Predictive modeling of the equine heel

Leah N. Guidry[1], Debra R. Taylor[1], R. Kent Sanders[3], Robert C. Cole[1], Dewey R. Wilhite[2], Fred J. DeGraves[4], Amy K. Sanders[1], Robert M. Bowker[5]

Departments of Clinical Sciences[1] and Anatomy, Physiology, and Pharmacology[2], Auburn University College of Veterinary Medicine, Auburn, AL
University of Utah, School of Medicine[3], Salt Lake City, UT
Western Kentucky University, Department of Animal Science[4], Bowling Green, KY
Michigan State University, College of Veterinary Medicine[5], East Lansing, MI

Abstract

Recently it has been proposed that healthy soft tissue structures of the equine heel play a primary role in equine soundness. Historically, little attention has been given to the significance of the health of the equine heel soft tissue structures, which are uniquely positioned so as to provide support and protection to the navicular apparatus. Namely these tissues are the digital cushion and collateral cartilages. We believe that volume characteristics of these structures can be accurately predicted through physical examination and routine diagnostic imaging. The goal of this study is to determine whether the volume of the soft tissue structures of the equine heel can be predicted by the inexpensive and non-invasive methods of physical, radiographic, and ultrasonographic examination. Thirteen left front hooves were collected from adult Thoroughbred horse cadavers (4-20 years of age). Physical, radiographic, and ultrasonographic examinations were performed on the hooves and multiple parameters were recorded. The hooves were then scanned using computed tomography (CT) and magnetic resonance imaging (MRI). Data from the CT and MRI scans was processed through Mimics® medical imaging software, to create 3D images of the middle phalanx, collateral cartilages, and digital cushion. The volumes of the 3D reconstructed tissues were recorded for comparison with ultrasonographic, radiographic, and physical exam parameters. It was found that the feet were able to be categorized into high, medium and, low total heel volume (THV) and digital cushion volume (DCV), and coronary band circumference was the only parameter evaluated that predicted DCV and THV with accuracy (p =0.0004, r^2 =0.693). The clinical parameters evaluated here were only sensitive enough to detect approximately 60% difference between feet in this study thus, it is doubtful that common clinical diagnostic techniques (physical, radiographic and ultrasound examination) will be sufficient for evaluation of heel development in future research endeavors on mature horses.

Introduction

Traditionally, equine foot lameness has been attributed to pathology of the bones, synovial structures, tendons and ligaments, and the lamina of the foot. Historically, little attention has been given to the significance of the health of the equine heel soft tissue structures, which are uniquely positioned so as to provide support and protection to the navicular apparatus. Namely, these tissues are the digital cushion and collateral cartilages. We believe that volume characteristics of the soft tissue structures of the equine heel can be accurately predicted through physical, radiographic, and ultrasonographic examination. The goal of this study was to determine whether the volume of the soft tissue structures of the equine heel could be predicted by the inexpensive and non-invasive methods of physical, radiographic, and ultrasonographic examination.

Materials & Methods

Thirteen left front feet were collected from Thoroughbred horse cadavers aged 4 – 20 years. The feet were imaged using computed tomography (CT)[b] and magnetic resonance imaging (MRI)[c]. CT images were obtained on the frozen feet in a transverse plane, perpendicular to the palmar angle of the distal phalanx, at 1.0 mm intervals and then filtered with a "kernel" for bone edge and soft tissue enhancement to create 0.6 mm images. The feet were thawed prior to MRI scanning. MRI images were obtained in the same plane using 1.5 mm intervals, a human knee coil, and either a 3 Tesla magnet[c] (n=10) or a 1.5 Tesla magnet[d] (n=3). Data from the CT and MRI scans was analyzed via Mimics® medical image processing software[a]. Three-dimensional images were constructed of the digital cushion, collateral cartilages, and the middle phalanx. The volumes of these anatomical structures were determined. Physical, radiographic, and ultrasonographic examinations were performed on the same feet. A physical examination scoring system for the equine heel was established in a previous study and used to examine all feet (Table 1, Figure 2). Each foot was imaged through the frog using ultrasonography to determine the thickness of the digital cushion (Figure 1). Calculated heel volume was determined by the multiplication of three parameters 1) distance between collateral cartilages (Figure 2a) 2) heel depth measured using Metron®[e] (Figure 3) and 3) the average thickness of the digital cushion (Avg. Thickness of DC = CSD x [DC+FD]). Coronary band circumference was also measured (Figure 2b). The relationships between clinical exam measurements (independent variables) and Mimics® values (dependent variables) were explored using repeated measures analysis[f]. P values ≤ 0.05 were considered significant.

Physical Examination Parameters

Parameter	Explanation
Negative area under frog	Scale (-5-0), score of the amount of air space between the frog and the ground, when the foot is on the ground (subjective)
Negative area above digital cushion	Scale (-5-0), score of the amount of empty space above digital cushion, between collateral cartilages, that is not filled with tissue (subjective)
Distance between collateral cartilages	Measurement of the distance between the collateral cartilages (cm)
Heel bulb depth	Measurement of depth of heel bulb (cm)
Central sulcus depth (CSD)	Measurement of depth of central sulcus (cm)
Digital cushion + frog depth (DC+FD)	Overall thickness of digital cushion, including the frog (cm)
Volume score (+/- frog)	Sum of the six parameters listed above, with/without negative area under the frog included

Table 1. Explanation of physical exam parameters

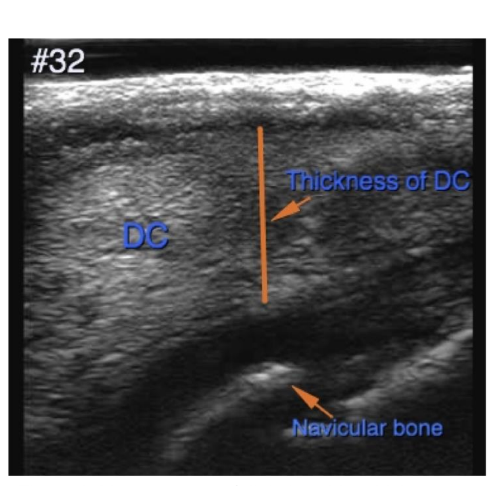


Figure 1. Measurement of digital cushion thickness through ultrasonographic examination

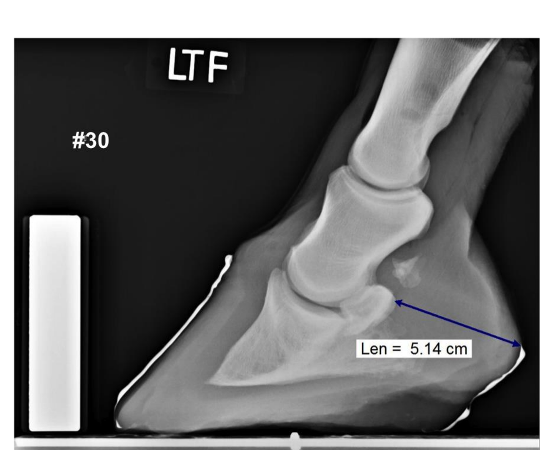


Figure 3. Measurement of heel length, using Metron®

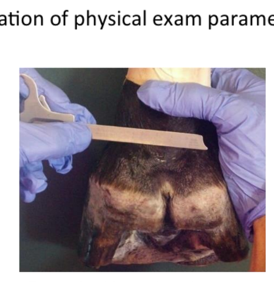


Figure 2a. Measuring distance between collateral cartilages

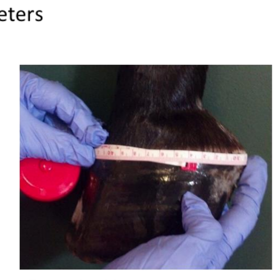


Figure 2b. Measuring coronary band circumference

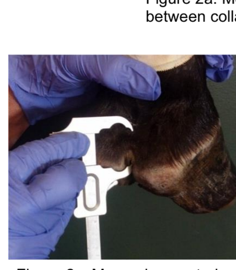


Figure 2c. Measuring central sulcus depth

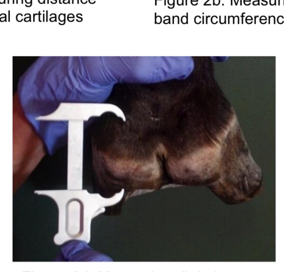


Figure 2d. Measuring digital cushion plus frog depth


Figure 2e. Measuring heel bulb depth

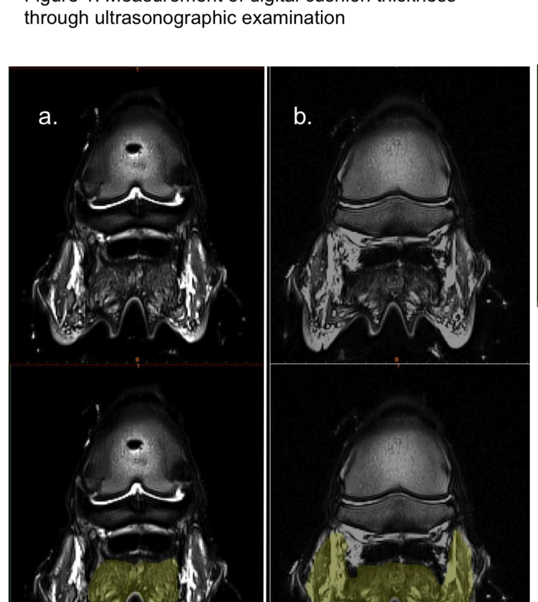


Figure 4. Mimics® reconstruction of the digital cushion (a.) and total heel volumes (b.)

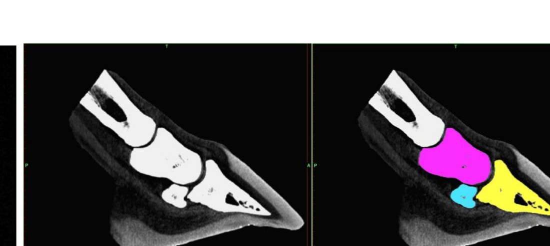


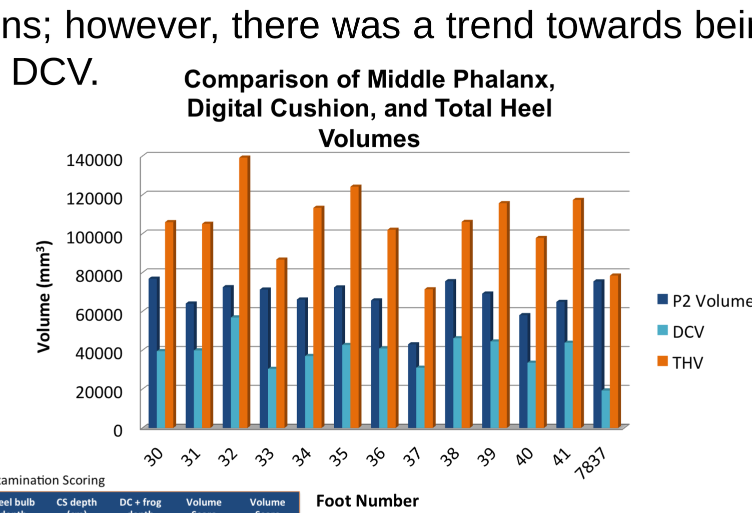
Figure 5. Mimics® reconstruction of the middle phalanx (purple)

Key

Abbreviation	Term
DC	Digital cushion
CC	Collateral cartilages
CS	Central sulcus
PE	Physical Examination
THV	Total Heel Volume
DCV	Digital Cushion Volume
CB Circum.	Coronary Band Circumference
U/S	Ultrasound
CSD	Central Sulcus Depth
DC+FD	Digital Cushion and Frog Depth

Results

Using the parameters designed for this study (Table 1), each foot was ranked based on predicted volume (Table 3). Data from the physical examinations is shown in Table 2. The volumes of the digital cushion (DCV), total heel soft tissue (THV), and middle phalanx (P2 Volume) were determined by three-dimensional reconstruction[a] (Figures 4 and 5). The feet were then ranked based on the following: PE Vol. with frog, PE Vol. without frog, DCV, THV, Calc. Vol., DC thickness, and coronary band circumference. These rankings are displayed in Table 3 to allow direct comparison. Through statistical evaluation it was found that coronary band circumference was predictive of THV (p = 0.0004, r^2 = 0.693). No other direct correlations existed between clinical examination findings and volumes from three-dimensional reconstructions; however, there was a trend towards being able to categorize feet into high, medium, and low THV and DCV.



Physical Examination Scoring

Foot #	Negative area under the frog	Negative area above the DC	Distance between CC (cm)	Heel bulb depth (cm)	CS depth (cm)	DC + frog depth (cm)	Volume Score (+ Frog)	Volume Score (- Frog)
30	-5	-5	5	3.3	1.9	3	3.2	8.2
31	0	-2	5	3.3	3.7	4	14	14
32	-3	-2.5	5	4.4	2.6	6	12.5	15.5
33	-5	-2.5	3	4.7	1.1	3	4.3	9.3
34	-3	-4	4	3.5	2.6	3	6.1	9.1
35	-2	-4	5	3.5	3.3	4	9.8	11.8
36	-5	-5	5	3.5	0.9	2.5	1.9	6.9
37	-4	-5	3	4.8	2.6	4	5.4	9.4
38	-1	-3	5	3.8	3.2	4	12	13
39	-1	-3	5	4.8	4	5	14.8	15.8
40	-3	-1	3	4.5	3.1	3.8	10.4	13.4
41	0	-3	5	5	3.1	4.3	14.4	14.4
7837	-1	-4	6	3.8	3.2	4.2	12.2	13.2

Table 2. Physical examination data

Foot Ranking Based on Clinical vs. Mimics® Evaluation

Rank	Foot # (PE Vol. + frog)	Foot # (PE Vol. - frog)	Foot # (Mimics DCV)	Foot # (Mimics THV)	Foot # (CB Circum.)	Foot # (U/S DC Thickness)	Foot # (Calc. Vol.)
1	39	39	32	32	41	39	32
2	41	32	38	35	32	36	39
3	31	41	39	41	39	32	31
4	32	40	41	39	35	38	7837
5	7837	31	35	34	34	40	41
6	38	7837	36	38	30	30	38
7	40	38	31	30	38	31	35
8	35	35	30	31	36	41	30
9	34	37	34	36	7837	7837	34
10	37	33	40	40	31	34	40
11	33	34	37	33	33	33	36
12	30	30	33	7837	40	35	37
13	36	36	7837	37	37	37	33

Table 3. Foot rankings based on physical examination volumes scores with and without frog (PE +/- frog), Mimics® volumes (DCV and THV), calculated volumes, thickness of DC on ultrasound, and coronary band circumference; in order from largest (1) to smallest (13)

Discussion

Coronary band circumference (Table 3, highlighted) was the only parameter evaluated that predicted DCV and THV with accuracy (p =0.0004, r^2 =0.693). However a trend was noted whereby several other parameters accurately categorized the hooves into low, medium, and high THV and DCV (Table 3). Data from this study serves as a very preliminary screening for clinical examination measures that may serve as predictor variables for anatomical characteristics of the equine heel.

Physical and clinical examination parameters may be useful to later categorize hooves into low, medium and high volume for clinical purposes. This could be used clinically to determine "hoof readiness" for athletic use of the horse. Previous studies indicate that a 5-10% change in volume of the equine heel can be expected over a 6-month period of hoof stimulation. The clinical parameters evaluated here will not be sufficient to detect the percent change as they were only sensitive enough to detect approximately 60% difference between feet in this study. It is also valuable to note that this study focused on the variation of THV and DCV within mature horses of a single breed (TB), therefore subtle differences between the feet were difficult to appreciate.

Based on the results of this study it is doubtful that common clinical diagnostic techniques (physical, radiographic and ultrasound examination) will be sufficient for evaluation of heel development in future research endeavors on mature horses. Therefore, soft tissue evaluation in future studies will require costly diagnostic imaging (MRI and CT scan) for Mimics 3D reconstruction in order to accurately evaluated small changes in soft tissue volumes.

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Footnotes

[a]CT was performed using a Siemens SOMATOM Definition CT Scanner
[b]MRI was performed using a Siemens Verio Open-Bore 3T Scanner
[c]MRI was performed using a Philips Infinion 1.5T Scanner
[d]Mimics® medical image processing software by Materialise
[e]Metron® by EponaTech LLC
[f]SAS® PROC GLIMMIX, Cary, NC

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