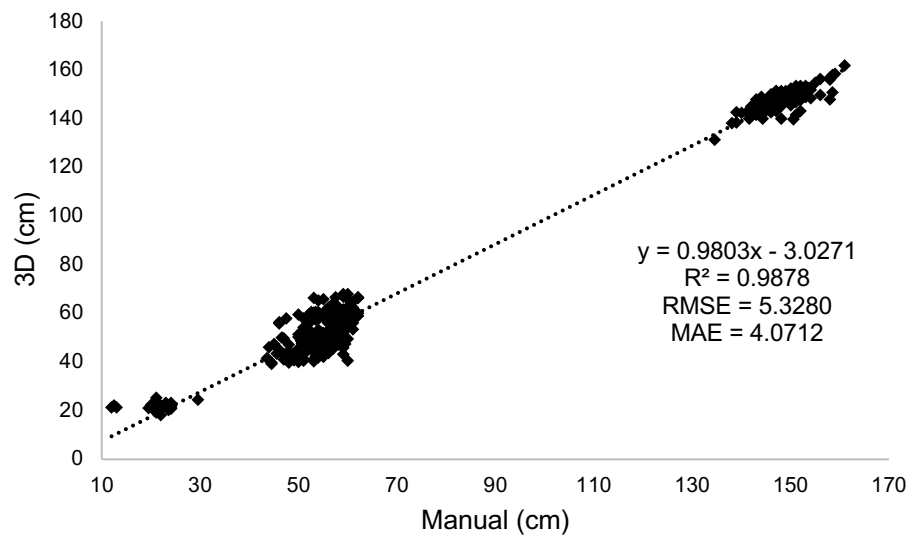
Quantitative Analysis

There was a high and positive correlation (> 0.6) for withers height, hip height, shoulder length, body length, and croup width (Table 1). A moderate and positive correlation ($0.3 < 0.6$) for croup length, and a low and positive correlation (< 0.3) for head length, neck length, back-loin length, and head width (Table 1).

Table 1: Comparison of body measurements between manual and 3D methods

	Correlation	Mean		Standard Deviation	
		Manual (cm)	3D (cm)	Manual (cm)	3D (cm)
WITHERS HEIGHT	0.7825	146.8690	143.4197	3.3423	22.6282
HIP HEIGHT	0.7823	145.5904	142.0852	3.1062	22.4449
HEAD LENGTH	0.0902	56.6578	55.2971	2.8382	9.2849
NECK LENGTH	0.2876	57.5595	56.2822	3.5116	9.1281
BACK-LOIN LENGTH	0.0616	53.8863	52.6401	4.1412	8.6232
CROUP LENGTH	0.3458	53.2386	52.2542	3.6923	8.3650
SHOULDER LENGTH	0.6847	52.4418	51.2555	3.7925	8.4016
BODY LENGTH	0.7551	151.8142	147.9966	4.8464	23.3859
HEAD WIDTH	0.1578	21.1904	20.2043	4.1015	5.5511
CROUP WIDTH	0.7552	49.3170	48.3204	2.9994	7.9088
OVERALL	0.9939	81.7162	80.2224	45.8808	46.4713

Considering all measurements (Graph 3), manual and 3D model, the MAE (4.07) found represented an error of around 5% concerning the general average of the 3D method and we found a R^2 of above 90%, demonstrating the accuracy of the method.



Graph 3: General manual and 3D measurements analysis by regression of all measurements.

For specific measurements, moderate precision was observed 55 to 60% with an error of around 2 cm for height at the withers, height at the croup, body length, and croup width (Figure 5).

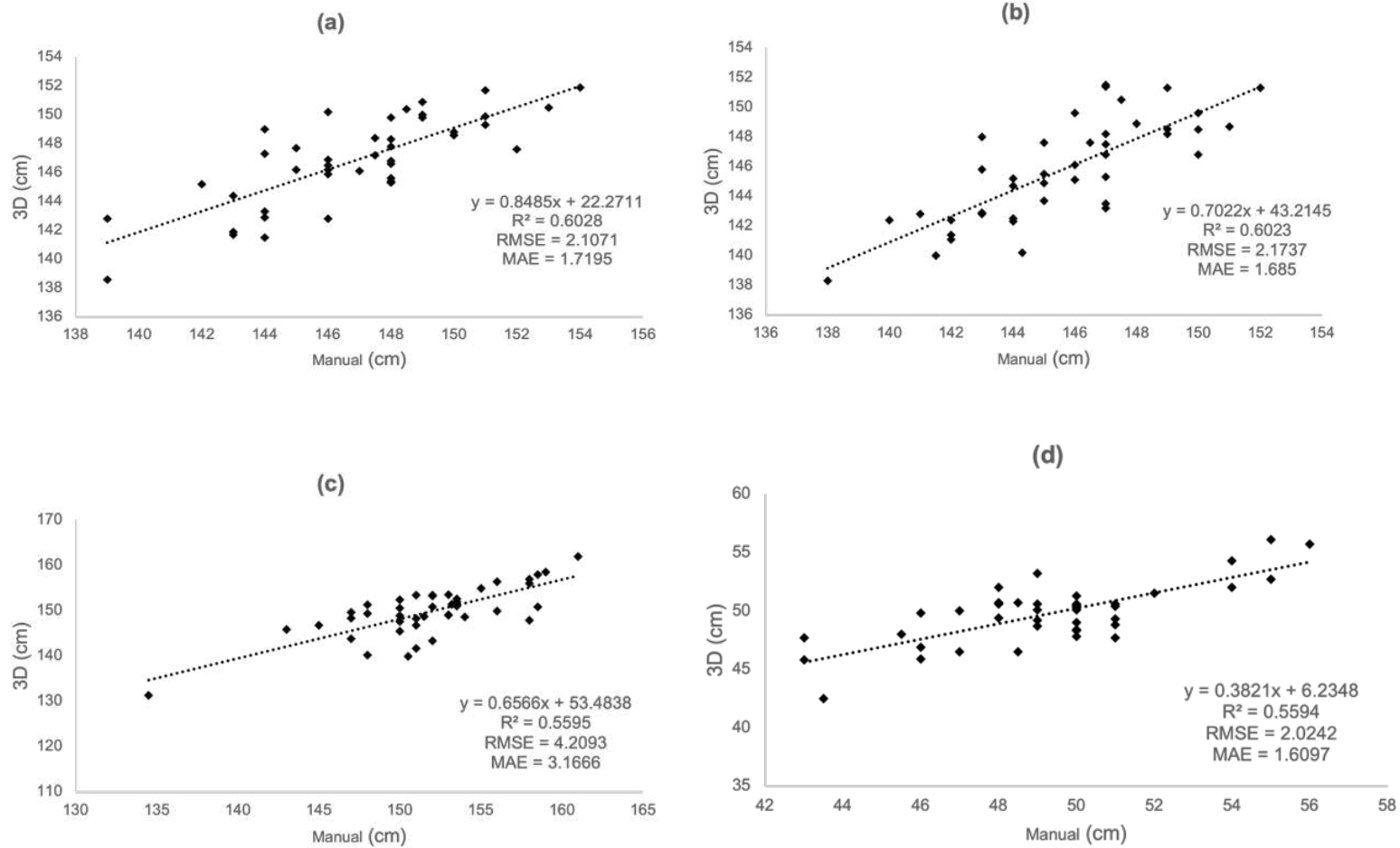
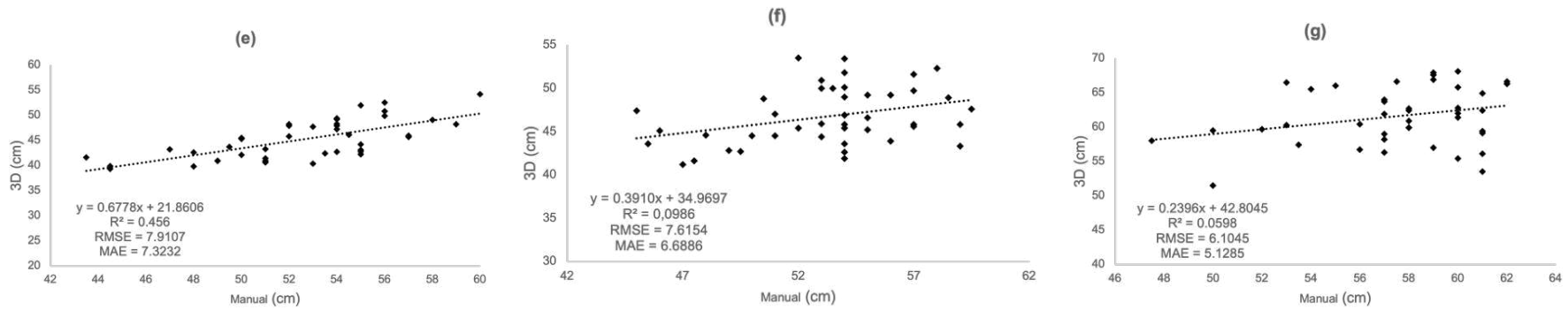


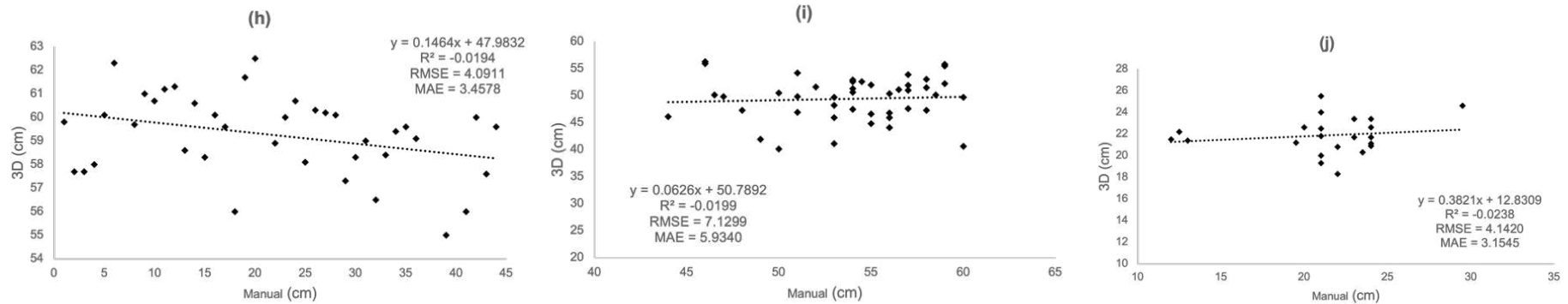
Figure 5: Represents the regressions of each separate measurement: Withers Height (a), Hip Height (b), Body Length (c), and Croup Width (d).

The measurements of shoulder length, croup length, neck length, head length, back-loin length, and head width obtained low precision from 2 to 45% with an average error ranging from 3 to 7 cm (Figure 6).

1



2



3

4 **Figure 6:** Represents the regressions of each separate measurement: Shoulder Length (e), Croup Length (f), Neck Length (g), Head
 5 Length (h), Back Loin Length (i), Head Width (j).

Discussion

Considering the 3D models obtained and classified as either good or poor, the highest quality results were observed in the torso region, with 78% of the models deemed satisfactory (Graph 1). Poorer-quality models were primarily attributed to limitations in the data collection process, which involved circling the entire animal while continuously aiming a camera equipped with a flash at the animal. As prey animals, horses tend to react to unfamiliar stimulus by moving away, and such movement disrupts the camera's spatial reference, thereby reducing the accuracy of the 3D reconstruction. This issue is particularly evident in highly mobile regions such as the head and neck, where horses often move in response to their surroundings, further complicating image acquisition.

Conversely, more accurate models were typically associated with animals displaying a docile temperament and minimal movement during scanning. These challenges are inherent in capturing data from live animals, especially considering that the Artec Leo (Artec 3D®) scanner is designed for use with static objects, making the process of scanning live, reactive animals especially demanding.

Regarding coat color, no descriptive differences were observed in the quality of the 3D models (Graph 2). This outcome may be attributed to the use of a camera equipped with a LiDAR (Light Detection and Ranging) sensor, which constructs three-dimensional representations based on depth data, that is, the distance between the scanner and the target rather than relying on visible light. As a result, the system is largely unaffected by variations in coat pigmentation, enabling consistent performance across animals with light or dark coats. This depth-based approach allows the sensor

to capture accurate morphological information regardless of color, thus facilitating model generation under a range of lighting and surface conditions.

Considering the quantitative results, the standard deviations for all measurements were higher in the 3D model compared to manual measurements (Table 1). One approach to reducing errors, as suggested by Freitag et al. (2021), involves marking the main anatomical reference points on the animal to facilitate morphometric evaluation in 2D images of horses.

Measurements with moderate to high correlations such as withers height, hip height, shoulder length, body length, and croup width were related to larger and less mobile anatomical regions, which likely improved measurement consistency. The moderate correlation for croup length may be affected by limb movement. Lower correlations for head length, neck length, and head width are likely due to the high mobility of these regions. Back-loin length was difficult to measure accurately in both 3D and manual methods, due to challenges in identifying precise anatomical points. These were similar as Pérez-Ruiz et al. (2020) reported, who found similar patterns using LiDAR for 3D morphometric analysis.

When analyze regressions, for overall measurements (Graph 3), morphometric were high accuracy as well as Freitag et al. (2021), Matsuura et al. (2024) and Pérez-Ruiz et al. (2020) who found R^2 above 0.97 and errors (RMSE) between 1.61 and 7.61. However, for each measurement of body parts the results corroborate with those demonstrated on correlations (Figures 5 and 6). In other words, precision and accuracy varied according to the evaluation site due to movements and the absence of markings on the anatomical points. Therefore, despite the errors, automated methods such as 3D scanning are promising for performing morphometric evaluations in a fast, accurate, and non-invasive manner. Santos et al. (2017) emphasize that further

development of data collection techniques is still required, particularly in addressing camera-to-animal angle deviations, animal positioning, and the accurate marking of anatomical landmarks on the horse.

In summary, this study represents the first use of the non-static Artec Leo scanner for equine morphometric 3D modeling. The three-dimensional imaging methodology for equine morphological evaluation has proven to be robust, producing consistent results supported by literature. However, improvements are still needed to achieve greater accuracy.

Ethics approval

CEUAP 62/2024

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) did not use any AI and AI-assisted technologies.

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ANEXO 1

ARTEC LEO 18 (Artec 3D ®) PROGRAM COMMANDS IMAGE PROCESSING

First step:

Cleaning -For this step, the Editor-Eraser tool was used to select the animal and remove the artifacts.

Second step:

Alignment of the frames, for this phase, the Align-Type Best Fit-Select all scans of the project-Align tool was used.

Global registration of the frames, using the Tools-Alignment-Global-Features-Geometry and Texture-Registration Mode-Separate and then together-Key Frame Ratio-10,000-Focus on Geometry-Search for Features within 30,000mm-Subsampling-1,000-Execute tool.

Third step:

Fusion of all scans of the animal, forming a single three-dimensional model. Using the Tools-Fusion-Resolution-1,000-Sharpness-1.00-Close Holes-Close Holes by Size-Smart fusion/by size/maximum relative hole radius-30,000-Remove Targets-Delete erroneous frames-Delete-Run tool.

Fourth step:

Correction of the 3D model, in this phase possible holes in the model are identified and corrected, using the Fix holes tool-Holes-Fill mode-Smooth-Select all-Apply.

Fifth step (optional):

Insertion of texture in the image, this step includes the possibility of adding the coat texture to the model, using the Texture tool-Select the model-Select the texture source-All scans-Preview-Apply.

Measurements of the 3D model: The previously described measurements of the animals are obtained directly from the model and, for this purpose, the Measurements-Linear Distance-Mark the points on the model-Save measurements tool was used.