FULL ARTICLE

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Linear measurements, body proportions, and biomechanical insights: morphological analysis of arabian horses in São Paulo, Brazil

Medições lineares, proporções corporais e perspectivas biomecânicas: análise morfológica de cavalos árabes em São Paulo, Brasil

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ABSTRACT

This study, conducted with meticulous scientific rigor, evaluated linear measurements, body proportions, and body indices in Arabian horses better to understand their morphology, aptitude, and biomechanics. The sample comprised 168 adult purebred Arabians (76 males and 92 females) housed in a horse farm in the Brazilian state of São Paulo. Twenty-six linear measurements were made using a measuring tape, from which morphometric indices were calculated. The data was meticulously analyzed using variance analysis and Tukey's test, with the level of significance set at 5%. The findings of this study, backed by robust statistical analysis, revealed that Arabian horses are geometric, slightly long-limbed (ectomorph), light-working horses and can bear loads equivalent to 25% of their body weight. Longer dorsolumbar, croup, and thigh length than front limb linear measurements suggest body disproportion. Similar findings have been reported in other athletic horse breeds, such as Quarter Horse and Brazilian Sport Horse, as physical exercise requires more propulsion than pleasure riding. Dactylo-thoracic and ability indices place Arabian horses in the light-working horse category, supporting this hypothesis. Some measurements and indices differed between genders, with males exceeding females in most cases, except for body length. Linear measurements proved to be essential tools for movement and conformation assessment. Arabian horses in this sample did not meet riding comfort standards but were thought to have good athletic potential based on linear measurements and proportions.

Keywords: Farming. Endurance horse. Morphology. Race.

RESUMO

Este estudo, conduzido com meticuloso rigor científico, avaliou medições lineares, proporções corporais e índices corporais em cavalos Árabes para uma melhor compreensão de sua morfologia, aptidão e biomecânica. A amostra foi composta por 168 cavalos Árabes puros adultos (76 machos e 92 fêmeas) alojados em uma fazenda de cavalos no estado brasileiro de São Paulo. Vinte e seis medições lineares foram realizadas usando uma fita métrica, a partir das quais os índices morfométricos foram calculados. Os dados foram meticulosamente analisados utilizando análise de variância e o teste de Tukey, com o nível de significância fixado em 5%. Os resultados deste estudo, respaldados por uma robusta análise estatística, revelaram que os cavalos Árabes são animais geométricos, ligeiramente alongados (ectomorfos), cavalos de trabalho leve e podem suportar cargas equivalentes a 25% de seu peso corporal. O comprimento dorsolombar, da garupa e da coxa mais longos do que as medições lineares dos membros anteriores sugerem uma desproporção corporal. Resultados semelhantes foram relatados em outras raças de cavalos atléticas, como o Quarto de Milha e o Cavalo de Esporte Brasileiro, uma vez que o exercício físico requer mais propulsão do que a equitação de lazer. Os índices dactilo-torácico e de habilidade colocam os cavalos Árabes na categoria de cavalos de trabalho leve, apoiando esta hipótese. Algumas medições e índices diferiram entre os gêneros, com os machos superando as fêmeas na maioria dos casos, exceto no comprimento corporal. As medições lineares se mostraram ferramentas essenciais para a avaliação do movimento e da conformação. Os cavalos Árabes desta amostra não atenderam aos padrões de conforto para equitação, mas foram considerados ter um bom potencial atlético com base em medições lineares e proporções.

Palavras-chave: Criação. Cavalo de enduro. Morfologia. Raça.

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Introduction

The Arabian breed, with its rich history dating back to 4000 BC in Mesopotamia, is one of the oldest and most esteemed horse breeds globally. These horses, domesticated by Middle Eastern Bedouins, were renowned for their unique combination of nimbleness and endurance, making them invaluable assets in warfare and labor until the Modern Era (Głażewska, 2010). Today, Arabian horses continue to showcase their exceptional qualities, excelling in endurance and horse racing events worldwide. This enduring legacy is a testament to the breed's unique qualities and continued relevance in the modern world. However, it is essential to note that the selection process for Arabian horses has traditionally focused primarily on conformational traits and aesthetic qualities.

The best-known Arabian horse populations are in the Middle East (including Egyptian purebreds), Europe (Polish and French), the United States, and Canada. However, mitochondrial DNA (mtDNA) studies have confirmed that Arabians originated from the Middle East and may currently be found in Eastern Middle East regions, Europe, and North America. High numbers of similar haplogroups with little genetic diversity among breeding mares in these groups have been demonstrated. Still, genetic selection criteria may differ among populations. Arabian horses are widely recognized for their outstanding beauty. However, racing performance-related characteristics are also desirable in this breed. Polish-Arabian horses are predominantly selected based on type (i.e., appearance), conformation, and racing ability (Głażewska et al., 2007), whereas French Arabians are primarily known for their racing prowess. In contrast, Eastern lineages tend to be selected for physical traits. Overall, Arabian horse selection has historically prioritized versatility while adhering to desirable beauty standards. Consequently, 2- to 2.5-year-olds initially used for racing are often trained for endurance riding later in life (Ropka-Molik et al., 2019).

Morphometry is a critical area of study in equiculture, providing invaluable insights into horses' physical conformation and bodily structure. One of the most notable aspects of the Arabian breed is its elegance and anatomical refinement, which often manifest in specific proportions and distinctive characteristics. Although morphometric analyses have been conducted in several saddle horse breeds, including *Pantaneiros* (Miserani et al., 2012), Brazilian gaited horses *Mangalarga Marchador* (Cabral et al., 2004), and *Campolina* (Berbari Neto, 2005), as well as Quarter Horses (Donofre et al., 2014), and Brazilian rodeo (*Vaquejada*) horses (Pimentel et al., 2011), studies on Arabian horses remain scarce. Relevant conformation-related measurements have been studied (Sadek et al., 2006), and their variability across three Polish horse breeding farms was investigated (Sobczuk & Komosa, 2012).

The Arabian horse breed is highly esteemed in Brazil for its versatility, beauty, and sporting prowess, particularly in equestrian endurance competitions. These horses excel in resilience, agility, and long-distance traversing over varied terrains. Their presence and triumphs in endurance competitions significantly promote and reinforce this sporting modality in the country. Additionally, integrating Arabian horses into genetic enhancement programs holds promise for improving other equine breeds cultivated in Brazil. Crossbreeding with Arabians can produce offspring with desirable traits such as endurance, aesthetic appeal, and docile temperament. These contributions demonstrate the significant role of the Arabian horse within the Brazilian equine industry across diverse facets.

This study aims to evaluate linear measurements, body proportions, and morphometric indices in Arabian horses bred in Brazil to gain deeper insights into their morphological characteristics, abilities, and biomechanical traits.

Materials and Methods

The sample comprised 168 adult purebred Arabians (76 males and 92 females) housed in different horse farms located in the Brazilian state of São Paulo: *Rach Stud* (Salto de Pirapora, 23°38'58" S,47°34'25" O), *Estrela Guia* (Sorocaba, 23°30'07" S,47°27'28" O), *Haras Meia Lua* (Sorocaba, 23°30'07" S,47°27'28" O), *Haras Serondella* (Salto de Pirapora, 23°38'58" S,47°34'25" O), *Estância Califórnia* (Tatuí, 23°21'24" S,47°51'27" O), *Haras Vila dos Pinheiros* (Indaiatuba, 23°5'18" S,47°13'24" O) and

São Paulo Jockey Club (São Paulo, 23°32'56" S,46°38'20" O). Selected horses were healthy adults aged 8.11 (± 5.17) years and duly vaccinated and dewormed.

Linear measurements (cm) were taken from the left side of the body using a measuring tape. Horses stood square on a flat surface and wore halters. Linear measurements are described in Table 1 and shown in Figure 1.

The following indices were calculated from linear measurements (Torres & Jardim, 1992):

- $Weight(kg) = (TC)3x80$ (1)

- Conformation index (CI): body length to thoracic circumference ratio. Body indices greater than 0.90 indicate ectomorph body type. Conformation indices between 0.86 and 0.88 indicate mesomorph body type. Conformation indices lower than 0.85 indicate endomorph body type. The conformation index is calculated using the following formula:

$$CI = \frac{LM1}{TC} \quad (2)$$

- Load index (I): weight (kg) a horse can bear effortlessly on its back while working at the trot or gallop. Load index is calculated using the following formula (number 56 being a constant):

$$I = (TC)2x\frac{56}{LM12} \quad (3)$$

- Ability index (Ia): weight-to-height ratio, a measure of aptitude. Ability indices lower than 2.60 indicate saddle horses. Ability indices between 2.75 and 2.60 indicate saddle or light working horse. Ability indices higher than 3.15 indicate draft horses. The ability index is calculated using the following formula:

$$Ia = \frac{Weight}{LM12} \quad (4)$$

Dactylo-thoracic index (DTI): cannon circumference-to-thoracic circumference ratio. This index is a ratio between body mass and limbs and allows the following classifications:

Hypermetric (heavy weight horses) = DTI > 11.5; eumetric (medium weight horses) = 10.5 ≤ DTI ≤ 10.8; hypometric (light weight horses) = DTI < 10.5. Dactylo-thoracic index is calculated using the following formula:

$$DTI = \left(\frac{Cannon\,circumference}{TC}\right)x100 \quad (5)$$

Table 1 – The description and definition of linear measurements and body circumferences of Arabian Horses

LM1	Craniocaudal length, from the scapulohumeral joint to the ischial tuberosity (body length).
LM2	Length from the scapulohumeral joint to the vertical tangent of the spinal process of the fifth thoracic vertebra.
LM3	Distance from the axial tangent of the spinal process of the fifth thoracic vertebra to the fifth lumbar vertebra.
LM4	The distance from the vertical tangent of the fifth lumbar vertebra to the ventral inguinal margin and from the horizontal tangent of the inguinal margin to the caudal margin of the gluteal muscle.
LM5	Distance from the oblique vertical tangent of the dorsal margin of the femorotibiopatellar region to the intertarsal joint.
LM6	Distance from the sacral tuberosity's vertical tangent to the femorotibiopatellar region's dorsal margin.
LM7	Distance from the iliac tuberosity's vertical tangent to the femorotibiopatellar region's dorsal margin.
LM8	Distance from the oblique vertical tangent of the iliac tuberosity to the ischial tuberosity.
LM9	Distance from the oblique vertical tangent of the iliac tuberosity to the dorsal margin of the femorotibiopatellar region.
LM10	Distance from the carpal torus to the ground.
LM11	Distance from the vertical tangent of the intertarsal joint to the ground.
LM12	The distance from the vertical tangent of the spinal process of the fifth thoracic vertebra to the ground (height).
Thoracic Circumference (TC)	Thoracic circumference was measured behind the withers using a measuring tape between the spinal processes of T8 and T9.
Dorsolumbar (DL)	Distance from the spinal process of T9 to the cranial portion of the tuber sacrale.
Forearm Circumference	The circumference is measured at the level of the proximal forearm, comprising the radius and the ulna.
Carpus Circumference	The circumference is measured at the level of the mid-radiocarpal joint, comprising the accessory carpal bone.
Cannon Circumference	The circumference is measured at the level of the proximal metacarpus, which comprises metacarpal bones II, III, and IV.
Neck Length	The distance from the cranial aspect of the dorsal arch of the atlas to the mid-third of the cranial border of the scapula is.
Head Length	Distance from the nuchal crest to the medial aspect of the lower incisor arcade.

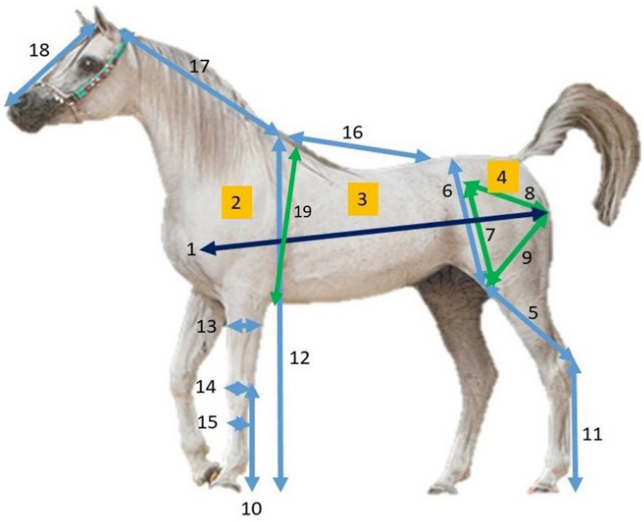

Figure 1 – Linear measurements taken from male and female Arabian horses. 1: LM1; 2: LM2; 3: LM3; 4: LM4; 5: LM5; 6: LM6; 7: LM7; 8: LM8; 9: LM9; 10: LM10; 11: LM11; 12: LM12; 13: forearm circumference; 14: carpal circumference; 15: cannon circumference; 16: dorsolumbar; 17: neck length; 18: head length; 19: thoracic circumference.

- Cannon load index (CLI): cannon circumference-to-body weight ratio. This index reflects the ability of limbs to carry body mass. The cannon load index is calculated using the following formula:

$$CLI = \left(\frac{Cannon\ circumference}{Weight} \right) x100 \quad (6)$$

Data were tested for normal distribution and analyzed using one-way ANOVA (analysis of variance). Tukey's test ($P < 0.05$) compared data from male and female horses. Statistical analyses were conducted using software (Minitab 19®).

Results

The results in Table 2 provide a comprehensive overview of the sample's linear measurements taken from male and female Arabian horses and various indices derived from these measurements. At the first moment, measurements were not distinguished by gender to reflect the Arabian breed overall (mean values, standard deviations, and coefficients of variation) taken from all horses in the sample (n = 168).

A high coefficient of variation (63.76) of age data reflects individual heterogeneity (breeding mares, male and female athletes, and stallions). In contrast, height measurements had the lowest coefficient of variation (2.30), attesting to breed homogeneity. Similar heights between males and females have been reported in a study investigating linear measurements in Egyptian Arabian horses (Sadek et al., 2006). The purebred Arabians in this sample were ectomorphs (0.94), eumetric (428.99 ± 37.13 kg), and of medium height (15,227 ± 3.67 cm).

These results provide valuable insights into Arabian horses' morphometric characteristics and physical attributes in the sample, highlighting their variability and potential implications for performance and conformation. The significant differences observed in specific measurements between genders suggest gender-specific morphometric traits within the Arabian breed.

The results presented in Table 3 provide a comparative analysis of morphometric indices between male and female purebred Arabian horses in the sample.

These findings highlight significant gender-based differences in morphometric indices among purebred Arabian horses. Female horses generally exhibited higher conformation, load-bearing capacity, and performance ability than male horses. These results provide valuable insights into Arabian horses' morphological and biomechanical characteristics, which may affect breeding, training, and performance evaluation within the breed.

Discussion

The results of this study indicate that horses with an ectomorph body type have a shorter back than the shoulder and the croup. This differs from previous studies suggesting that in well-balanced saddle horses, the back should be shorter than the shoulder and the croup (Torres & Jardim, 1992). Table 2 shows that females had longer bodies than males. This difference may be because females are primarily selected for breeding, while males are selected for breeding and sport. The results of this study align with the linear measurement data obtained from Quarter Horses in a previous study by Donofre et al. (2014). Despite having different intended uses, such as endurance and sprint races for Arabians and Quarter Horses, respectively, both breeds rely on gallop. A longer croup (LM4) is believed to be associated with higher propulsive ability. This hypothesis is supported by conformation, ability, and DTI indices in this sample, as they are skill indicators.

Head length is an essential factor in determining the breed traits of horses. Arabian horses are known for their small, delicate heads and concave noses, which are prominent features. The head plays a crucial role in the horse's movement, providing balance and momentum. The study's average head and neck lengths were 61.13 cm (± 2.47) and 82.36 cm (± 6.07). A longer neck is considered a compensatory trait rather than a conformation defect in horses with smaller heads. The muscular neck muscles also play a vital role in

Table 2 – The following list comprises linear measurements in cm taken from Arabian horses of both genders

	Mean	SD	Variance	CV
Age (years)	8.11	5.17	26.75	63.76
LM1	161.72	7.36	54.24	4.55
LM2	36.76	4.61	21.26	12.54
LM3	64.85	7.13	50.93	11.00
LM4	59.95	5.88	34.66	9.82
LM5	59.64	3.07	9.45	5.16
LM6	73.52	4.27	18.25	5.81
LM7	48.14	2.76	7.64	5.74
LM8	58.25	3.35	11.22	5.75
LM9	61.20	3.81	14.55	6.23
LM10	52.31	5.62	31.59	10.74
LM11	60.43	2.26	5.14	3.75
LM12	152.27	3.67	13.46	2.30
TC	174.89	5.07	25.70	2.90
DL	68.09	3.98	35.84	8.38
Forearm circumference	43.00	2.50	6.27	5.82
Carpus circumference	30.64	1.55	2.40	5.06
Cannon circumference	19.67	0.86	0.75	4.40
Head length	61.13	2.47	6.11	4.05
Neck length	82.36	6.07	36.91	7.38
Weight (kg)	428.99	37.13	1378.95	8.66
DTI	0.11	0.00	0.02	4.65
CI	191.83	10.33	106.71	5.39
LI	107.43	5.78	33.47	5.39
AI	2.68	0.21	0.04	8.12

Note: SD = standard deviation; CV = coefficient of variation; LM = linear measurements; TC = thorax circumference; DL = dorsolumbar; DTI = dactyl-thoracic index; CI = conformation index; LI = load index; AI = ability index.

Table 3 – Comparative analysis of mean±standard deviation indices in male and female purebred Arabian horses

Indices	Males	Females	p
Weight (kg)	419.72±3.58	440.77±3.60	0.280
Body Index	0.93±0.03	0.95±0.02	0.776
DTI	0.11±0.00	0.11±0.00	0.980
Conformation index	$188.92±9.96^{B}$	$194.22± 8.81^{A}$	>0.001
LI	$105.79±4.93^{B}$	$108.76±5.57^{A}$	0.012
AI	$2.63±0.20^{B}$	$2.75±0.31^{A}$	0.030
CLI	$4.77±0.40^{A}$	$4.52±0.34^{B}$	0.010

Note: DTI = dactyl-thoracic index; CI = conformation index; LI = load index; AI ability index; CLI = cannon load index. Values followed by different superscript capital letters in the same row differ significantly ($P < 0.05$).

controlling the shoulder, arm, and thoracic limb muscles, providing the horse with greater agility (Denoix, 2014). Therefore, horses with extended shoulders and forearms may have shorter necks to offset their body balance, as shown in a study investigating Arabian lineage variabilities in three Polish horse farms (Sobczuk & Komosa, 2012).

Thoracic circumference findings in this sample are in keeping with data reported in Arabian (Sadek et al., 2006), Criollo (Kuntz Filho and Löf, 2007), and Brazilian rodeo Quarter horses (Pimentel et al., 2011). Horses with wider chests are thought to have more extraordinary athletic ability, as this region comprises the lungs and heart. Wider thoracic circumference in females (Table 2) may also have reflected that most female horses in this sample were breeding mares.

Cannon circumference did not differ significantly between males and females in this sample. Similar findings have been reported in Criollo (Pimentel et al., 2018), Brazilian rodeo Quarter horses (Meneses et al., 2014), and Arabian horses (Sadek et al., 2006). Biometric studies investigating sport horse breeds also revealed similar cannon circumference between male and female English Thoroughbred, Quarter, and Arabian horses (Rezende et al., 2014). However, forearm circumference in that study was wider in males, probably due to bulkier muscle mass.

The dorsolumbar region connects the anterior and posterior segments of the horse's body and transfers impulse forces generated by the hind limbs. An isolated analysis of this variable suggests that horses with shorter backs are more comfortable to ride. However, combined analysis of dorsolumbar length and height measurements revealed that athletic horse breeds such as Brazilian Sport Horse (Godoi et al., 2012), Criollo (Pimentel et al., 2018), and Quarter Horse (Donofre et al., 2014) tend to be ectomorphs, and therefore have longer a longer back, as observed in this study. Longer dorsolumbar length is associated with greater lumbar span at the gallop and enhanced transfer of impulse forces generated by the hind limbs. This hypothesis is further supported by longer croup length (LM8) in Arabian horses in this study, potentially leading to more effortless propulsion. Dorsolumbar length did not differ significantly between males and females in this sample.

Linear measurements 7, 8, and 9 form the so-called croup triangle (Hedge, 2004)—ideally an equilateral triangle. These measurements differed in horses in this sample, revealing disproportions between the hind limbs and remaining body parts. However, horses with longer croups also have longer croup muscles, translating into more extraordinary contractile ability and longer hind limb stride (Nascimento, 1999).

The load index represents the weight (kg) a horse can bear effortlessly on its back while working at the trot or gallop. The mean load index in Arabian horses in this study was 107.43, meaning they can carry a load equivalent to 25% of their body weight. Hence, a 410 kg horse can carry 102.5 kg between rider and tack (Table 3). A combined analysis of load and ability indices indicates that these horses can hold such weights while retaining their nimbleness. Female horses in this study had higher load indices than males. This may have reflected that the formula accounts for thoracic circumference, which was broader in females, probably because this sample comprised more breeding mares than female athletes. The ability index was also higher in female horses. However, this variable placed both genders in the light working horse range.

The conformation index is the ratio between squared thoracic circumference and height. According to Torres & Jardim (1992), animals with conformation indices equal to or lower than 2.11.25 make ideal saddle horses, and the higher the index, the more apt the horse is for work. Despite differences between genders, with females achieving higher conformation indices than males, horses in this sample were thought to meet ideal saddle horse standards. Dactylo-thoracic and cannon load indices did not differ significantly between males and females in this sample.

Linear measurements (height/LM12, body length/LM1, thoracic, forearm, carpus, and cannon circumference) and body indices (ability and dactylo-thoracic) reported in African Bard Horses (Benhamadi et al., 2018), one of the breeds giving rise to Arabian horses, were similar to values found in this sample. According to Sobczuk & Komosa (2012), different morphology in horses bred at three vital Polish horse farms reflects different selection criteria between farms. However, similar height, croup length, chest depth, and limb length suggest that traits associated with body shape and harmony are retained, different from traits related to physical performance.

In Brazil, Arabian horses are selected primarily for conformation and beauty and are subject to subjective judgment in contests. In countries where horses have been used in wars, the versatile nature of Arabian horses has long been recognized, and these animals have been selected for racing. The findings of this study suggest Arabian horses have high athletic potential despite their lightweight and delicate appearance.

Conclusion

This study analyzed the physical characteristics and biomechanical attributes of purebred Arabian horses. The findings indicated significant differences in morphometric indices between male and female horses. The study also identified specific body proportions and linear measurements characteristic of the breed. The morphometric indices provide insights into the biomechanical capabilities of Arabian horses, including their ability to bear loads and their overall performance potential. These findings have implications for breeding and selection practices within the Arabian horse community. Future research could explore additional aspects of Arabian horse morphology and biomechanics, such as the relationship between morphometric traits and performance outcomes in various equestrian disciplines. This research informs breeding practices, training protocols, and overall management strategies for Arabian horses in diverse equestrian pursuits.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Statement

This study was approved by CEUA of Universidade Cruzeiro do Sul, protocol No. 004/2017, dated September 06, 2017.

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