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Research Article

Quantitative evaluation of limb conformation in various age cohorts of thoroughbreds

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ABSTRACT

An ideal horse should possess a limb conformation that enhances athletic capabilities and adjusts to varying loads. The structure of the limbs greatly influences a horse's performance and overall success. The study aimed to identify the limb conformations of Thoroughbreds across various age groups through quantitative assessments. Limb conformation data were captured from the horse's front, left side, and rear using simultaneous photographs. Simultaneous photography ensured that snapshots of the horse were consistent, with no variations between photographs caused by movement. The limb conformation of 137 Thoroughbred horses was assessed recording measurements of limb length, and angles at ages 6, 12, 18, 24, 36, and 48 months. From 6 to 36 months, the heights of withers and croups increased consistently, with the most significant growth occurring within the first 24 months. Forelimb length saw notable increases from 6 to 24 months in both genders, but the growth between 24 and 48 months was not significant. The angle of the front fetlock was straightest in the 6-month-old group, decreasing to mature levels after 12 months. The findings indicate that the croups of horses were higher than their withers across all assessed ages, potentially altering the horse's center of gravity and placing more stress on the forelimbs. The ratio of distal extremity lengths to total leg length increased with age.

INTRODUCTION

The concept of conformation in horses, referring to their overall body shape and structure, has been a subject of interest dating back to the earliest documented analysis by the Greek historian and philosopher Xenophon (430–354 BC). The evolution of this interest has led to extensive research exploring the correlation between a horse's physical attributes and its performance capabilities. Conformation is often interpreted as the interplay between form and function, suggesting a link between a horse's physical appearance and its potential for athletic performance (Hedge and Wagoner, 2004). This relationship extends to the selection process in breeding, where both conformation and behavioral traits are considered significant factors (Van Weeren and Denoix, 2006). In the context of racehorse breeding, specific body structure traits are pivotal for selection, emphasizing the need for breeding programs to prioritize structural characteristics conducive to high athletic performance (Jakubec et al., 2009; Belloy and Bathe, 1996). The establishment of evaluation criteria for a horse's body structure is vital, aiming at identifying the ideal traits that enhance athletic abilities (Belloy and Bathe, 1996). Moreover, recognizing age-related morphological changes is fundamental to understanding the potential for disabilities in horses. The goal of conformation assessments is to meticulously analyze the body's measurements, such as lengths and angular values, to delineate the synergistic relationships among various body parts (Hedge and Wagoner, 2004; Yıldırım, 2014). Such assessments are essential for elucidating the connection between conformation and performance in sport horses, which remains a critical area of research (Moore, 2010). Furthermore, a lack of understanding regarding the impact of conformation on health and performance can lead to suboptimal decisions in horse selection (Sanchez et al., 2013).

Clinical experiences have shown a link between abnormalities in the limbs and specific diseases of the locomotor system in sport horses (Dolvik and Klemetsdal, 1999; Smith et al., 2006; Van Weeren and Denoix, 2006). Assessing conformation is crucial for evaluating the musculoskeletal health, balance, and athletic capabilities of thoroughbreds (Harris, 1993; Bakhtiari and Heshmat, 2009). Objective assessment of conformation requires the collection of quantitative data, eg limb measurements.

Measurements can be directly taken on the animal, yet fully preventing movement during this process is challenging. The horse's movement during or between measurements can lead to varied results. Therefore, despite reliance on direct observation in conformation research, photograph-based measurements are often preferred. Photographic methods enable various individuals to conduct measurements at different times,

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ensuring consistency. This approach has been widely utilized and supported by numerous studies in the field (Fedorski and Pikula, 1988; Delahunty et al., 1991; Stover, 2003; Kavazis and Ott, 2003; Anderson and McIlwraith, 2004; Mawdsley et al., 1996; Yıldırım and Erden, 2023).

The conformation of a racehorse's body and limbs significantly impacts its health and performance (Anderson et al., 2004). Investigating the limb structures of horses across different age groups can enhance our understanding of these correlations. This study is designed to analyze the limb conformation of Thoroughbred horses in various age groups using morphometric measurements. The findings are anticipated to deepen our knowledge of how limb structures in horses evolve with age and gender, and how conformation in horses changes with age and gender, and how these changes may influence the risk of injury.

MATERIALS and METHODS

Study Population

All horses involved in this study were thoroughbreds born in Türkiye, specifically bred for flat racing and listed in the racing pedigree. Rigorous screening was conducted to exclude any horses with visible injuries or abnormalities in their musculoskeletal systems. Additionally, a thorough visual inspection ensured the absence of conformational defects in the horses' bodies and limbs. From an initial pool of 300, 137 horses were deemed suitable for the study. The younger horses, aged 6–18 months, were sourced from stud farms located in İzmir. The older group, aged 24-48 months, consisted of horses that had participated in flat races held by the Turkish Jockey Club at the Izmir Şirinyer Hippodrome. Rather than continuously monitoring the developmental progress of the same horses throughout the study, we opted for a population comprising various horses. This decision was made to address time limitations. However, it remained essential that all horses within the same age group were reared on the same farm, adhering to identical care conditions.

The structure of a horse's hooves significantly impacts limb conformation. Standardizing this variable was crucial. In Türkiye, Turkish Jockey Club grants licenses to farriers responsible for hoof care. As a result, consistent monthly hoof care practices were established, effectively eliminating variations arising from differences in nail structure.

The descriptive age and gender characteristics of the horses included in the study are presented in Table 1.

Photographs Characteristic

For the photo session, the horses were positioned on a level surface and maintained in the correct posture by the support staff. Proper posture is defined as the horse standing with all four feet evenly on the ground, limbs positioned naturally, and the head oriented forward. Each horse was photographed on a stable, flat surface. Once the horses were properly positioned, three photos were taken simultaneously from the left, front, and rear using Canon EOS 350D digital cameras, set to a resolution of 4752x3168 dpi. This approach follows the methods used in previous studies (Anderson and McIlwraith, 2004; Sadek et al., 2006), ensuring consistency in the photographic documentation of the horses' conformation. The cameras were set up on tripods positioned three meters from the horse and at a height of 0.9 meters, as shown in Figure 1.

In the context of photographing horses, specific guidelines were followed to ensure consistent and accurate measurements. These guidelines were crucial for maintaining uniformity across all images. The left side of the horse was aligned perpendicular to the camera. The horse itself stood squarely relative to the camera. Both the left forelimb and hind limb were positioned as vertically as possible concerning the ground. The horse was centered within the frame. Photographers maintained perfect parallel alignment with the horse's horizontal axis. The camera was positioned just behind the horse's center of gravity (specifically, the 9th to 11th costal part) along the lateral thoracic wall. Importantly, the camera was neither higher, lower, nor offset forward or backward from this position. The photographer ensured that the camera was exactly at the midpoint between the two forelimbs or hind limbs. All photographs adhered to the same distance, height, and focus settings. This consistency allowed for standardized images of both upper and lower extremities. As long as this measurement technique remains consistent, the resulting values will be repeatable.

A radio-frequency remote control facilitated the synchronized operation of the three cameras. To ensure the photographs accurately reflected the horse's true size, the lengths of Mc3 (the third metacarpal bone) and Mt3 (the third metatarsal bone) on the left front and hind legs, respectively, were measured and noted. Once the images were uploaded to a computer, calibration was performed using the Mc3 measurements for the forelimbs and the Mt3 measurements for the hind limbs. This calibration process, along with all measurements, was conducted using the Vet Eickemeyer® Medizintechnik für Tierärzte (EIVIS) software, with the first author (IGY) responsible for all measurements.

Table 1. The descriptive age and gender properties of the horses in the study.

Sex	6 months	12 months	18 months	24 months	36 months	48 months	Total
♂	12	12	12	11	10	10	67
♀	12	16	11	10	10	11	70
Total	24	28	23	21	20	21	137

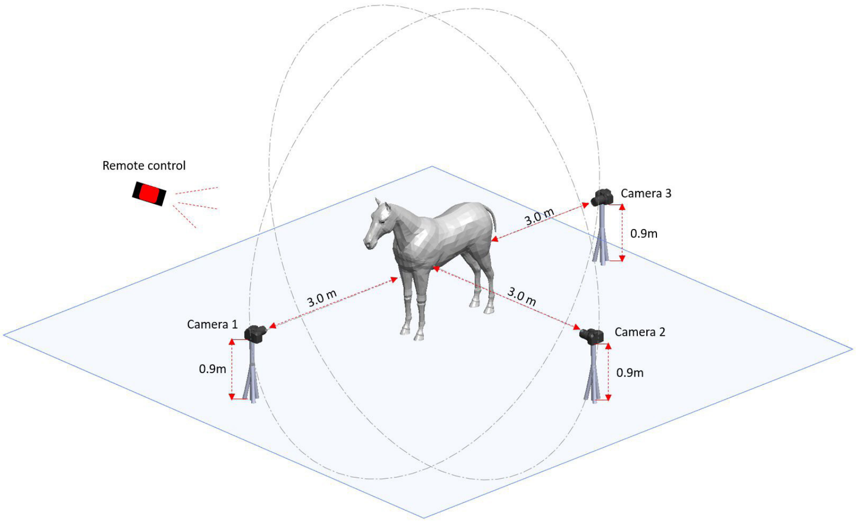

Figure 1. Simultaneous photo image technique. Three cameras are synchronized to capture photographs simultaneously, operated by a radiofrequency remote control.

Table 2. The descriptive of the variables studied.

Trait	Side	Description
Upper Leg Length	front	Shoulder joint (1) to carpal joint (2)
Mc3 Length	front	Carpal joint to metacarpophalangeal joint (3)
Pastern Length	front	Metacarpophalangeal joint to mid-coronary band (4)
Carpal Angle	front	Shoulder joint to carpal joint to metacarpophalangeal joint
Fetlock Angle	front	Carpal joint to metacarpophalangeal joint to mid-coronary band
Coronary Angle	front	Metacarpophalangeal joint to mid-coronary band to hoof tip (5)
Coronary Width	front	Medial to lateral width of the coronary band
Hoof Width	front	Medial to lateral width of hoof at ground touch region (6-6')
Wither Height	left	Heighest point of withers (7) to ground
Elbow Angle	left	Shoulder joint (8) to elbow joint (9) to mid-carpus (10)
Carpal Angle	left	Elbow joint to carpal joint to metacarpophalangeal joint (11)
Forelimb Length	left	Elbow joint to mid-carpal joint
Fetlock Angle	left	Carpal joint to metacarpophalangeal joint to mid-coronary band (12)
Lateral Hoof Angle	left	Between the dorsal and palmar edges of the hoof (orange lines)
Front Pastern Angle	left	Metacarpophalangeal joint to mid-coronary band to hoof axis
Croup Height	left	Heighest point of croup (13) to ground
Stifle Angle	left	Hip joint (14) to stifle joint (15) to tarsal joint (16)
Hock Angle	left	Stifle joint to tarsal joint to metatarsophalangeal joint (17)
Rear Fetlock Angle	left	Tarsal joint to metatarsophalangeal joint to hoof axis
Rear Pastern Angle	left	Metatarsophalangeal joint to mid-coronary band (18) to hoof axis
Rear Hoof Angle	left	Between the dorsal and plantar edges of the hoof
Caudal Genu Angle	rear	Ischiatic tuberosity (19) to mid-popliteal regio (20) to calcaneal tuberosity (21)
Caudal Tarsal Angle	rear	Mid-popliteal regio to calcaneal tuberosity to metatarsophalangeal joint
Mt3 Length	rear	Base of 3rd metatarsal (22) to metatarsophalangeal joint (23)
Rear Fetlock Angle	rear	Calcaneal tuberosity to metatarsophalangeal joint to mid-hoof at central sulcus (24)
Rear Pastern Length	rear	Metatarsophalangeal joint to mid-hoof at central sulcus

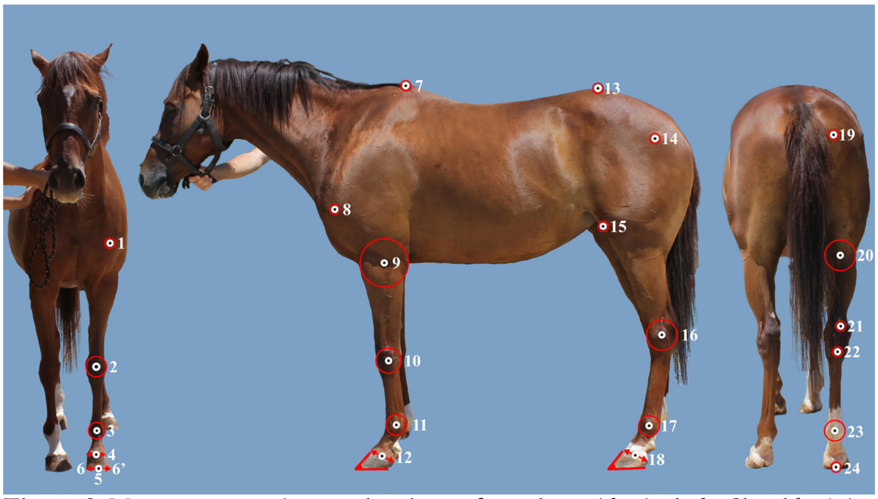

Figure 2. Measurement points on the photos from three sides include: Shoulder joint (1), Carpal joint (2), Metacarpophalangeal joint (3), Mid-coronary band on the forelimb (4), Hoof tip (5), Ground contact region of the hoof (6-6'), Highest point of the withers (7), Shoulder joint (8), Elbow joint (9), Mid-carpus (10), Metacarpophalangeal joint (11), Mid-coronary band on the forelimb (12), Highest point of the croup (13), Hip joint (14), Stifle joint (15), Tarsal (hock) joint (16), Metatarsophalangeal joint (17), Mid-coronary band on the hind limb (18), Ischiatic tuberosity (19), Mid-popliteal region (20), Calcaneal tuberosity (21), Basis base of 3rd metatarsal (22), Metatarsophalangeal joint (23), and Central sulcus on the mid-hoof (24).

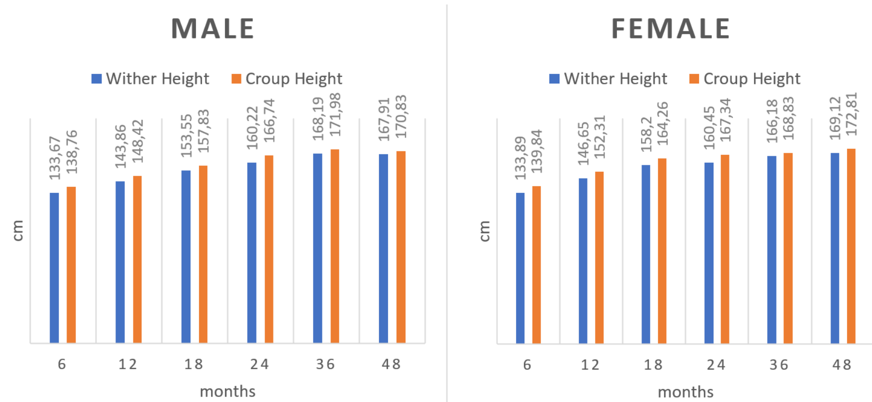

Figure 3. Changes in mean withers and croup heights in male and female horses aged 6 to 48 months (Height in cm).

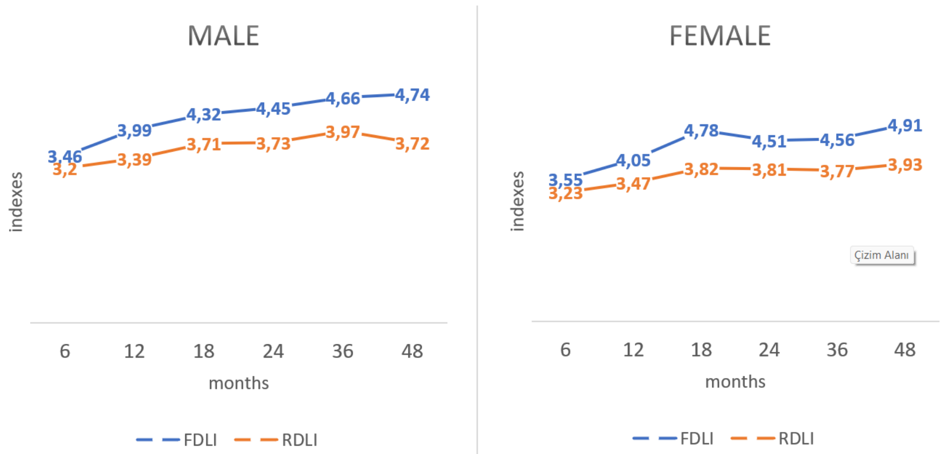

Figure 4. Changes in front (FDLI) and rear (RDLI) distal extremity indexes for males and females from 6 to 48 months.

Table 3. The measurements on the male horses (cm and degree). The data is presented as mean and standard error (MV± SEM).

Traits	Side	6 month	12 month	18 month	24 month	36 month	48 month	P
Upper Leg Length	front	57.40±1.05^{d}	59.93±1.25^{cd}	65.65±0.96^{a}	62.09±1.32^{bc}	66.44±0.65^{a}	64.78±0.53^{ab}	0.000
Mc3 Length	front	25.11±0.34^{a}	24.07±0.27^{ab}	23.56±0.35^{b}	24.40±0.54^{ab}	23.74±0.11^{b}	23.71±0.29^{b}	0.022
Pastern Length	front	13.49±0.26^{a}	11.91±0.34^{b}	11.96±0.32^{b}	11.60±0.20^{b}	12.35±0.27^{b}	11.68±0.22^{b}	0.000
Carpal Angle	front	175.66±0.47^{ab}	176.54±0.62^{a}	175.90±0.64^{ab}	175.57±1.08^{ab}	174.16±0.41^{b}	177.17±0.38^{a}	0.65
Fetlock Angle	front	176.03±0.74^{abc}	174.19±0.82^{c}	177.06±0.62^{ab}	176.21±0.57^{abc}	175.36±0.61^{bc}	177.83±0.40^{a}	0.006
Coronary Angle	front	178.28±0.35^{a}	178.40±0.42^{a}	178.85±0.30^{a}	178.64±0.28^{a}	178.33±0.31^{a}	178.04±0.29^{a}	0.625
Coronary Width	front	8.56±0.13^{c}	8.95±0.19^{c}	10.33±0.17^{a}	9.63±0.14^{b}	9.50±0.13^{b}	9.48±0.11^{b}	0.000
Hoof Width	front	9.84±0.23^{d}	11.00±0.12^{c}	12.74±0.26^{a}	11.83±0.27^{b}	12.30±0.15^{ab}	12.62±0.15^{a}	0.000
Wither Height	left	133.67±1.72^{e}	143.86±1.39^{d}	153.55±2.56^{c}	160.22±1.95^{b}	168.19±0.78^{a}	167.91±0.97^{a}	0.000
Elbow Angle	left	145.02±1.46^{ab}	141.04±1.37^{bc}	141.62±1.26^{bc}	139.38±1.27^{c}	149.82±2.87^{a}	145.00±1.13^{ab}	0.001
Carpal Angle	left	177.97±0.32^{a}	177.99±0.12^{a}	178.57±0.25^{a}	178.50±0.35^{a}	178.59±0.20^{a}	178.45±0.21^{a}	0.331
Forelimb Length	left	35.29±0.92^{d}	39.03±1.01^{c}	41.82±0.79^{b}	43.30±0.61^{ab}	45.33±0.17^{a}	45.23±0.37^{a}	0.000
Fetlock Angle	left	151.95±0.97^{a}	148.16±0.62^{b}	145.46±1.32^{b}	146.90±1.44^{b}	145.92±0.64^{b}	145.70±0.96^{b}	0.000
Lateral Hoof Angle	left	55.76±1.29^{cd}	61.21±0.64^{a}	58.39±0.78^{b}	58.01±0.86^{bc}	54.47±0.27^{d}	54.06±0.82^{d}	0.000
Front Pastern Angle	left	165.61±1.57^{c}	173.81±1.09^{b}	176.65±0.80^{a}	176.99±0.63^{a}	177.73±0.49^{a}	178.13±0.26^{a}	0.000
Croup Height	left	138.76±1.31^{e}	148.42±1.77^{d}	157.83±2.60^{c}	166.74±2.69^{b}	171.98±1.13^{a}	170.83±1.39^{a}	0.000
Stifle Angle	left	114.34±1.02^{b}	115.40±1.13^{b}	115.37±1.44^{b}	116.76±1.02^{b}	115.52±0.58^{b}	120.57±0.56^{a}	0.003
Hock Angle	left	146.54±0.93$^{a.b}$	145.49±0.57^{b}	146.71±0.75^{ab}	148.30±1.10^{a}	146.25±0.56^{ab}	144.30±0.67^{b}	0.032
Rear Fetlock Angle	left	159.61±1.23^{a}	154.24±1.44^{b}	153.18±1.57^{b}	152.34±1.80^{b}	154.76±0.52^{b}	159.20±0.45^{a}	0.000
Rear Pastern Angle	left	170.72±1.69^{b}	175.16±0.67^{a}	176.09±0.84^{a}	176.60±1.12^{a}	178.00±0.21^{a}	174.94±0.63^{a}	0.000
Rear Hoof Angle	left	58.91±1.25^{ab}	61.02±0.88^{a}	60.66±1.05^{a}	57.41±1.26^{bc}	54.80±0.41^{c}	57.47±0.93^{bc}	0.001
Caudal Genu Angle	rear	177.21±0.56^{a}	174.57±0.60^{b}	176.70±0.87^{ab}	175.67±0.77^{ab}	174.90±0.92^{ab}	176.11±0.80^{ab}	0.113
Caudal Tarsal Angle	rear	176.74±0.74^{a}	177.45±0.75^{a}	173.62±1.52^{b}	176.50±0.60^{a}	176.72±0.86^{a}	177.38±0.38^{a}	0.041
Mt3 Length	rear	29.69±0.58^{c}	30.12±0.45^{bc}	29.58±0.68^{c}	31.25±0.50^{ab}	30.69±0.21^{abc}	31.85±0.27^{a}	0.014
Rear Fetlock Angle	rear	177.76±0.46^{a}	177.24±0.86^{a}	176.90±0.43^{a}	176.70±0.40^{a}	177.69±0.38^{a}	177.87±0.42^{a}	0.56
Rear Pastern Length	rear	13.56±0.42^{ab}	13.64±0.31^{ab}	12.94±0.28^{cb}	13.39±0.36^{abc}	12.53±0.06^{c}	14.06±0.20^{a}	0.024

a,b,c,d: Different letters in the same line are statistically significant ($P<0.05$).

Table 4. The measurements on the female horses (cm and degree). The data is presented as mean and standard error (MV± SEM).

Traits	Side	6 month	12 month	18 month	24 month	36 month	48 month	P
Upper Leg Length	front	57.61 ± 0.93^{b}	58.19 ± 1.03^{b}	60.08 ± 0.96^{b}	63.94 ± 0.87^{a}	64.74 ± 0.97^{a}	64.59 ± 0.74^{a}	0.000
Mc3 Length	front	24.75 ± 0.24^{a}	23.76 ± 0.41^{ab}	21.98 ± 0.45^{b}	24.04 ± 0.34^{ab}	25.04 ± 0.35^{a}	23.06 ± 1.98^{ab}	0.154
Pastern Length	front	12.96 ± 0.16^{a}	12.43 ± 0.29^{a}	11.08 ± 0.28^{b}	11.49 ± 0.17^{b}	11.35 ± 0.18^{b}	11.40 ± 0.28^{b}	0.000
Carpal Angle	front	175.53 ± 0.56^{abc}	175.04 ± 0.46^{bc}	177.30 ± 0.36^{a}	174.24 ± 1.01^{bc}	173.91 ± 0.44^{c}	176.03 ± 0.71^{ab}	0.005
Fetlock Angle	front	177.22 ± 0.56^{a}	173.93 ± 0.71^{b}	177.70 ± 0.54^{a}	176.42 ± 0.66^{a}	176.90 ± 0.46^{a}	176.76 ± 0.60^{a}	0.000
Coronary Angle	front	178.27 ± 0.33^{a}	178.11 ± 0.37^{a}	178.35 ± 0.38^{a}	178.81 ± 0.24^{a}	178.35 ± 0.31^{a}	178.39 ± 0.12^{a}	0.789
Coronary Width	front	8.58 ± 0.10^{b}	9.04 ± 0.18^{ab}	9.10 ± 0.19^{ab}	9.55 ± 0.28^{a}	9.18 ± 0.11^{a}	9.31 ± 0.14^{a}	0.014
Hoof Width	front	9.98 ± 0.18^{b}	11.83 ± 0.30^{a}	12.24 ± 0.30^{a}	11.89 ± 0.15^{a}	11.58 ± 0.10^{a}	12.23 ± 0.25^{a}	0.000
Wither Height	left	133.89 ± 1.71^{d}	146.65 ± 1.47^{c}	158.20 ± 2.58^{b}	160.45 ± 1.90^{b}	166.18 ± 0.49^{a}	169.12 ± 0.87^{a}	0.000
Elbow Angle	left	144.82 ± 0.87^{a}	138.06 ± 1.43^{b}	144.95 ± 1.84^{a}	139.54 ± 0.94^{b}	145.36 ± 0.34^{a}	145.69 ± 0.47^{a}	0.000
Carpal Angle	left	177.89 ± 0.39^{b}	177.61 ± 0.17^{b}	178.15 ± 0.34^{ab}	178.75±0.23a	178.89 ± 0.19^{a}	178.40 ± 0.22^{ab}	0.012
Forelimb Length	left	38.23 ± 0.58^{c}	39.56 ± 0.56^{bc}	41.04 ± 0.80^{b}	43.67 ± 0.87^{a}	44.10 ± 0.18^{a}	45.34 ± 0.68^{a}	0.000
Fetlock Angle	left	150.85 ± 0.67^{a}	145.24 ± 0.77^{bc}	146.57 ± 1.22^{bc}	146.69 ± 1.00^{b}	143.90 ± 0.79^{c}	146.19 ± 0.69^{bc}	0.000
Lateral Hoof Angle	left	58.38 ± 1.40^{a}	57.97 ± 0.60^{ab}	57.30 ± 0.95^{ab}	57.45 ± 0.71^{ab}	55.22 ± 1.24^{bc}	53.32 ± 0.65^{c}	0.003
Front Pastern Angle	left	171.09 ± 2.01^{b}	174.18 ± 0.93^{ab}	175.90 ± 0.91^{a}	175.30 ± 0.72^{a}	176.08 ± 0.35^{a}	176.44 ± 0.41^{a}	0.011
Croup Height	left	139.84 ± 2.30^{d}	152.31 ± 1.65^{c}	164.26 ± 2.56^{b}	167.34 ± 1.98^{ab}	168.83 ± 1.14^{ab}	172.81 ± 0.98^{a}	0.000
Stifle Angle	left	114.45 ± 1.22^{c}	114.76 ± 0.35^{c}	115.51 ± 1.77^{c}	116.75 ± 0.77^{bc}	119.07 ± 0.55^{ab}	121.03 ± 1.06^{a}	0.000
Hock Angle	left	148.53 ± 1.16^{ab}	146.47 ± 0.60^{bc}	145.86 ± 0.79^{c}	145.10 ± 0.84^{c}	150.53 ± 0.75^{a}	144.72 ± 0.90^{c}	0.000
Rear Fetlock Angle	left	159.20 ± 1.70^{a}	156.56 ± 0.95^{ab}	152.74 ± 0.55^{cd}	155.06 ± 1.87^{bc}	150.71 ± 0.90^{d}	157.34 ± 0.93^{ab}	0.000
Rear Pastern Angle	left	172.43 ± 1.43^{b}	172.87 ± 0.85^{b}	177.51 ± 0.74^{a}	177.25 ± 0.52^{a}	176.65 ± 0.32^{a}	175.90 ± 0.33^{a}	0.000
Rear Hoof Angle	left	60.29 ± 1.17^{a}	61.35 ± 0.77^{a}	57.42 ± 1.00^{bc}	59.18 ± 0.98^{ab}	55.99 ± 0.36^{c}	55.34 ± 0.26^{c}	0.000
Caudal Genu Angle	rear	176.88 ± 0.34^{ab}	174.89 ± 0.86^{bc}	177.57 ± 0.42^{a}	174.39 ± 0.75^{c}	176.33 ± 0.85^{abc}	176.09 ± 0.60^{abc}	0.022
Caudal Tarsal Angle	rear	175.98 ± 0.70^{ab}	174.50 ± 0.92^{b}	175.54 ± 0.90^{ab}	176.15 ± 0.79^{ab}	176.02 ± 0.76^{ab}	177.49 ± 0.38^{a}	0.170
Mt3 Length	rear	29.38 ± 0.45^{b}	30.20 ± 0.31^{ab}	30.18 ± 0.33^{ab}	30.59 ± 0.22^{a}	30.88 ± 0.51^{a}	31.17 ± 0.36^{a}	0.026
Rear Fetlock Angle	rear	176.72 ± 0.64^{cb}	176.05 ± 0.64^{c}	176.60 ± 0.49^{cb}	177.69 ± 0.61^{abc}	178.69 ± 0.12^{a}	177.98 ± 0.36^{ab}	0.011
Rear Pastern Length	rear	13.80 ± 0.44^{a}	13.68 ± 0.25^{ab}	12.79 ± 0.42^{b}	13.30 ± 0.23^{ab}	13.88 ± 0.27^{a}	12.72 ± 0.15^{b}	0.039

a,b,c,d: Different letters in the same line are statistically significant (P<0.05).

Measuring Points

Reference points for the measurements were established based on previous studies (McIlwraith et al., 2003; Anderson and McIlwraith, 2004; Sadek et al., 2006; Weller et al., 2006). Easily identifiable bone protrusions in the photographs were chosen as reference points. Additionally, the midpoint of the circles drawn around the elbow, carpal, fetlock, and hock joints served as reference points for measurements. These measurements and their corresponding reference points are detailed in Table 2 and illustrated in Figure 2.

The term "distal extremity" was used to describe the forelimbs below the carpal joints and the hindlimbs below the tarsal joints. To determine the lengths of the distal extremities for both the front and hind limbs, the lengths of Mc3 and Mt3, along with the pastern lengths for the respective limbs, were added together. Additionally, front (FDLI) and rear (RDLI) distal limb indexes were calculated by dividing the total distal extremity lengths by the wither height for the forelimbs and the croup height for the hindlimbs. These calculations helped assess the proportional changes in the lengths of the distal extremities relative to the horse's age, as measured at the withers for the forelimbs and at the croup for the hindlimbs.

Data Analysis

All measurements were conducted by the same researcher (IGY) to avoid any interobserver variability issues. The data was analyzed using SPSS 15.0 for Windows. To test the reliability and validity of the measurements, one horse was randomly selected and measured five times at different intervals. Additionally, measurements from photographs of five different horses were taken at various intervals. The coefficient of variation (%CV) was then calculated based on these measurements, as outlined by Özdamar (2004). The Student's t-test was applied to compare the front and hindlimb parameters across genders for each age group. To examine the differences in mean values of conformation parameters across age groups, a One-Way Analysis of Variance (ANOVA) was conducted. For any significant differences found, Duncan's multiple comparison test was used to further analyze the data.

RESULTS

The coefficient of variation (CV) for all measurements was below 5%, indicating high repeatability and reliability in measurements obtained from photographs. The heights of the withers and croups showed a consistent and significant increase from 6 to 36 months, with the most substantial growth occurring in the first 24 months. After 24 months, the growth rate stabilized, and there was no statistically significant difference in the increase between 36 and 48 months. According to the data, croup heights exceeded wither heights across all age groups examined in this study (Figure 3).

The FDLI and FDLI, which show the ratio of the lengths of the limbs' distal parts to the height of the body, tended to rise with age (Figure 4). However, this trend was not consistently stable.

The measurement values for male and female horses across various age groups are detailed in Table 3 and 4. A significant increase in forelimb length was noted in both genders from 6 to 24 months, with no marked changes observed from 24 to 48 months. The values for the front carpal angle and Mc3 length in males and females did not show significant differences across the age groups. The front fetlock angle was higher in the 6-month age group, indicating the steepest structure at this early age. As the horses aged, the fetlock angle gradually aligned with the mature anatomical norms, reducing the differences observed between age groups. Front pastern angle, 6-month-old males exhibited values of 165°, while females showed 171°. These angles were observed to adjust to 178° for males and 176° for females over time.

DISCUSSION

Photographic methods are widely used in horse conformation research, as evidenced by several studies that have utilized images taken from the front, side, and rear of horses (McIlwraith et al., 2003; Andersson and McIlwraith, 2004; Senna et al., 2015; Mostafa and Elemmawy, 2020). A common challenge in such research is that horses cannot remain completely still for each photo, potentially leading to variations in the images due to movement. In our study, measures were taken to minimize the differences between images caused by the horse's movement. Specifically, photos were captured simultaneously from three different angles using cameras positioned around the horse. This method aimed to reduce discrepancies in the images, especially in angular measurements involving the length of joints and bones, by ensuring consistency across all photographs.

In studies examining the conformation of the horse, it can be quite challenging to achieve perfect posture in photographs taken from the front and back. It may not always be possible to maintain perfect posture. However, this methodology appears to have been used in previous studies (McIlwraith et al., 2003; Andersson and McIlwraith, 2004; Senna et al., 2015; Mostafa and Elemmawy, 2020). Therefore, to avoid possible misrepresentation, a real, unaltered photo was deliberately chosen to include in the article. To avoid these mistakes, researchers need to be more meticulous, patient, and perfectionist, especially when taking photos from the front and back.

The risk of injury in horses is significantly influenced by age, which is a key factor in assessing the distribution and origin of injuries (Stover, 2003). Up to 13% of postnatal foal conformation defects, which usually corrected by the age of three (McIlwraith et al., 2003). By three years old, horses typically achieve normal body conformation. The development of thoracic and pelvic limb bones occurs at different times, from 3-4 months to 24-36 months (Butler et al., 2005). Musculoskeletal issues are more common in two-year-old horses due to intense training and racing, while older horses more often face tendon and ligament injuries (Perkins et al., 2005; Cogger et al., 2008). In our study, significant changes in limb length and angle were noted in Thoroughbred horses, especially in the first two years, continuing until three years of age. As tissues adapt to changes in limb morphology in the two to three-year age range, the stress of training and racing can predispose them to injuries.

Withers and croup heights are key indicators of a horse's morphological structure. Mawdsley et al. (1996) found the wither height to be 157.20 cm in two-year-old female horses and 158.34 cm in males, with three-year-old thoroughbreds measuring 160.30 cm and 161.91 cm, respectively. Bakhtiari and Heshmat (2009) reported wither heights in thoroughbreds to be 163.4 cm for males and 161.8 cm for females. In our study, the wither height was observed to be 168.19 cm in three-year-old (36 months) males and 166.18 cm in females, with no significant differences between three- and four-year-old horses. The variations between these studies could be attributed to differences in measurement and calibration techniques.

Andersson and McIlwraith (2004) documented wither and croup heights in thoroughbreds as 122.28 cm and 125.32 cm in weanlings, 142.80 cm and 143.79 cm in 1-year-olds, 154.66 cm and 153.64 cm in 2-year-olds, and 154.61 cm and 153.09 cm in 3-year-olds, respectively. In our research, the wither and croup heights for male horses were measured at 133.67 cm and 138.76 cm in 6-month-old foals, 143.86 cm and 148.42 cm in 1-year-olds, 160.22 cm and 166.74 cm in 2-year-olds, and 168.19 cm and 171.98 cm in 3-year-old horses, respectively. For females, these values were 133.89 cm and 139.84 cm in 6-month-olds, 146.45 cm and 152.31 cm in 1-year-olds, 160.45 cm and 167.34 cm in 2-year-olds, and 166.18 cm and 168.63 cm in 3-year-olds. Minor differences in measurements between our study and that of Andersson and McIlwraith were anticipated. However, a notable distinction was that in their study, wither height exceeded croup height from the yearling stage onwards, whereas in our study, croup height was greater than wither height across all age groups. This higher croup structure in our study's horses, despite no current or past musculoskeletal issues, suggests a deviation from the ideal conformation where the croup and withers are level, facilitating optimal agility, balance, and gait. A croup higher than the withers, indicating disproportionately long hindlimbs, can affect stride and lead to forging issues (Thomas, 2005; Ross and McIlwraith, 2011). Gruyaert et al. (2022) found that 29% of horses with lameness or performance issues had higher tuber sacrale compared to the withers. This underscores the need for further exploration into the implications of wither and croup height discrepancies on performance and injury risks.

The pastern length value represents the distance between the metacarpophalangeal joint and the mid-coronary band. However, photographic measurements do not fully capture changes in the length of the phalanges. Specifically, the fetlock angle decreases from 151.99 to 145.70 degrees in males and from 150.85 to 146.19 degrees in females during the 6–48-month period. Concurrently, the fetlock angle in male horses decreased from 151.95° to 145.70°, and in females from 150.85° to 146.19°. These findings suggest that this joint gradually transitions toward a more slopped wrist structure over time. Consequently, there is a reduction in the pastern length value in 2D images taken from the front. These changes in the front pastern length and fetlock angle were found to be consistent, indicating a harmonious adjustment in the metacarpophalangeal joints. However, this type of consistent relationship was not observed between the rear pastern lengths and angles.

The study also tracked changes in limb length relative to the overall body height using the front distal limb index (FDLI) and rear distal limb index (RDLI). According to these indices, the distal sections of both the front and hind limbs tended to grow proportionally larger with age. Notably, the increase in FDLI was more pronounced than that in RDLI for both males and females, suggesting a greater relative growth in the distal parts of the front limbs compared to the hind limbs.

The axis of the limb should be straight when viewed from in front of the limb (Thomas 2005). Deviations from this ideal angle can indicate disruptions in the limb's axial alignment, as described by Hedge and Wagoner (2004). In the study, the front pastern angle in males increased from 165.61° to 178.13° and in females from 171.09° to 176.44°. The rear fetlock angle in males rose from 170.72° to 174.94° and in females from 172.43° to 175.90°. These increases suggest that, while younger horses showed more pronounced breaks due to their angles deviating further from 180°, older horses' measurements tended to align more closely with the ideal. One factor that might influence these observations is the hoof care practices, specifically whether hooves are trimmed in a way that complements the individual conformation characteristics of each horse. The coronary angle, a measurement taken from the front, consistently reached the standard value of 178° across both genders and all age groups in this study, suggesting a generally well-maintained mediolateral balance of the hoof (Colles et al., 2022).

In a study focused on limb conformation in Thoroughbreds used for jumping, Senna et al. (2015) reported front limb length measurements as follows: forelimb at 46.02 cm, Mc3 at 28.67 cm, and Mt3 at 37.44 cm. In contrast, the measurements in our study for both males and females ranged from 35–45 cm for the forelimb, 23–25 cm for Mc3, and 29–31 cm for Mt3. The discrepancy in measurements could be attributed to Senna et al. taking their measurements from the front, whereas ours were taken from the left side of the horse. Regarding angular measurements, Senna et al. reported the elbow angle at 138.30°, carpal angle at 177.70°, front pastern angle at 142.70°, stifle angle at 114.9°, and rear pastern angle at 149.8°. In our study, these angles were found to be within 139-145° for the elbow angle, 177-178° for the carpal angle, 145-151° for the front pastern angle, 114-120° for the stifle angle, and 152-159° for the rear pastern angle. The angular measurements between the two studies showed similarities, suggesting a consistency in angular measurements. However, the variation observed in the front and rear pastern angles could potentially be linked to differences in hoof trimming practices, influenced by the distinct functional requirements of the horses in each study. This highlights the potential need for further research into how conformation aligns with function in horses of the same breed but used for different purposes.

In their research on the conformation characteristics of Thoroughbreds, both healthy and with musculoskeletal disabilities, Mostafa and Elemmawy (2020) found the rear pastern angle to average 152.8° in healthy horses and 144.7° in those with musculoskeletal issues. In our study, the rear pastern angles ranged from 152.34° to 159.61° in males and 150.71° to

159.20° in females. These findings suggest that the horses in our study, which did not include any with a history of injury, exhibited rear pastern angles within a range indicative of a low risk for musculoskeletal disorders. Thus, the outcomes of our research align with those of Mostafa and Elemmawy, further supporting the correlation between rear pastern angles and musculoskeletal health in Thoroughbreds.

Hoobs et al. (2022) highlighted that hoof shape and functionality in Thoroughbred racehorses evolve with growth and the physical demands placed upon them. In our investigation, the narrowest front hoof width measurements were recorded at the 6-month mark for both sexes. Beyond the age of 1, no significant changes in hoof width were observed in females, whereas in males, an increase in hoof width continued until the age of two. Furthermore, a reduction in the angles of both front and rear hooves was noted in females from 6 months to 4 years. In contrast, males exhibited varying differences across different age groups. This suggests that hoof development follows a more consistent pattern in females compared to males.

The study's findings provide insights into the changes in limb anatomy across different genders and age groups. While these data allow for comparisons with results from other studies, the emergence of unexplained findings highlights areas for future research and raises questions that warrant further investigation.

Limitations: The study utilized distinct horses across various age groups, contributing significant data to an under-researched area. Future research should ideally monitor the same horses over extended periods and include a broader sample size for more comprehensive insights. The process of standard photographic measurements presents challenges, necessitating careful consideration of environmental factors, stress conditions, and the perspectives of breeders and owners during the planning stages. Due to concerns from breeders and horse owners about potential speculation on their horses' conformation traits, private records were kept confidential. Consequently, this study does not include data on the horses' eventual performance outcomes.

CONCLUSIONS

The findings from this study provide valuable insights into the conformational changes in different limb regions, influenced by age and gender. Notably, the distal limbs experienced significant changes and development, demonstrated by an increase in distal extremity indices with age. In all age groups studied, the croup was consistently higher than the withers, potentially shifting the horse's center of gravity forward and placing additional strain on the forelimbs. Despite these observations, there were no reported injuries across the different age groups. Future research could be directed toward understanding the implications of these conformational characteristics and their potential impact on horse health and performance.

DECLARATIONS

Ethics Approval

This study was carried out with the permission of Aydın Adnan Menderes University, Animal Experiments Local Ethics Committee, numbered B.30.2.ADÜ.0.06.00.00/124-HEK/2009/64.

Conflict of Interest

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Author Contributions

Idea, concept, and design: İGY, HE

Data collection and analysis: İGY

Drafting of the manuscript: İGY, HE

Critical review: HE

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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