Journal of Equine Veterinary Science 31 (2011) 379-382

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

A Nonlinear Model for Estimating Hoof Surface Area in Unshod Meat-type Horses

Pere-Miquel Parés i Casanova PhD

Department of Animal Production, Animal Science and Health, University of Lleida. Lleida, Catalunya, Spain

Keywords:
Cavall Pirinenc Català
Equidae
Measurement
Scaling

A B S T R A C T

The aim of this study was to develop a simple, inexpensive, and noninvasive technique for estimating the hoof surface area (HSA) of unshod horses under field conditions. It was hypothesized that HSA in horses can be extrapolated from simple linear hoof measurements. Two linear measurements—lateromedial width and dorsoplantar width—were obtained from all four feet of 57 unshod meat-type horses. Different algorithms for determining HSA were developed. The most simple equation was HSA = $(1.229 \times LM)^{1.071} \times (DP)^{0.772}$ (where LM = lateromedial width and DP = dorsoplantar width), representing a good nonlinear model with a standard deviation of error for the estimate of 5.150 and a coefficient of multiple determination of 0.9384. This formula may be helpful as a repeatable, nonintrusive, and easily performed in vivo estimation of the hoof surface of unshod horses, at least in the studied breed.

1. Introduction

The study of the horse hoof improves knowledge of the equine hoof and that may in turn benefit hoof management practices. The sole, which is firmly attached to the external hoof capsule through its attachment to the white line, may also be an important load-bearing structure [1,2]. Hoof balance affects the distribution of forces and patterns of movement of the limbs [3,4], and alterations in these components of locomotion [5,6] are hypothesized to contribute to limb injury. The hoof size, among other measurements, can be associated with the risk of forelimb musculoskeletal injury, specifically including fatal suspensory apparatus failure and cannon bone lateral condylar fracture [7]. The load-bearing pattern of the equine foot has been investigated in managed domestic horses [8,9], but an easy method to estimate the hoof surface area (HSA) seems to be necessary.

Stachurska et al. [10] evaluated differences between fore and hind hoof dimensions and Roland et al. [11] studied the geometric symmetry of the sole surface. Kane et al. [7] obtained area measurements from digital photographic images but they did not establish any estimation. Surprisingly, the method of directly estimating HSA in horses under field conditions has been neglected in the scientific literature. This estimation can address questions of veterinary significance, such as on overall distortion of the hoof and the contribution of sole to weight bearing, and also provides the clinician with a tool to quantify simultaneously differences in hoof area and limb loading. Estimating HSA, including between population breeds, may also assist in determining whether sole area does relate to foot health and how this can be tested clinically.

The ability of the "Cavall Pirinenc Català" (CPC) horses to travel unshod for long distances over heterogeneous terrains with apparently no harmful side effects may be because of the unique morphology of the hoof which has responded to this challenging Pyrenean environment. The high volume of biomechanical events may induce adaptive responses of the weight-bearing structures in contact with the substrate [12]. Our aim in this study was to establish an easy method for evaluating equine HSA in CPC horses using

Corresponding author at: Pere-Miquel Parés i Casanova, PhD, Department of Animal Production, Animal Science and Health, University of Lleida, Avenue Alcalde Rovira Roure, 191, E 25198-Lleida, Catalunya, Spain.
E-mail address: peremiquelp@prodan.udl.cat.

0737-0806/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.jevs.2011.03.020

easily taken in vivo and nonintrusive measurements. A multiple regression analysis was used, with the important aspect to be considered being which independent variables were most relevant for determining the dependent variable. Obviously, comparisons with other breeds are needed because the effect of a particular breed's characteristics on the given formula could be huge.

2. Materials and Methods

At a commercial abattoir, all four feet were collected from the fresh cadavers of 57 CPC horses (28 males and 29 females). The CPC (Catalan Pyrenean Horse) is a horse that is bred for meat and is found in the NE Pyrenees along the Spanish and French border [13]. Horses of this breed have bodies with long proportions and short legs, thus are compact with a broad build, predominantly chestnut [14]. They are inexpensive and undemanding horses bred for meat and are reared outdoors all year round. The animals are never stabled and graze throughout the year. No care is given to keep hooves healthy, but it seems that hoof wall problems occur with limited frequency in this breed.

The animals studied were approximately 12 months of age (estimated live weight: 356.8 kg), and they presented with neither abnormal general appearance nor signs of clinical lameness. Any feet with gross hoof lesions and obvious signs of poor foot health were excluded from the study. No hooves had been cared for (trimmed or shoed), so studied animals must be considered *naturally* shaped. None of the females was gestational. Horses were aged by a combination of dentition examination and official documentation year identification. Animals belonged to six different farms and were reared under relatively uniform feeding and management conditions, always with a lack of abrasive wearing by the environment.

After slaughter, the feet were removed from the cadaver by cutting at the fetlock joints. All four feet were washed with fresh water before measuring to clarify reference points. Ground surface measurements were taken on sole "fresh" projections, outlining the round edges with a pen on paper. The original drawings were subsequently photocopied. A computerized image analysis system (300 ppi) was then used to measure ground surface with digital picture analysis software [University of Texas Health Science Center in San Antonio (UTHSCSA) Image Tool 3.0 software, available on the Internet at ftp://maxrad6.uthscsa.edu]. This software tool has been partially developed for this application and is therefore able to properly evaluate areas [15]. The boundary of the ground surface was delimitated digitally by 50 to 60 points. The polygon area was calculated in square centimeters by the corresponding option of the UTHSCSA software and recorded as HSA. Because spatial calibration is available in UTHSCSA to indicate real linear and area dimensional measurements, all the photocopies included a measuring piece to facilitate calibration by the software. Lateromedial (LM) and dorsoplantar (DP) widths were also taken digitally with the UTHSCSA program. LM width was obtained by measuring the widest part between the quarters, whereas DP width was obtained by measuring the longest distance between the toe and the most plantar point of the central groove. These single reference points have been selected for convenience. The author performed all the measurements.

Pearson's correlations were performed to investigate relationships between the various hoof measurements. To determine the most suitable regression equation for the criteria, standard deviation of error (SD_E), residual sum, residual average, residual sum of squares (RSS), coefficient of multiple determination (R^2), and adjusted coefficient of multiple determination (Ra^2) observed in HSA were used to evaluate and compare different regression models. The goodness of fit of the models was assessed by examining the regressions of residuals. Each model was then assessed based on its algorithm simplicity. The data were analyzed using Data Fit, version 9.0.59 (http://www.curvefitting.com), and PAST, version 1.94b (Hammer and Harper, 2009, http://folk.uio.no/ohammer/past)[16]. Because of the limited number of CPC cases with different ages available for study, the model could not be adjusted for the effects of age.

The research was conducted between October 2009 and June 2010. Ethical approval was not required as all measurements were recorded postmortem at a commercial abattoir plant.

3. Results

The hoof measurement results obtained are shown in Table 1. No statistical differences in HSA were present between males and females ($P > .05$). Measured hooves were a fairly uniform group (Coefficient of Variation = 16.4 %), indicating a consistent sole type. They were obviously bigger than those from Thoroughbred racehorses [7]. Bearing surface area increases with incremental load increase. There may be less wear in the peripheral sole owing to the increased surface area in ground contact.

All measured values showed a normal distribution ($W > 0.978$), and it is assumed that added bias is not there when developing the formula for predicting HSA ($skewness_{HSA} = 0.541$ and $kurtosis_{HSA} = 0.450$). Both LM and DP widths showed a significant correlation coefficient with the area ($r = 0.898$ and 0.811, respectively, $t < 0.001$). The high correlation coefficients between measurements suggest that either of these variables or a combination of the two could provide a good estimate for predicting the HSA of CPC horses.

Of the 242 best-fitted algorithms obtained, the simplest nonlinear model with a SD_E of 5.150 was represented by the following: $(a \times LM)^b \times (DP)^c$, where $a = 1.2295$, $b = 1.0710$, and $c = 0.7723$. The high coefficient of multiple determination ($R^2 = 0.938$) indicated that the equation predicted differences in HSA quite well for the independent data set. Figure 1 shows that the residual follows a straight line

Table 1
Metric results obtained

	LM Width (cm)	DP Width (cm)	LM Width:DP Width	Hoof Area (cm^2)
Average (X ± SD)	12.4 ± 0.08	12.0 ± 0.07	1.0 ± 0.08	125.9 ± 20.67
Maximum	16.5	15.2	1.3	201.9
Minimum	9.9	9.2	0.8	83.7
W	0.978	0.993	0.989	0.978

LM, lateromedial; DP, dorsoplantar; X, average; SD, standard deviation; W, Shapiro–Wilk normality test.

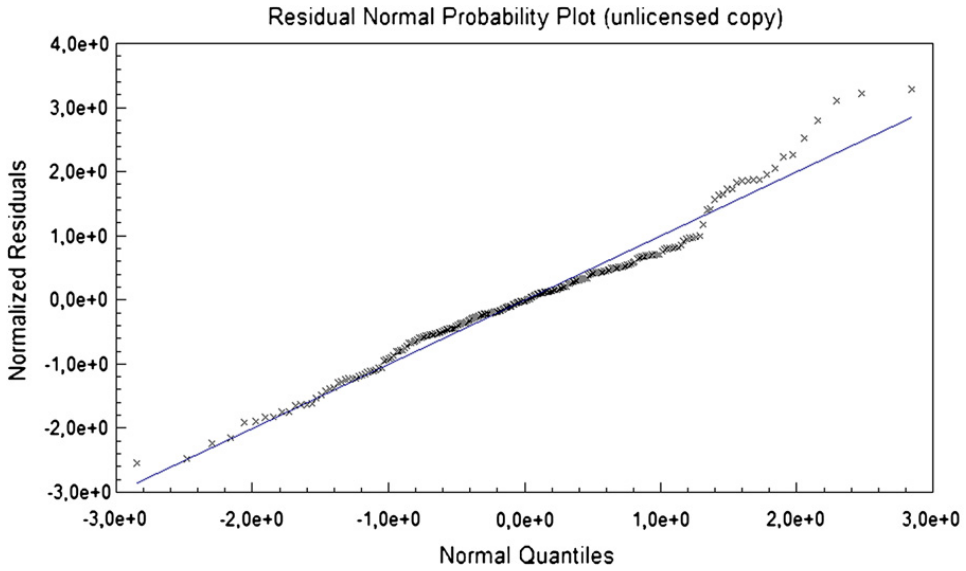

Fig. 1. Normal probability plot of the residuals. A normal distribution is evidenced by the points roughly lying on a straight line. The plot demonstrates adequate normality of the residuals. The discrepant high data have not been removed from the analysis.

pattern and there are no unusual patterns or outliers. As a result, the assumption regarding the residuals was not violated. The correlations between the observed HSA and the residuals were very low ($r = 0.245$), indicating that the deviation between actual and predicted values did not vary across the entire validation data set.

4. Discussion

Contrary to popular belief, the extensive reared domestic horse should be used as an ideal model for the domestic unshod horse foot. But to our knowledge, HSA of different breeds of horses has not been previously compared.

In cows, Clark et al. [17] estimated the ground surface area of calves for each claw by pressing the claw down on a sheet of paper covered with polyethylene film placed over an inkpad. Our method seems easier and cleaner. Moreover, it is possible to store photocopies to conserve the original raw material for further studies. The results obtained prove that it is possible to estimate HSA from linear dimensions that are repeatable, nonintrusive, and easily performed. The formula obtained may make it easier to estimate the hoof surface in vivo, at least in the horses studied. With regard to the validation exercise, high precision of prediction was obtained and the equation only overpredicted HSA by an average of 3.7 cm^2, which represents approximately 5.1% of the observed value. It is important that this bias be taken into consideration if the current equation is used in practice.

The proposed method has only been tested on one specific breed, although the sample size relative to the number of cases in this study resulted in high power for the statistical analyses conducted. No one method can be considered the "correct" method for any kind of horse until comparisons are made over a wide range of breeds. Comparisons over a wide range of breeds are needed because the effect of a particular breed's characteristics on the given formula could be huge, at least in horses used for other purposes. Although the size of the hoof may differ from breed to breed, the basic structure and shape are the same, so the estimations presented in this article probably do not differ very much for other breeds.

New experiments could now assess weight bearing and pressure distributions on CPC hooves.

Acknowledgments

The author thanks the generosity of MAFRISEU SA in La Seu d'Urgell (Catalunya, Spain) for supplying all the horse legs and the associated information for each animal.

References

[1] Ovnicek EJ, Peters D. Wild horse hoof patterns offer a formula for preventing and treating lameness. AAEP Proceedings 1995;41:258-60.
[2] Rooney JR. Functional anatomy of the foot. In: Floyd AE, Mansmann RA, editors. Equine podiatry. St Louis, MO: Saunders Elsevier; 2007.
[3] Lochner FK, Milne DW, Mills EJ, et al. In vivo and in vitro measurement of tendon strain in the horse. Am J Vet Res 1980;41:1929-37.
[4] Riemersma DJ, Van Den Bogert AJ, Jansen MO, et al. Influence of shoeing on ground reaction forces and tendon strains in the forelimbs of ponies. Equine Vet J 1996;28:126-32.
[5] Moyer W, Anderson JP. Lameness caused by improper shoeing. J Am Vet Med Assoc 1975;166:47-52.
[6] Pool RR, Meagher DM. Pathologic findings and pathogenesis of racetrack injuries. Vet Clin North Am Equine Pract 1990;6:1-30.
[7] Kane AJ, Susan M, Stover SM, Bock KB, Gardner IA. Hoof Balance Characteristics Associated with Catastrophic Injury of Thoroughbred Racehorses. AAEP Proceedings 1998;9:281.
[8] Dejardin LM, Arnoczky SP, Cloud GL. A method for determination of equine hoof strain patterns using photoelasticity: an in vitro study. Equine Vet J 1999;3:232-7.
[9] Heel MC, Barneveld A, Weeren PR, Back W. Dynamic pressure measurements for the detailed study of hoof balance: the effect of trimming. Equine Vet J 2004;36:778-82.
[10] Stachurska A, Kolstrung R, Pieta M, Silmanowicz P, Klimorowska A. Differentiation between fore and hind hoof dimensions in the horse (*Equus caballus*). Arch Tierz 2008;51:515-644.
[11] Roland E, Stover SM, Hull ML, Dorsch K. Geometric symmetry of the solar surface of hooves of Thoroughbred racehorses. Am J Vet Res 2003;64:1030-9.
[12] Thomason J. The hoof as a smart structure. In: Floyd AE, Mansmann RA, editors. Equine podiatry. St Louis, MO: Saunders Elsevier; 2007.

[13] Fernández M, Gómez M, Delgado JV, Adán S, Jiménez M. Guía de Campo de las Razas Autóctonas Españolas. Madrid, Spain: SERGA; 2009.
[14] Parés PM, Parés R. Algunas características fanerópticas del caballo Bretón Ceretano. Avances en Alimentación y Mejora Animal 1997;37:53-7.
[15] Wilcox DS, Dove BW, McDavid D, Greer DB. UTHSCSA ImageTool version 30. Austin: University of Texas; 2002.
[16] Hammer Ø, Harper DAT, Ryan PD. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4 (1). Available at: http://palaeo-electronica.org/2001_1/past/issue1_01.html, 2001.
[17] Clark CR, Petrie L, Waldner C, Wendell A. Characteristics of the bovine claw associated with the presence of vertical fissures (sandcracks). Can Vet J 2004;45:585-93.