CHARACTERISTICS OF HEALTH PARAMETERS AND THE DIGITAL CUSHION IN HORSES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Studies examining lameness conditions and health concerns for horse owners are important for education and future research. To investigate this, a survey and two studies were conducted. For the survey, a total of 152 responses were collected. Horse owners ranked lameness as the top concern (35%), followed by colic (21%). Lameness issues were ranked as the top (37%) veterinary expense. To validate a non-invasive ultrasound technique for imaging the digital cushion, ten cadaver limbs were evaluated. There was a strong correlation ($r = 0.73$; $p = 0.02$) between ultrasound and actual measurement. To establish baseline values, 25 mature, stock-type horses were imaged. Mean values for age, weight, and BCS were 10.5 years, 477.2 kg, and 5.5, respectively. Mean values for digital cushion of the left fore and hind were 0.96 and 1.04 cm, respectively. When comparing shod versus unshod horses, no significant difference ($p = 0.13$) was observed.

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DEDICATION

To my family for giving me opportunities, love, and prayers.

To my husband for the countless words of encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAEP .... American Association for Equine Practitioners

AVMA .... American Veterinary Medical Association

BCS .... body condition score

cm .... centimeters

CT .... computed tomography

kg .... kilograms

kPa .... kilopascal

LF .... left fore

LH .... left hind

ms .... milliseconds

MRI .... magnetic resonance imaging

NAHMS .... National Animal Health Monitoring System

ND .... North Dakota

std err .... standard error

USDA .... United States Department of Agriculture

yr .... year

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

Horses in the U.S. are considered livestock; however, in contrast to most of the other livestock species, horses are not used for food purposes. A horse's purpose and job have progressed from a work animal to that of a performance animal (USDA, 2006). Anything that prevents or hinders a horse from their purpose as a performance animal can lead to economic or welfare concerns.

Lameness is a complicated condition with many possible causes. It has been defined as any alteration of a horse's gait, which can manifest in such ways that change performance (AAEP, 2005) and ultimately result in a loss of performance. It has been cited as the most common cause of lost performance (Jeffcott et al., 1982) and is considered the most important medical problem in horses, with an annual incidence of 8.5-13.7% (Anon, 2002). Equine veterinarians ranked musculoskeletal research as a top priority (89% of respondents) and four of the top five ranked diseases for research priority were lameness related (AAEP, 2009). Research to minimize lameness is not only a welfare concern, but also an economic one as it is a leading cost for horse owners, with an estimate of $432 in veterinary costs, drugs, and care per lameness event (Anon, 2002). For centuries, the phrase "no hoof, no horse" has been used; yet there are many mechanisms of this important structure that are not fully understood (Mishra and Leach, 1983). Therefore this literature review will describe specific structures in the equine foot, and discuss current lameness conditions commonly affecting these structures.

The front limbs support 60-65% of the horse's weight (Baxter, 2011), and it has been hypothesized that the concussion at impact in the forelimb is greater than in the hind limb (Back et al., 1995). Thus, it is not surprising that, 81% of limb injuries involve the forelimbs (Williams et al., 2001). Conditions such as laminitis, navicular disease, and sole abscesses are ranked as the most common lameness conditions (USDA, 1998), and are also conditions found in the distal forelimb of horses. Therefore, it can be concluded that the majority of lameness occur in the distal limb of the horse.

The distal limb of the horse is also important with regard to blood flow. The weight-bearing force as the horse's hoof contacts the ground is utilized for effective return of venous blood from the digit (Mishra and Leach, 1983). Proper circulation is critical in the equine hoof to ensure nourishment of the digital tissues (Harris et al., 2006). The hoof wall is rigid in nature and therefore there is little room for expansion to accommodate edema. Because the hoof wall also encloses the digit, it is predisposed to vascular compression secondary to tissue swelling (Hood et al., 1993). Thus, normal function of the hoof can be disrupted by trauma and/or disease (Mishra and Leach, 1983), and any disruptions to normal circulation have the potential to create soundness problems.

Many discussions revolve around structures of the external portion of the equine foot, comparing conformation to movement and the potential for lameness. Conformation of the equine hoof can determine shape, wear, flight pattern of the foot, and distribution of weight (Ross and Dyson, 2003). A good foot is always desirable (Ross and Dyson, 2003) because if the horse does not have the correct alignment and angles in the hoof, it could lead to excess stress on the tendons and ligaments, creating a potential for lameness. The variation in structure from one horse's hoof to the another can contribute to the reason why some horses live their entire life with no foot problems while others experience chronic foot problems (Bowker, 2003).

Looking beyond the external conformation of the digit to the internal structures (Figure 1) can reveal new perspectives on what is causing certain lameness issues in response to conformation (Bowker, 2003). The internal structures determine the externally viewed conformation. When looking at the internal portion of the equine foot, there are many structures that can be examined. Laminar attachments between the hoof wall, the distal phalanx, digital cushion, and ligamentous connective tissues are all internal structures, which may have significant roles in the anti-concussive mechanisms of the foot (Bowker et al., 1998). Biomechanical stress to internal structures may be responsible for chronic hoof problems and could also exacerbate some lameness conditions (Bowker, 2003). Detailed research on each internal structure can reveal specific conditions and diseases that affect a horse's soundness.

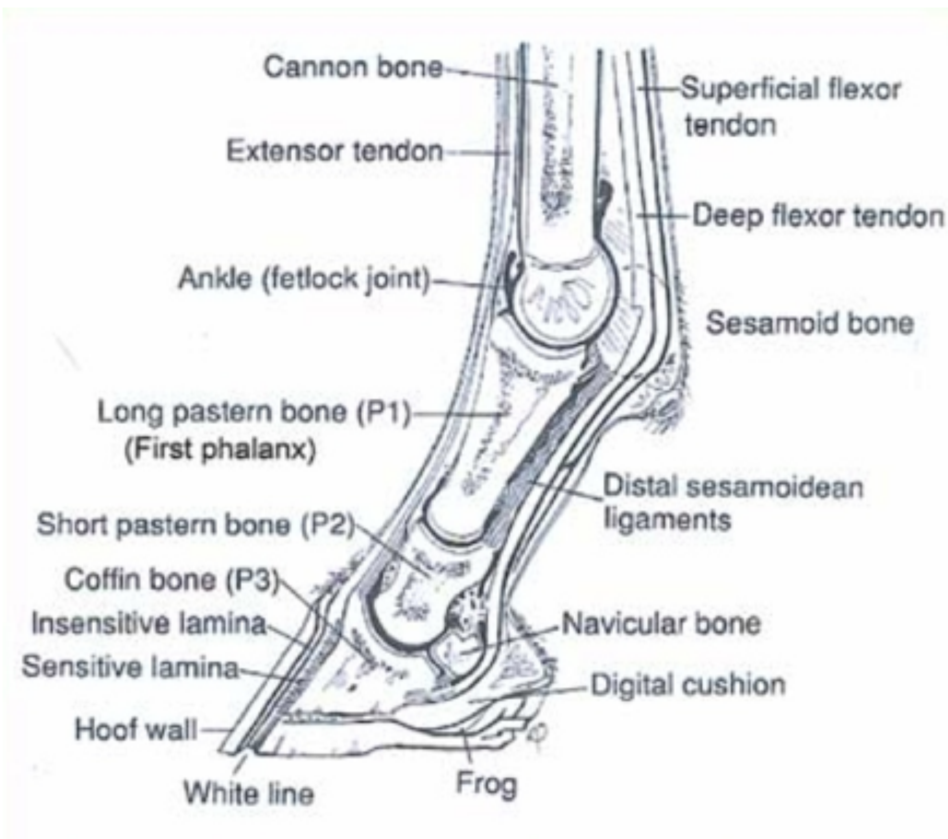

Figure 1.1. Diagram of internal anatomy of distal limb in the horse (Sales, 2003).

Laminar Attachments & Distal Phalanx

Laminar attachments include both the sensitive and insensitive laminae. The internal surface of the hoof wall carries the insensitive laminae and the sensitive laminae attach to the distal phalanx. These two layers bind together strongly. If there is damage to the laminar layers, the horse can develop laminitis, which continues to have widespread implications for equine welfare (Bailey et al., 2004). According to the USDA (2000), laminitis impacts 2% of the United States horse population each year (~150,000 horses per year), and is known to be a common and debilitating disease (Bailey et al., 2004). Laminitis is a complex condition brought about by several interacting factors (Hood et al., 1993). During the developmental phase and onset of laminitis there is vasodilation of the veins in the hoof. This leads to the acute phase where the laminae become inflamed. Laminitic horses will develop a pronounced digital pulse in one or both front feet, along with an increased hoof wall surface temperature (Hood et al., 1993; Pollitt and Davies, 1998). When the disease becomes chronic, attachment to the distal phalanx is affected and the disease is serious. The distal phalanx is the most distal bone in the horse's leg, and chronic cases occur when this bone rotates away from the hoof wall (Stashak, 1987), which is commonly referred to as founder. This has been reported as the most serious disease in the equine hoof, leading to devastating loss of function (Pollitt 2004). A horse's ability to return to athletic soundness has an inverse relationship with the degree of bone rotation (Stick et al., 1982).

Alford et al. (2001) examined risk factors for both acute and chronic laminitis in a multicenter, matched case-control study. Acute laminitis was defined as the onset of lameness in one or more feet, accompanied by signs of pain and pounding digital pulse and/or warm feet. Acute cases also had no evidence of displacement of the distal phalanx as determined by radiographic examination. Chronic laminitis was defined as lameness and/or hoof abnormalities with a previous diagnosis of acute laminitis and evidence of displacement of the distal phalanx.

Results from this study found that there was an increase in risk for horses with acute laminitis in a bimodal pattern, with 5 to 7 years of age and 13 to 31 years of age being at a higher risk, which suggests there are two periods of susceptibility to laminitis (Alford et al., 2001). This study also identified that horses of older age, specifically 10 years and older, are at an increased risk of chronic laminitis. In a descriptive epidemiological study of equine laminitis, Slater et al. (1995) found that chronic cases were seen in horses that were significantly older, and shoeing and trimming were a more common part of the treatment protocol in these cases. In both acute and chronic cases, phenylbutaxone was the most common drug used (Slater et al., 1995). Both Slater et al. (1995) and Alford et al. (2001) found that mares were more likely than geldings to develop both acute laminitis and chronic laminitis, potentially due to endogenous and exogenous estrogen (Alford et al., 2001). Diverse breeds were not well represented in these studies, but clinicians agreed that overweight horses, especially those in the pony breeds, are more susceptible to laminitis (Stashak, 1987). A cresty neck (associated with obesity) was significantly correlated with both acute and chronic laminitis (Alford et al., 2001). These results suggest that obese mares of increased age are the most susceptible to developing laminitis.

Distal Sesamoid

Another internal structure of the hoof that can play a role in lameness of the horse is the distal sesamoid bone (also called the navicular bone). This bone provides a gliding surface at the point where the deep digital flexor tendon changes angles and continues down to attach at the distal phalanx (Bowker, 2003; Wilson et al., 2001). As a result of this role, the bone experiences a compressive force during the stance phase of movement (Wilson et al., 2001). When a horse has a chronic and degenerative forelimb lameness associated with degenerative changes in the cartilage, bone, and surrounding tissues of the distal sesamoid bone (Rijkenhuizen, 1989), while also experiencing bilateral lameness characterized by a toe first landing and a shortening of the anterior phase of the stride (Stashak, 1987), the horse is suffering from the condition navicular disease.

This disease is complex in nature and can be caused by biomechanical stress, circulatory disturbances, and genetic factors. It has been reported that significant changes occur in the medulla of the navicular bone, its palmar cortex and fibrocartilage, and the adjacent tendon (Wright et al., 1998). Biomechanical stress occurs in horses with collapsed heels making them more susceptible to navicular disease as the acute hoof angle leads to an increased passive load on the distal sesamoid bone from the deep digital flexor tendon (Wright and Douglas, 1993). The shape of the proximal articular border of the distal sesamoid bone has been found to be inherited as well as predispose horses to navicular disease when that border is more concave (Dik et al., 2001). An imbalance in blood supply in the limb is observed in horses with navicular disease, with a reduction of the distal blood supply and a compensatory reaction in the proximal, medial, and lateral blood supply (Rijkehuizen, 1989).

For treatment purposes, heel wedges have been shown to significantly reduce the force that is exerted on the distal sesamoid bone by the deep digital flexor tendon in navicular horses (Willemen et al., 1999). With treatment, 65-75% of horses with this disease show improvement in performance, but only 40-50% remain sound for 1-2 years (Rijkehuizen, 2006). Research done by Wilson et al. (2001) studied the compressive force exerted on the navicular bone in horses with navicular disease. They found that the peak stress exerted on the navicular bone was not significantly different in normal horses versus horses with navicular disease, although the stress on the navicular bone at mid-stance was different (Wilson et al., 2001). These data suggest that horses with navicular disease might attempt to compensate for the condition by unloading their heels by contracting their deep digital flexor muscle, increasing the force in the deep digital flexor tendon. This will however increase the force on the navicular bone, which seems to be counter-intuitive to the horse, but could indicate other sources of pain in the hoof. This may result in a positive feedback loop mechanism that leads to the progressive and chronic nature of navicular disease (Wilson et al., 2001).

Digital Cushion

The equine digital cushion has not be studied extensively in terms of its potential role as an internal structure of the hoof that could be associated with lameness; although, anatomy and composition of this structure has been described. The digital cushion lies between the lateral cartilages and above the frog and epidermal bars of the horse's hoof and is comprised of collagen, elastic fiber bundles, fibrocartilage, and adipose tissue (Bowker, 2003). The digital cushion has been mentioned as playing a role in shock absorption when the hoof contacts the ground; along with being described as a blood pumping mechanism to encourage venous blood return from the digit upward to the leg (Bowker et al., 1998).

Bowker et al. (1998) observed differences in digital cushion composition across and within breeds. Feet examined from Arabians, Morgans, and Tennessee Walkers had digital cushions that consisted of fibro-elastic or fibrocartilaginous and elastic tissues rather than adipose and elastic tissues. In contrast, Thoroughbreds, Quarter Horses, Standardbreds, and their crosses had digital cushions composed of fibrocartilaginous tissue with primarily adipose and elastic tissues. From all the breeds represented in this study, it was also observed that the hind foot digital cushion was composed primarily of adipose and elastic tissue when compared to the fore foot (Bowker et al., 1998).

The changes in digital cushion composition from fat, elastic, and isolated collagen bundles to a stronger fibrocartilage are a normal progression with increasing age (Bowker, 1998). Through stimulation of the solar surface and frog as a horse ages, the fibrocartilage begins to form distally and progresses proximally toward the distal sesamoid bone. With this gradual development to a stronger cartilage, the apparent health of the palmar foot may improve. Horses that have a healthier palmar foot may also have less clinically evident chronic foot problems compared to those with an underdeveloped digital cushion (Bowker, 2003). Also, the variability of the digital cushion within and between breeds suggests that there is a potential genetic predisposition of certain breeds toward either a fibrocartilaginous digital cushion or one consisting of more adipose tissue, and also that these connective tissues within the foot may be responsive and/or adaptive to various external stimuli; such as bodyweight, age, and forces at ground impact (Bowker et al., 1998).

Energy Dissipation

Original studies from the 1800s proposed two traditional theories for how the hoof dampens impact to explain energy redistribution and dissipation when a horse's hoof contacts the ground; the depression theory (Coleman, 1805; Peters, 1883), and the pressure theory (Clark, 1809; Lungwitz, 1883). Both of these theories explain that the digital cushion plays a role. The depression theory emphasizes that the downward movement of the middle phalanx into the digital cushion will force the lateral cartilages out. The pressure theory suggests that the frog pushes up on the digital cushion when the hoof contacts the ground, moving the lateral cartilages outward while the digital cushion serves as a shock absorber. Both theories predict that blood is pumped from the foot at impact and that the digital cushion has positive pressure, absorbing energy before the outward deflection of the cartilages (Bowker, 2003).

In contrast, as technology has advanced, Dyhre-Poulsen et al. (1994) found that negative pressure was recorded in the digital cushion during ground contact and stance phase in a study using implanted pressure transducers. The pressure measured in the digital cushion decreased rapidly (30ms) during the stance phase to -40 kPa, and remained low until the hoof started rolling over the toe for push off and pressure returned to normal. One hypothesized explanation for the negative pressure in the digital cushion was loading of the hoof caused expansion of the hoof walls and therefore increased volume inside the hoof; although, stretching the deep digital flexor tendon could also diminish the pressure. Other factors that have the potential to affect the pressure could be the rate of change in shape of the hoof and the velocity of the impact (Dyhre-Poulsen et al., 1994). J.J. Thomason (1998) suggests that movement of the hoof at impact begins from pressure on the toe, flaring the quarters abaxially, which then allows movement of the heel. This furthermore supports the hypothesis that increased hoof volume allows for negative pressure in the digital cushion.

Taylor et al. (2005) reported that displacement of the digital cushion during the stance phase occurs in patterns consistent with response to palmar displacement of the second phalanx. This indicates the digital cushion is playing a passive role in the equine foot (Taylor et al., 2005). This displacement pattern of the digital cushion is also inconsistent with the early pressure and depression theories, further supporting the negative pressure reported by Dhyre-Poulsen et al. (1994).

Due to the findings in the biomechanical study by Dyhre-Poulsen et al. (1994), Bowker (1997) proposed a new hemodynamic flow hypothesis, which suggests that this negative pressure is created by the outward movement of the hoof cartilage while simultaneously the impact energies force venous blood throughout the lateral cartilages, providing further negative pressure as a vacuum action draws blood up from the solar surface of the hoof. He suggests that disturbances in this mechanism could produce greater energies to other portions of the distal limb, potentially resulting in lameness.

Even with the uncertainty in which theory explains proper energy dissipation of the hoof, it can be determined that there are changes in pressure and absorption of energy within the foot, and that the digital cushion plays a role in shock absorption. Overall, if there is inefficient energy dissipation in the hoof when it is loaded there is the potential for adverse effects in the strength and support of the foot (Bowker et al., 1998), as well as potential for gradual production of lameness conditions.

Dairy Cattle Digital Cushion

Similar to horses, lameness is one of the most significant welfare issues of high producing dairy cows in North America, as well as being a financial concern (Oikonomou et al., 2014). Although there are limited studies regarding the digital cushion in horses, this structure has been studied in dairy cattle. It has been observed that digital cushion thickness has a high association with BCS, where an increase in BCS was paired with an increase in digital cushion thickness. Along with that, it was also shown that thin digital cushions were a strong predictor of lameness (Bicalho et al., 2009). Thus, thin dairy cows will have thin digital cushions and are more likely to suffer from lameness.

A well-developed digital cushion is necessary to cushion and prevent contusions that lead to lameness (Bicalho et al., 2009), and cattle with a thicker digital cushion should have feet that are biomechanically resilient and less prone to lameness (Gard et al., 2015). There is also the potential to minimize lameness by maximizing the surface area of the digital cushion as well as the volume of the second and third phalanges. A recent study found that cattle maintained and exercised on alternative terrain consisting of dirt, stones, and grass increased volume and surface area of the digital cushion compared to cattle maintained in grass paddocks and not encouraged to exercise (Gard et al., 2015). Researchers determined that an increase in the volume and surface area of the digital cushion and distal phalanges should have a positive effect on hoof health, which in turn could potentially make cows less susceptible to lameness (Gard et al., 2015).

Another study investigated the association between digital cushion thickness and sole temperature measured by infrared thermography (Oikonomou et al., 2014). It was hypothesized that digital cushion thickness may be associated with early signs of inflammation as measured by increased sole temperature. Sole temperature decreased as digital cushion thickness increased, supporting the association of the digital cushion with sole temperature (Oikonomou et al., 2014). Dairy cattle are found to be the most productive when they are pain free, which means development and application of further research along with protocols that prevent lameness are necessary to maintain health and production (Gard et al., 2015). Increased knowledge of the digital cushion and its relationship to lameness may also be important in horses to maintain health and welfare, in addition to maintaining performance by preventing of lameness.

Imaging Techniques

Previous detailed studies of the digital cushion in horses have come from cadaver legs (Bowker et al, 1998) and focused on compositional changes and energy dissipation. Other than functional anatomy, there is limited data on the digital cushion in horses. This could be due to the difficulty in viewing internal structures of the hoof in a live horse because of the tough keratin of the hoof capsule (Busoni and Denoix, 2001).

To view the internal structures non-invasively, researchers are limited to the use of magnetic resonance imaging (MRI), computed tomography (CT), radiograph, and ultrasound. Magnetic resonance imaging displays detailed images of both bone and soft tissue with high contrast and sections can be made in any plane (Whitton et al., 1998); however, it is not cost effective for most horse owners. Radiographs and CT are able to image both bone and soft tissue, but compared with MRI the soft tissue images are poor (Whitton et al., 1998), which would not be beneficial when examining many internal structures of the foot, including the digital cushion. Also, the biggest disadvantage to CT is the necessity for general anesthesia (Rijkenhuizen, 2006), which in turn reduces economic availability.

In cattle, MRI and CT have been used to determine the exact location of the digital cushion and calculate volumes and surface areas of the digital cushion and bony structures of the foot (Gard et al., 2015). The use of CT has also been used to collect cross-section anatomy of the digit (Raji et al., 2008), as well as being used for viewing morphological changes (Tsuka et al., 2012). The use of ultrasound has also been used to gather data on the thickness of the digital cushion (Bicalho et al., 2009).

Ultrasonography is a safe, non-invasive, and useful technique to visualize soft tissue structures. It has been specifically used in the distal limb for identification of soft tissues in the fetlock of a standing horse (Denoix et al., 1996), and is important in diagnosis of distal limb lameness (Crisan et al., 2010). It is also relatively inexpensive and easily available in field situations (Denoix et al., 1996; Smith and Smith, 2008); however, proper scanning technique is required to obtain a good quality and reliable image (Denoix et al., 1996). For the best resolution in regions where the soft tissues is only a few centimeters thick, such as in the limb, a high frequency (5.0-7.5 MHz) is needed for visualization of soft tissues (Rantanen, 1982). This resolution will allow separation of soft issue interfaces to be seen (Rantanen, 1982). Although a 5 MHz probe will show images of the internal structures, the use of a 7.5 MHz probe allows better imaging through better resolution and near-field imaging ability (Denoix et al., 1996).

Although the use of ultrasound has been used widely and proves to be an excellent means to visualize soft tissue structures, there are some difficulties when looking at internal hoof structures. The equine hoof capsule is a tough, keratin barrier that can pose a challenge (Busoni and Denoix, 2001). Obtaining ultrasound images of the equine distal limb has been described through ultrasonographic imaging of the palmarodistal aspect and also through a transcuneal approach (Bolen et al., 2007, Denoix et al., 1996; Busoni and Denoix, 2001; Crisan et al., 2010). Both of these techniques require proper preparation. When obtaining images of the palmarodistal aspect, the probe should be placed in the distal phalangeal area and between the heel bulbs (Bolen et al., 2007). Bolen et al. (2007) explains that because the palmar surface of the distal aspect is not flat, good contact between the probe and the skin may be difficult. Clipping of the hair and washing the skin with warm water is necessary to improve sound transmission, and high pressure on the probe is required (Bolen et al., 2007).

To obtain good quality ultrasonographic images using a transcuneal approach, proper preparation is essential (Denoix et al., 1996; Busoni and Denoix, 2001) as the shape, size, and moisture content of the frog can create differences and challenges in image quality (Busoni and Denoix, 2001). It is necessary for the sole and superficial frog to be trimmed to remove loose superficial material and pared smooth to expose softer tissue (Kidd et al., 2014; Busoni and Denoix, 2001; Olivier-Carstens, 2004). In a study done by Busoni and Denoix (2001), the foot was placed in warm water for 10-15 minutes to soften the frog and sole, and in a study done by Olivier-Carstens (2004) soaking the sole in water improved the image quality further by rehydration of the solar surface. Scanning is performed on the solar surface of the hoof toward the apex of the frog with the use of transmission gel (Crisan et al., 2010; Busoni and Denoix, 2001).

The use of cadaver limbs has been used to compare ultrasonographic changes with macroscopic findings in horses. A study by Busoni et al. (2006) looked at ultrasound images of the podotrochlear apparatus, which includes the distal sesamoid bone, collateral and impar ligaments of the distal sesamoid bone, distal deep flexor tendon, and podotrochlear bursa. This region was examined using a transcuneal approach in equine cadaver limbs with known abnormalities of the podotrochlear apparatus. Authors stated that the use of ultrasound was a viable technique for identification of an abnormal podotrochlear apparatus in this study, but there were some limitations on detecting tendon lesions. Even with some limitations, it was still concluded that the use of the ultrasound could be useful as a basis for interpretation of future studies (Busoni et al., 2006). Although, in this study the podotrochlear apparatus was the only region of interest, and no measurements of other structures were obtained.

The composition of the digital cushion has been briefly described through the use of ultrasound (Busoni and Denoix 2001), but specific measurements regarding its size in relation to other variables have not been reported. An ultrasound scanning technique using the transcuneal approach was used to visualize the internal portions of the hoof, including the digital cushion (Crisan et al., 2010; Chope, 2007; Busoni and Denoix, 2001). The digital cushion is positioned between the deep digital flexor tendon and the frog and has a homogenous pattern, along with being the most superficial structure on the ultrasound images (Busoni and Denoix, 2001).

Although descriptions and measurements of the digital cushion have been reported, no validated procedure has been described. A validated ultrasound procedure for digital cushion visualization is needed to allow further study of the digital cushion and its potential association with lameness in horses.

The following chapters will discuss studies examining horse health concerns of horse owners and preliminary data on the digital cushion. The first study focuses on economic costs and welfare issues associated with horses in North Dakota. The second study focuses on validating a ultrasound procedure for measuring the digital cushion. The last study focuses on obtaining preliminary data regarding digital cushion thickness in horses. A summary of those studies will be discussed, including directions for future research.

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CHAPTER 2. NORTH DAKOTA HORSE HEALTH SURVEY

Abstract

Information regarding horse owners' concerns relative to horse health is necessary to identify future research and public education efforts. Therefore, the objective of this study was to gather information from North Dakota horse owners regarding health concerns and expenses for horses. A fifteen-question survey was posted through social media and kept active for two weeks. All survey procedures were approved by the North Dakota State University Institutional Review Board. Participants were limited to ages 18 and older and required to be a North Dakota resident. The survey instrument included questions relating to the participant's involvement in the horse industry, number of horses owned and cared for, frequency of use for a veterinarian and the expense paid per year, frequency of use for a farrier and expense paid per year, top concerns of horse health, and horse health issues resulting in the highest veterinary expenses. A total of 152 responses were collected during the two-week period. When participants were asked how long they have been involved in the horse industry, 84% responded with 11 years or more and the majority (80%) owned horses for hobby/pleasure riding. Data indicated that 82% of horse owners in North Dakota spend an average of $500 or less on veterinary expenses per horse per year; with the majority (69%) of owners only using a veterinarian two times per year or less. Twenty-six percent of these owners reported using veterinary services only for emergencies, and 60% reported that they do the work themselves. Farrier use was more frequent with 45% of horse owners using a farrier every 4-8 weeks. When asked to rank which health issues caused the most concern, 35% of horse owners ranked lameness as the top concern, followed by colic (21%). Outside of routine veterinary expenses (vaccination, de-worming, dental, etc.), lameness issues

were ranked as the top (37%) veterinary expense. In summary, although the majority of owners reported yearly veterinary expenses below $500, there was a concerning number of owners who do not use regular veterinary services. Also, issues relating to lameness and colic are highly concerning to ND horse owners. Future education and research efforts should be focused on the value of routine veterinary care as well as issues relating to lameness and colic.

Introduction

A study released by the American Horse Council in 2005 reported that there are 9.2 million horses in the United States and 4.6 million Americans directly involved in the industry as horse owners, service providers, employees and volunteers; with many more indirectly involved as spectators. The report also stated that there are horses in every state, and the horse business is a highly diverse industry, with many activities in all regions of the country (American Horse Council, 2005). Coupled with the diverse industry and the many people involved there are also concerns related to horse health and welfare. Therefore, information regarding horse owner concerns relative to horse health is important for focusing future research and public education efforts. Estimates of the economic cost can be helpful in prioritizing research and management (USDA, 2001).

Information on a national level regarding common health problems that occur in equine operations has been recorded. The USDA (2005) developed a study to provide the nation's equine population with equine health and management education. They reported that the top three conditions affecting the most horses were 1) injury/wounds/trauma (25.7% of operations); 2) lameness, leg, or hoof problems (15.5% of operations); and 3) colic (10.4% of operations). Besides old age, these three conditions were also reported by the USDA as causing the highest cause of death in horses. Information on the national level is vital for overall horse health knowledge, but information on a state level can also be useful for research and education efforts to targeted audiences.

Data regarding horse owners concerns in the state of North Dakota is not completely known, but necessary for proper horse care and management. Therefore, the objective of this study was to gather information from North Dakota horse owners regarding health concerns and expenses for their horses.

Materials and Methods

A fifteen-question, on-line survey was developed using commercially available survey software (Qualtrics, 2015). All survey procedures were approved through the North Dakota State University Institutional Review Board. A complete listing of survey questions is contained in Appendix A. The target participants for this study were horse owning, North Dakota residents 18 years of age or older. Participants were contacted through county extension offices by email as well as social media. The survey was available online for a two-week period. At the completion of the two-week period, responses were analyzed using the Qualtrics survey software.

Results and Discussion

A total of 152 responses were collected. By nature of the survey design, participants that completed the survey were all horse owning, North Dakota residents that were 18 years of age or older.

Horse Ownership

This section of the survey collected information on horse ownership, focusing specifically on how long survey participants have been involved the industry as well as asking them to identify in which ways they are involved.

How long have you been involved in the horse industry?

When asked how long participants have been involved in the horse industry, 84% of participants responded with 11 years or more (Table 1). Only one participant reported being involved in the industry for less than a year. It has been written that before someone becomes an expert in a field, many years of practical training are required (Boshuizen, 2004). In surgical research it is recommended that new surgeons be placed in high-volume hospitals to allow them to become experts with the increased hands-on experience (Hogan and Winter, 2008). Therefore, this allows us to determine in the current study that with the majority of participants being involved in the equine industry for 11 year or more, they have increased knowledge and more practical, hands-on training.

Table 2.1. Total amount of time that North Dakota horse owners have been involved in the horse industry

Item	Response		%
< 1 year		1	1%
1-5 year(s)		11	7%
6-10 years		12	8%
11 years or more		128	84%
Total		152	100%

How many horses do you own?

Survey participants were asked to identify the number of horses in which they own. Participant responses varied widely, ranging from one horse to participants having 11 or more horses (Table 2). More specifically, 67% of survey participants owned six horses or less and 34% owned seven or more horses.

In the USDA national study (2005), horse operations were split into categories, where a small operation was considered to have 5-9 horses, a medium operation had 10-19 horses, and a large operation had 20 or more horses. The number of small operations was much greater the number of large operations, with small operations accounting for 66% of all operations and large operations only accounting for 8% of all operations. They found that as the operation size increased, the percent of horses for personal use decreased.

With the range in number of horses owned per survey participant in the current study, it indicates that there may be a some variety in how participants care and manage their horses (large operation vs. small operation), which we anticipate might have contributed to diversity in management perspectives when participants continued taking the current survey; although, in the current study there is lack of a large operation population as described by the national study. When compared to the national study, it would suggest that in the current study the majority of horses are used for personal use due to the majority stating they owned 10 or fewer horses (80%). This would categorize them in the small to medium operation category of the national study, where there is a higher percent of personal use for their horses. This correlates well with the finding in the current study that 80% of respondents use their horse(s) for pleasure/hobby purposes (Table 4).

Table 2.2. Total number of horses owned per North Dakota horse owner

Item	Response		%
0 horses		0	0%
1-3 horses		53	35%
4-6 horses		48	32%
7-10 horses		21	14%
11 or more horses		30	20%
Total		152	100%

If you care for outside horses, horses other than your own, please indicate the total number of horses normally in your care.

Participants were asked to indicate how many horses they manage outside of their own. The majority of participants in this study (66%) do not take care of horses owned by others (Table 3), which aligns with the USDA national study (2005) stating that the smaller operations were associated with personal horse use. Those that do care for horses other than their own responded with a variety of total number of horses in their care. Sixteen percent indicated they care for 1-3 outside horses, 5% indicated that they care for 4-6 outside horses, 3% indicated that they care for 7-10 outside horses, and 9% indicated that they care for 11 or more outside horses. Thus, this suggests that the current survey was mainly completed by owners focused primarily on the care of their own horses instead of commercial (boarding) situations. This is further supported by the data collected regarding horse owner's industry involvement, which is presented in the next section.

Table 2.3. Total number of horses, other than own, normally in the care of a North Dakota horse owner

Item	Response		%
I don't take care of horses owned by others		100	66%
1-3 horses		24	16%
4-6 horses		8	5%
7-10 horses		5	3%
11 or more horses		14	9%
Total		151	100%

What is your involvement in the horse industry? Please select all that apply.

In addition to identifying how many horses participants own and care for, they were also asked to identify in which way they use those horses. The majority (80%) of participants indicated that they own horses for hobby/pleasure riding purposes (Table 4). Although this was the majority, there were a wide range of other industry involvement represented, including showing (45%), working/ranch (37%), rodeo (34%), breeding (28%), and lessons/training (24%) being other primary uses. The small percent that responded with "other" identified their involvement in the industry to be 4H programs, judging, mounted shooting, university instructor, horse rescue, and equine massage.

These findings are consistent with the USDA national study (2005) where pleasure was recorded as the primary use (45.7% of operations). In both the USDA and current study, participants are involved in ways that require their horses to be healthy and able to do work as a performance animal. Therefore, this further supports the premise that understanding concerns of high priority to health and wellness is crucial to keeping horses working as performance animals.

Table 2.4. North Dakota horse owners' involvement in the horse industry

Item	Response	%
Hobby/Pleasure	121	80%
Breeding	42	28%
Show	69	45%
Rodeo	51	34%
Racing	4	3%
Barn manager	12	8%
Lessons/Training	36	24%
Working (ranch horse)	56	37%
Farrier	10	7%
Veterinarian	3	2%
Other	8	5%

Horse Care Costs

To collect information on where economic concerns relating to horse health are focused in the equine industry, this section of the survey questioned how often veterinarians and farriers were utilized by owners in the state of North Dakota, along with the associated cost of that use.

On average, how often do you use a veterinarian?

When asked how often participants use a veterinarian, the majority (69%) of owners reported using a veterinarian two times per year or less (Table 5). Twenty-six percent of these owners reported using veterinary services only for emergencies, with 7% of these owners using a veterinarian never or rarely (Table 5). The rare use of a veterinarian in the state of North Dakota is concerning. In the USDA national study (2005), 74% of horse operations reported using veterinarian services at least once per year. This national study did not specify how many times per year a veterinarian was used, but there were still 26% of horse owners not using veterinarian services nationally.

Table 2.5. Average use of a veterinarian for North Dakota horse owners

Item	Response		%
Never to rarely		10	7%
Only when an emergency		40	26%
1-2 times per year		55	36%
3-6 times per year		43	28%
Monthly		4	3%
Total		152	100%

If you answered "only when in an emergency" or "never to rarely" for the previous question, why do you choose not to use a veterinarian?

From the 33% of owners that previously reported using veterinary services only for emergencies or never to rarely (Table 5), 60% of these owners reported that they do the work themselves (Table 6). The participants that selected "other" gave reasons such as having accident free horses. An AVMA national study (2012) specifically looking at dog and cat owners found that in 2011, 45% of cat owners did not use a veterinarian during that year, and among dog owners, 19% did not use a veterinarian. The primary reason given by pet owners was that their pets were not sick or injured, similar to the reasons given by horse owners in the current study.

Although this gives an explanation to why some North Dakota horse owners may not regularly use a veterinarian, it is concerning that a large percentage of horse owners are doing the work himself or herself instead of strictly using a trained and experienced professional. This survey question allowed participants to select only one answer, and thus, there may be multiple issues contributing to the lack of regular veterinary use. Geographic location and the average use of a veterinarian for North Dakota horse owners could be correlated, as the availability of a veterinarian in rural areas may create problems. According to the USA Today, the demand for rural veterinarians has remained strong (Cauchon, 2008). Furthermore, from a sample population of United States veterinarians who previously worked in rural practices, it was found that issues such as emergency calls, time off, salary, and practice atmosphere influence a shortage of veterinarians in rural practice (Villarroel et al., 2010). If veterinary services are unavailable as well as veterinary care being too expensive, the best choice for horse owners may be to do the work themselves. Further clarification of this question in the future would allow for better understanding of what prevents owners from scheduling regular veterinary visits.

Table 2.6. North Dakota horse owner's reason for choosing not to use a veterinarian

Item	Response		%
Too expensive		8	13%
Not one available in my area		4	7%
I do the work myself		36	60%
Other		12	20%
Total		60	100%

On average, how many times do you use a farrier?

Participants were also asked to indicate how often they use a farrier for their horses. Farrier use was more frequent than veterinary use with 45% of horse owners using a farrier every 4-8 weeks and only 13% never to rarely using a farrier's services (Table 7). This is consistent with the USDA national study (2005), where regardless of operation size a farrier was usually used. Normal farrier use is considered to be every 4-8 weeks. Therefore, these results suggest there is less need for education on topics of hoof care and farrier use and the focus for horse health care should be targeted on the importance of regular veterinary exams. However, the high use of farrier services could indicate that there are concerns related to hoof care that require attention.

Table 2.7. Average use of a farrier for North Dakota horse owners

Item	Response		%
Never to rarely		20	13%
1-3 times a year		24	16%
4-5 times a year		40	26%
Every 4-8 weeks		68	45%
Total		152	100%

If you answered "never to rarely" for the previous question, why do you choose not to use a farrier?

Those that answered "never to rarely" for farrier use reported that they do the work themselves (Table 8). The participants that selected "other" gave reasons such as the lack of farrier service in their area due to the farriers being busy, and having problems getting a farrier to come on a regular basis.

Even though the percent of horse owners in North Dakota that do not use a farrier is low, the concern that there is a lack of farrier service in some areas of the state should still be addressed. The current survey did not collect location information, so future data collection could investigate locations within the state that are lacking in farrier services.

Table 2.8. North Dakota horse owner's reasons for choosing not to use a farrier

Item	Response		%
Too expensive		2	6%
Not one available in my area		4	11%
I do the work myself		20	57%
Other		9	26%
Total		35	100%

Health Concerns Facing the Horse Industry

There are a variety of health challenges in the equine industry and the ability to narrow down those challenges to focus on the top concerns affecting the majority of horse owners is important. This section of the survey focused on gaining a better understanding of what challenges are of the highest concern and expense for North Dakota horse owners.

What horse health issues concern you? Rank the options from top (highest concern) to bottom (lowest concern).

When asked to rank which health issues caused the most concern, 35% of survey participants ranked lameness as the top concern, followed by colic (21%) (Table 9). The USDA national study (2005) reported that lameness and colic were the most common health conditions leading to cause of death in equine operations, outside of injury/wounds/trauma and old age. This correlates with the information recorded in the current study. Injury/wounds/trauma and old age were not available selections for the ND survey participants; although those in the current study that selected "other" as a concern mentioned flies/mosquitoes, dental, and genetic issues as concerns for their horse's health. A survey by the National Animal Health Monitoring Service

(USDA, 1998) identified that horse trainers ranked leg problems as a top priority (30.8%). The farm/ranch category also had a top priority for leg problems (38.1%) followed by digestive problems (36.5%), while those in the showing category had an equal priority for leg and digestive problems. In the ND survey, 161 respondents were involved in training, farm/ranch, and showing, and similar to the NAHMS results, lameness and colic (digestive problem) were a top concern. In contrast, those in the racing category of the NAHMS survey had a highest concern for respiratory (32.8%) issues followed by leg problems (27.2%). Although respiratory concerns were an option for the ND survey, the number of racing industry representatives was small (3%) and therefore, it is not surprising that respiratory disease was ranked lower on the list of concerns. In preparation for the USDA (1998) study, a NAHMS Equine Needs Assessment Survey asked participants to rank their priority of the horse's body-system problems for in-depth study focus. The top body-system problems stated by respondents were leg/hoof problems (conditions leading to lameness), digestive problems (colic or diarrhea), and respiratory problems (strangles, pneumonia, reactive airway disease). The results from the ND survey show the similar concerns amongst horse owners in North Dakota.

Table 2.9. Horse health concerns of North Dakota horse owners

Item	Priority							Total Responses
	1	2	3	4	5	6	7	
Lameness issues	34.69%	29.93%	19.73%	10.88%	4.08%	0.00%	0.68%	147
Colic	21.09%	15.65%	17.01%	17.01%	22.45%	6.80%	0.00%	147
Nutrition issues	14.29%	13.61%	19.05%	18.37%	23.81%	10.20%	0.68%	147
Respiratory problems	12.93%	23.13%	20.41%	21.77%	17.01%	4.76%	0.00%	147
Parasites	10.20%	16.33%	17.69%	23.81%	21.77%	9.52%	0.68%	147
Reproductive problems	4.76%	1.36%	4.76%	6.80%	10.88%	64.63%	6.80%	147
Other	2.04%	0.00%	1.36%	1.36%	0.00%	4.08%	91.16%	147

What is the average cost for veterinary expenses that you spend on each horse per year?

Survey participants were asked to estimate their cost for veterinary expenses for each horse per year. Data from this question indicated that 82% of horse owners in North Dakota spend an average of $500 or less on veterinary expenses per horse per year (Table 10). It has been estimated that the cost of maintaining a horse per year is $1,825, which does not include veterinary or farrier costs (Lenz, 2008). This information is also known in some states, where in Indiana is it reported that the expected costs per horse per year for basic health care is between $788.45-$1,460.45 (Conley and Koontz Equine Hospital, 2013). Information for dog and cat owners from ASPCA (2012) has shown proper care for your dog (depending on size) or cat including expected veterinary expenses can cost anywhere from $1,035-$1,843.

On average, this data suggests that horse owners are not spending much money per year on veterinary services. This supports the previous data showing 69% of owners use veterinary services less than twice a year. It would be beneficial for horse owners to have further information on the national average of expenses per horse per year separated by everyday care versus average veterinary expense. Further clarification on what the expected costs are for veterinary expenses on a state basis, specifically in North Dakota, would account for potential state differences.

Table 2.10. Average cost for veterinary expenses that North Dakota horse owners spend on each horse per year

Item	Response		%
$0-100		47	31%
$101-500		78	51%
$501-1000		20	13%
$1001 or more		7	5%
Total		152	100%

Which of these health issues represent the highest veterinary expense for you as a horse owner?

Outside of routine veterinary expenses (vaccination, de-worming, dental, etc.), lameness issues were ranked as the top (37%) veterinary expense (Table 11). Colic was ranked behind lameness with 12% of participants ranking it for their top veterinary expense (Table 11). The rest of the horse health issues presented in the survey had low percentages of veterinary expenses for North Dakota horse owners.

Analysis from the USDA survey (1998) reported that the annual lameness incidence was 8.5-13.7 events/100 horses with a cost of vet services equaling $432 per event. When adjusted for inflation for 2015, the cost of vet services for lameness would equal $627 per event (Bureau of Labor Statistics). For colic, the annual incident was 4.2 events/100 horses with a cost of vet services equaling $160 per event, with a total of $232 when adjusted for inflation in the current year (Bureau of Labor Statistics). Although the current study did not break out the cost spent by health concern there is a strong economic cost associated with these two conditions.

Although not reported in the current ND survey, the USDA study (1998) reported a 110-day loss of use per lameness event. This could be a contributing factor to why lameness represents the highest concern and veterinary expense for horse owners. The associated days lost of use per event for colic was lower than it was for lameness with a total loss of 2.4 days per colic event.

Table 2.11. Horse health issue that represents the highest veterinary expense for North Dakota horse owners

Item	Response	%
Respiratory problems	12	8%
Lameness issues	55	37%
Colic	18	12%
Parasites	15	10%
Reproductive problems	12	8%
Nutrition issues	9	6%
Other	28	19%
Total	149	100%

Implications

This survey of North Dakota horse owners presents similar results to previous national surveys and helps confirm that welfare and economic concerns for horse owners are consistently found in lameness and colic. Although the majority of participants in this study reported yearly veterinary expense below $500, there were an alarming number of owners who do not use regular veterinary services and do the work themselves. Future education and research efforts should be focused on the value of routine veterinary care as well as issues relating to lameness and colic. However, there are some limitations that come with this survey, which include lack of information in some subjects; geographic location of participants, the type of veterinary work North Dakota horse owners are doing themselves, and in what way North Dakota horse owners spend their money at veterinary clinics. In the future, asking additional questions could strengthen this survey.

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CHAPTER 3. ULTRASOUND PROCEDURE FOR MEASURING THE DIGITAL CUSHION IN HORSES

Introduction

Ultrasonography is a safe, non-invasive, and also relatively inexpensive technique to visualize soft tissue structures. With the ultrasound's ability to depict soft tissue interfaces, it allows for determination of size, shape, position, and tissue texture of internal structures (Rantanen, 1982). The technology of ultrasound can also detect injuries before reaching the state of debilitation (Genovese et al., 1986). It has been specifically used in the distal limb for identification of soft tissues in the fetlock of a standing horse (Denoix et al., 1996), as well as for other limb joints and muscles (Smith and Smith, 2008). Most importantly it has proved to be important in diagnosis of distal limb lameness in the horse (Crisan et al., 2010).

There has been much improvement in the quality of images from ultrasound (Smith and Smith, 2008), and portable machines allow for practicality in field situations (Denoix et al., 1996; Smith and Smith, 2008). For the best image resolution in regions where the soft tissues are only a few centimeters thick, such as in the limb, a high frequency (5.0-7.5 MHz) is needed for visualization of soft tissues (Rantanen, 1982). For the best resolution in regions where the soft tissues is only a few centimeters thick, such as in the limb, a high frequency (5.0-7.5 MHz) is needed for visualization of soft tissues (Rantanen, 1982). This resolution will allow separation of soft issue interfaces to be seen (Rantanen, 1982). A 5 MHz probe will show images of the internal structures, however the use of a 7.5 MHz probe allows better imaging through better resolution and near-field imaging ability (Denoix et al., 1996).

Although the ultrasound has been used widely and proves to be an excellent means to visualize soft tissue structures, there are some difficulties when looking at internal hoof structures. The equine hoof capsule is a tough, keratin barrier that can pose a challenge (Busoni and Denoix, 2001). Therefore, if a proper scanning technique is not performed it can become difficult to obtain a good quality and reliable image from ultrasound (Denoix et al., 1996). Obtaining ultrasound images of the equine distal limb has been described through ultrasonographic imaging of the palmarodistal aspect and also through a transcuneal approach (Bolen et al., 2007, Denoix et al., 1996; Busoni and Denoix, 2001; Grewal et al., 2004; Crisan et al., 2010). Both of these techniques require proper preparation. When obtaining images of the palmarodistal aspect, the probe should be placed in the distal phalangeal area and between the heel bulbs (Bolen et al., 2007). Bolen et al. (2007) explains that because the palmar surface of the distal aspect is not flat, good contact between the probe and the skin may be difficult. Clipping of the hair and washing the skin with warm water is necessary to improve sound transmission, and high pressure on the probe is required (Bolen et al., 2007).

To obtain good quality ultrasonographic images for visualization of the internal structures of the hoof using a transcuneal approach, proper preparation is essential (Denoix et al., 1996; Busoni and Denoix, 2001) as the shape, size, and moisture content of the frog can create differences and challenges in image quality (Busoni and Denoix, 2001). It is necessary for the sole and superficial horn of the frog to be trimmed to remove any loose material and pared smooth to expose softer tissue (Kidd et al., 2014; Busoni and Denoix, 2001; Olivier-Carstens, 2004). In some studies, the foot can be placed in warm water for 10-15 minutes to allow for further softening of the frog (Busoni and Denoix, 2001; Busoni et al., 2006), and in a study done by Olivier-Carstens (2004) soaking the sole in water improved the image quality further by rehydration of the solar surface. Scanning can then be performed on the solar surface of the hoof toward the apex of the frog with the use of transmission gel (Crisan et al., 2010; Busoni and Denoix, 2001).

The use of cadaver limbs has been used to compare ultrasonographic changes with macroscopic findings in horses. A study by Busoni et al. (2006) looked at ultrasound images of the podotrochlear apparatus. This region was examined through the frog in equine cadaver limbs with known abnormalities of the podotrochlear apparatus. Authors stated that the use of ultrasound was a viable technique for identification of an abnormal podotrochlear apparatus, but there were some limitations on detecting tendon lesions. Even with some limitations, it was still concluded that the use of the ultrasound could be useful as a basis for interpretation of future studies (Busoni et al., 2006). However, in this study the podotrochlear apparatus was the only region of interest, and no measurements of other structures were obtained.

Some internal structures of the hoof, including laminar attachments, the distal phalanx, and the distal sesamoid bone, have been described well (Busoni and Denoix, 2001; Busoni et al., 2006; Crisan et al., 2010; Olivier-Carstens, 2004); whereas other structures, such as the digital cushion, have received less attention. The composition of the digital cushion has been briefly described through the use of ultrasound (Busoni and Denoix 2001), but specific measurements regarding its size in relation to other variables have not been reported. An ultrasound scanning technique using the transcuneal approach, described by Crisan et al. (2010), Busoni and Denoix (2001), and Chope (2007), was used to visualize the internal portions of the hoof, including the digital cushion. The digital cushion is positioned between the deep digital flexor tendon and frog and has a homogenous pattern, along with being the most superficial structure on the ultrasound images (Busoni and Denoix, 2001). Although descriptions and measurements of the digital cushion have been reported, no validated procedure has been described.

A validated ultrasound procedure to obtain digital cushion measurements is needed to allow repeatable studies of the digital cushion in horses. Therefore, the objective of this study was to develop and validate a standard method for ultrasound imaging of the digital cushion, and it was hypothesized that a technique for imaging and measuring the digital cushion could be validated using cadaver limbs.

Material and Methods

The ultrasound procedure was validated using 12 equine cadaver limbs obtained from the North Dakota State University Veterinary Diagnostic Laboratory.

Ultrasound Measurement

Measurements were taken from cadaver hooves using a transcuneal approach. The frog was prepared by paring any superficial horn until soft, spongy tissue was present (Kidd et al., 2014; Busoni and Denoix, 2001, Olivier-Carstens, 2004). Scanning was performed through the frog (Crisan et al., 2010; Busoni and Denoix, 2001) using an Aloka 3500 ultrasound and 7.5 MHz microconvex probe. The digital cushion could be visualized lying dorsal to the frog and proximal to the deep digital flexor tendon and measurements of thickness (cm) obtained (Figure 1).

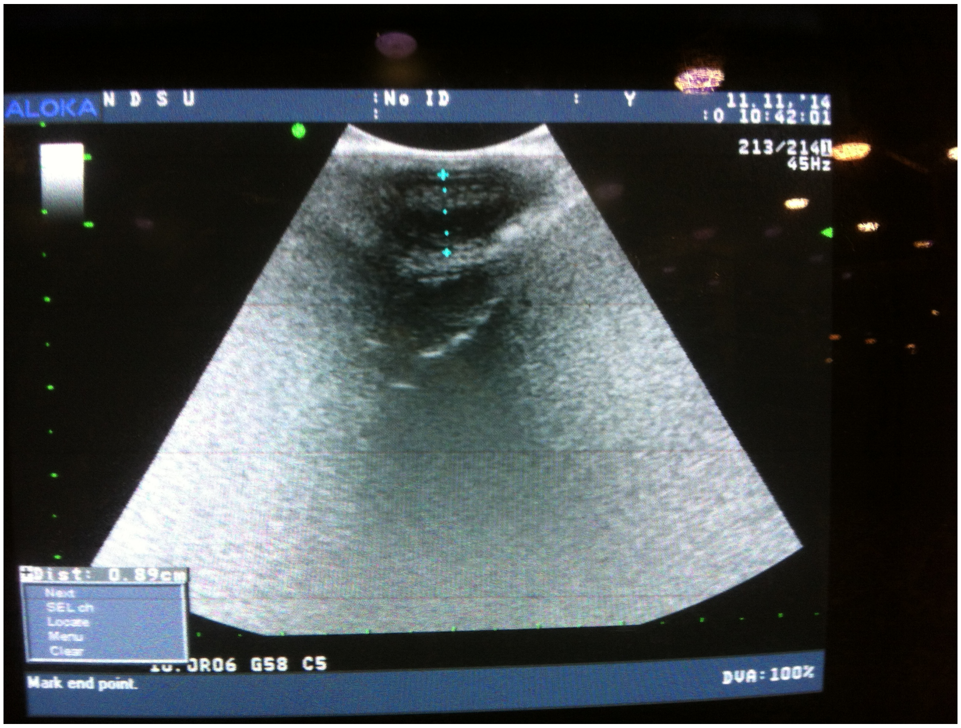

Figure 3.1. Ultrasound image of the equine digital cushion.

Actual Measurement

After ultrasound measurements were recorded, hooves were split using a table saw (Hobart Model 5212 Meat Saw) on a sagittal plane (Figure 2). By gross examination, digital cushion thickness (cm) was measured through the use of a digital caliper just proximal to the insertion of the deep digital flexor tendon (approximate point where ultrasound measurement was obtained).

Figure 3.2. Image showing sagittal section of the equine distal limb. The dotted-line represents the location where actual measurement of the digital cushion thickness was taken.

Statistical Analysis

To analyze the data, the PROC CORR procedure of SAS was used and a p-value ≤ 0.05 was considered significant.

Results

Correlation of ultrasound measurements to actual measurements showed a strong correlation between the two ($r = 0.90$; $p < 0.0001$) (Figure 3).

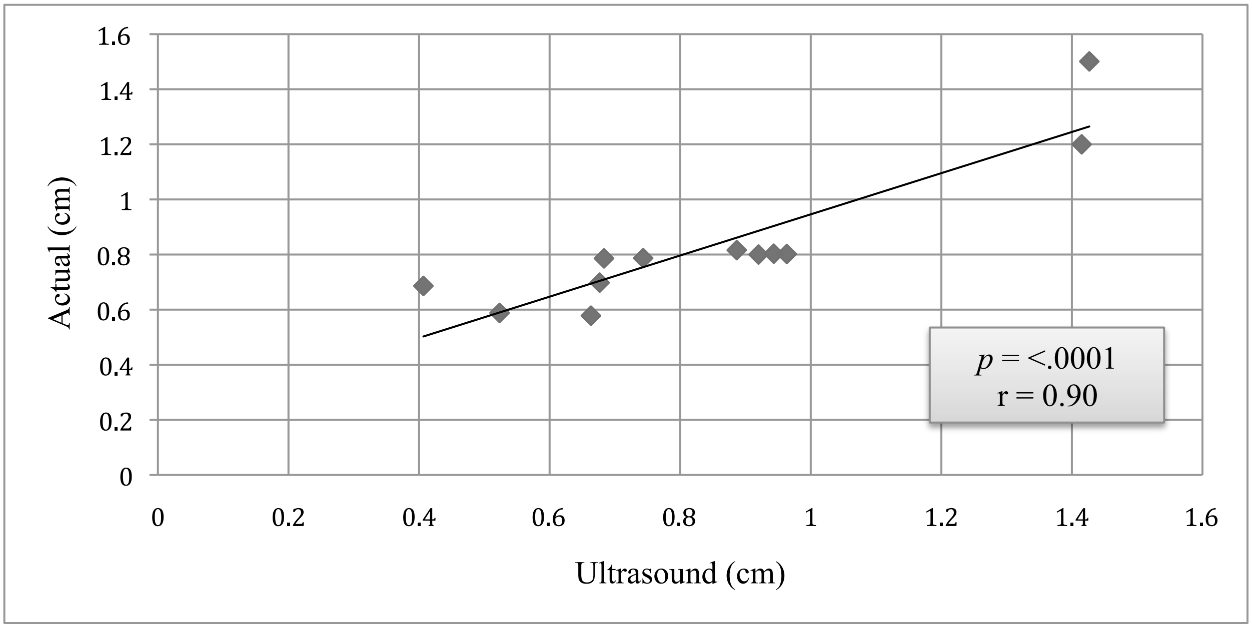

Figure 3.3. Correlation of ultrasound measurement to actual measurement in the digital cushion of equine cadaver feet.

Discussion

The current study was done to evaluate the usefulness of ultrasound for visualizing and measuring the digital cushion in horses using a transcuneal approach. Previous research has reported ultrasound images of the digital cushion and other internal distal limb structures (Denoix et al., 1996; Busoni et al., 2006; Smith and Smith, 2008), but no validated procedure for obtaining measurements was reported.

The current study found a strong correlation of the described ultrasound procedure to the actual measurement of the digital cushion, therefore providing a standardized technique for obtaining measurements of the digital cushion through the use of ultrasound. The procedure provides a cost-effective, non-invasive, and portable method for easy access to digital cushion measurements. It should be noted though that cadaver limbs with a thick or dry frog were more difficult to ultrasound, and the image was less clear. More extensive paring of the superficial horn was required before the image was well visualized. Those limbs with a thinner frog were more easily imaged.

With a standardized technique, further research regarding the digital cushion can be performed. Specifically, this technique can be used to examine potential correlations of digital cushion thickness to other variables such as age, breed, sex, and body condition score. Histological composition of the digital cushion has been recorded, and differences have been reported between age and breed (Bowker et al., 1998). Although differences in composition of the digital cushion do not necessarily warrant a change in digital cushion thickness, this comparison has not been examined. However, there is the potential for changes to occur in the digital cushion with changing composition and therefore further investigation is needed.

Furthermore, the digital cushion has been described as a shock absorber in energy dissipation in the equine foot (Dyhre-Poulsen et al., 1994). Changes in pressure and absorption of energy within the foot could affect strength of the foot as well (Bowker et al., 1998). Strength of the foot could affect the overall health of the foot, and predispose a horse to a lameness condition. Ultimately any correlations of digital cushion thickness to lameness conditions would be beneficial to veterinarians and horse owners, as lameness is a top research priority (AEEP, 2009) as well as the most important medical problem in horses (Anon, 2002).

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CHAPTER 4. A PRELIMINARY STUDY CHARACTERIZING THE DIGITAL CUSHION IN STOCK-TYPE HORSES

Abstract

The digital cushion is important for the dissipation of force as the foot contacts the ground. If there is inefficient energy dissipation in the foot, potential exists for development of lameness conditions. Research in cattle has shown a correlation between thin digital cushions and lameness; however, limited research on the digital cushion is available in horses. Therefore, the objectives of this preliminary study were to 1) establish baseline values in mature, stock type horses with adequate BCS and 2) compare the baseline values to values in shod horses. To meet the first objective, 25 mature, stock-type horses of varying age, height, and weight were used to establish baseline values for the digital cushion. Digital cushion thickness of the left fore and left hind foot was determined using ultrasound. Data were analyzed using the PROC MEANS procedure of SAS. Mean values for age, weight, and BCS were 10.5 years, 477.2 kg, and 5.5, respectively. Mean values for the digital cushion of the left fore and left hind were 0.96 and 1.04 cm, respectively. To meet the second objective, the digital cushions of six shod horses (front feet only) were imaged and thickness recorded to allow comparison against the previously collected baseline data. Data were analyzed using the PROC GLM procedure of SAS. Data indicated that there was no significant difference ($p = 0.13$) between the digital cushion thickness of the left front foot in shod vs. non-shod horses. Overall, baseline values for digital cushion thickness of front and hind feet were established for mature, stock type horses. Initial comparison of digital cushion thickness in shod vs non-shod horses suggest that there are no differences; however, it should be noted that this was a preliminary study and the sample size extremely small. Further

verification of these preliminary data is needed before comparisons between different variables that may affect thickness of the digital cushion are made.

Introduction

Conditions such as laminitis, navicular syndrome, and sole abscesses have been reported as the most common lameness conditions (USDA, 1998). These conditions all occur in the distal portion of a horse's limb, therefore it can be concluded that the majority of lameness occurs here. It has also been reported that since the horse carries more weight on their forelimbs, the concussion in the distal portion of the forelimbs is greater (Back et al., 1995). Some of the structures in the distal limb include laminar attachments, the distal phalanx (P3), the distal sesamoid bone (navicular bone), the deep digital flexor tendon, and the digital cushion. Biomechanical stress on these internal structures of the hoof can cause chronic hoof problems leading to lameness (Bowker, 2003).

Specifically looking at the digital cushion, a large structure in the distal limb, there has been limited research regarding its role in lameness conditions. Research has shown that the digital cushion plays a role in energy dissipation in the hoof as it is loaded. Dhyre-Poulsen et al. (1994) reported negative pressure in the digital cushion through the use of pressure transducers. Inefficient energy dissipation may increase biomechanical stress and gradually produce lameness conditions. Due to the findings by Dhyre-Poulsen et al. (1994), Bowker (1997) proposed a new hemodynamic flow hypothesis, which suggests that this negative pressure is created by the outward movement of the hoof cartilage while simultaneously the impact energies force venous blood throughout the lateral cartilages, providing further negative pressure as a vacuum action draws blood up from the solar surface of the hoof. He suggests that disturbances in this mechanism could produce greater energies to other portions of the distal limb, potentially resulting in lameness.

Clinical signs of lameness are associated with weight bearing; therefore, when looking at energy dissipation in the hoof the focus should be during the stance phase (Stashak, 1987). A study by Reopstorff et al. (1999) found that most differences in concussion-dampening mechanisms of the distal limb were seen in the initial part of this phase. Furthermore, Dhyre-Poulsen et al. (1994) demonstrated changes in digital cushion pressure in shod and unshod horses during the stance phase. Pressure was decreased in both shod and unshod horses, indicating expansion of volume inside the hoof in both cases; however, in the shod horse, there was a delay in decreased pressure along with a steeper pressure decrease potentially due to restriction of the hoof wall from the shoe (Dhyre-Poulsen et al., 1994). This low pressure also lasted a shorter amount of time in the shod horse. The lengthened delay in pressure in the shod horses could indicate that the shoe impedes hoof expansion, and without shoes the hoof wall can move freely (Dyhre-Poulsen et al., 1994). It has been reported in other research that the attachment of a shoe reduces expansion of the hoof capsule but does not affect the expansion of the heels (Colles, 1989).

In contrast to the horse, the dairy cattle digital cushion has been researched more extensively. Specifically, research has shown that thin digital cushions were a strong predictor of lameness and a well-developed digital cushion is necessary to cushion and prevent contusions that lead to lameness (Bicalho et al., 2009). It has also been reported in dairy cattle that sole temperature decreased as digital cushion thickness increased, suggesting that inflammation and a thin digital cushion are associated (Oikonomou et al., 2014). Inflammation is a source of pain, and dairy cattle are found to be the most productive when they are pain free (Gard et al., 2015).

However, similar studies examining correlations of the digital cushion to pain and the role of the digital cushion in lameness in the horse have not been done.

Measurements of the digital cushion have been described through the use of ultrasound using the transcuneal approach (Crisan et al., 2010; Kidd et al., 2014; Busconi and Denoix, 2001, Grewal et al., 2004); however, standard values have not been reported. Therefore, the objective of this study was to obtain preliminary baseline measurements in sound horses, where it was hypothesized that baseline values would indicate thicker digital cushions in forelimbs compared to hind due to increased weight bearing. After baseline values were established, the second objective was to compare the baseline values to values in shod horses. It was hypothesized that shod horses would have a thinner digital cushion thickness due to restriction from the shoe on hoof wall expansion, potentially changing energy dissipation through the hoof and digital cushion.

Material and Methods

All animal procedures were approved by the North Dakota State University Institutional Animal Care and Use Committee.

Baseline Values

To obtain baseline values of digital cushion thickness, 25 mature, stock-type horses from North Dakota State University were used. These horses were of varying age, height, and body weight. Height measurements were obtained using an aluminum measuring stick. Body weight was obtained using the weight calculation of heart girth x heart girth x length divided by 330 on all horses. Body condition score (BCS) was determined using a 1-9 scoring system (Henneke et al., 1983). Height and body weight were obtained by the same individual, while body condition score was obtained from the average of two trained observer scores. All horses were sound at the time of the study and had no known history of chronic lameness conditions.

Ultrasound images were obtained from the left fore and hind foot using the previously described ultrasound technique (Chapter 3). The ultrasound measurements were all obtained by the same ultrasound as well as by the same individual, under same conditions. With the limb flexed, the superficial frog was pared and scanning performed using a transcuneal approach (Busconi and Denoix, 2001; Grewal et al., 2004).

Shod vs. Unshod

For comparison of shod horses vs. unshod horses, six mature, stock-type horses from North Dakota State University were used, all fitted with metal shoes. These measurements for shod horses were compared to the previously found baseline values (unshod). Horses in the shod group were accustomed to wearing shoes and had been routinely shod for a minimum of eight weeks prior to data collection. The majority of the shod horses had front shoes only; therefore ultrasound measurements were obtained from only the left fore.

Statistical Analysis

The data was analyzed in SAS using the PROC MEANS and PROC GLM procedure with a least square means statement. Significance was set at $p \leq 0.05$.

Results and Discussion

Baseline Values

The mean value for age was 10.5 years, mean value for weight was 477.2 kg, and mean value for body condition score was 5.5 (Table 1).

Table 4.1. Mean values for age, body weight, and body condition score for 25 mature, stock-type horses

Variable	Mean	Std Err
Age (yr)	10.5	0.88
Weight (kg)	477.2	16.54
BCS (1-9)	5.5	0.13

Horses in the current study were of optimal BCS (Henneke et al., 1983), and were housed and fed similarly. For most light riding horses, BCS is optimal at a score of 5 to 6 (AAEP, 2005). A study done in dairy cattle reported that body condition score is positively correlated with digital cushion thickness with thinner cattle having a thinner digital cushion. Additionally, it was found that those cattle with a thinner digital cushion were more prone to lameness conditions (Bicalho et al., 2009). Therefore, only sound horses with an optimal BCS were utilized in the current study.

Composition of the digital cushion in horses has also been reported to vary across and within breeds (Bowker et al., 1998), where stock-type horses have digital cushions composed of fibrocartilaginous tissue with adipose and elastic tissue. It has been described that some light-type horses (Arabians, Morgans, etc.) have digital cushions composed of fibro-elastic or fibrocartilaginous and elastic tissues rather than adipose and elastic tissues. Therefore, to minimize variation, horses in the current study were all of similar breed. Horses from the current study were also mature horses. Digital cushion composition normally progresses from fat, elastic, and isolated collagen bundles to a stronger fibrocartilage with age. This change in composition has been reported to occur around 4-5 years of age (Bowker, 2003); therefore, mature horses were used as digital cushion composition is expected to be unchanged at this age.

When comparing the left fore to the left hind digital cushion, the mean left fore measured 0.96 cm and the mean left hind measured 1.04 cm. There was no difference between fore and hind digital cushion thickness ($p = 0.17$; Figure 1).

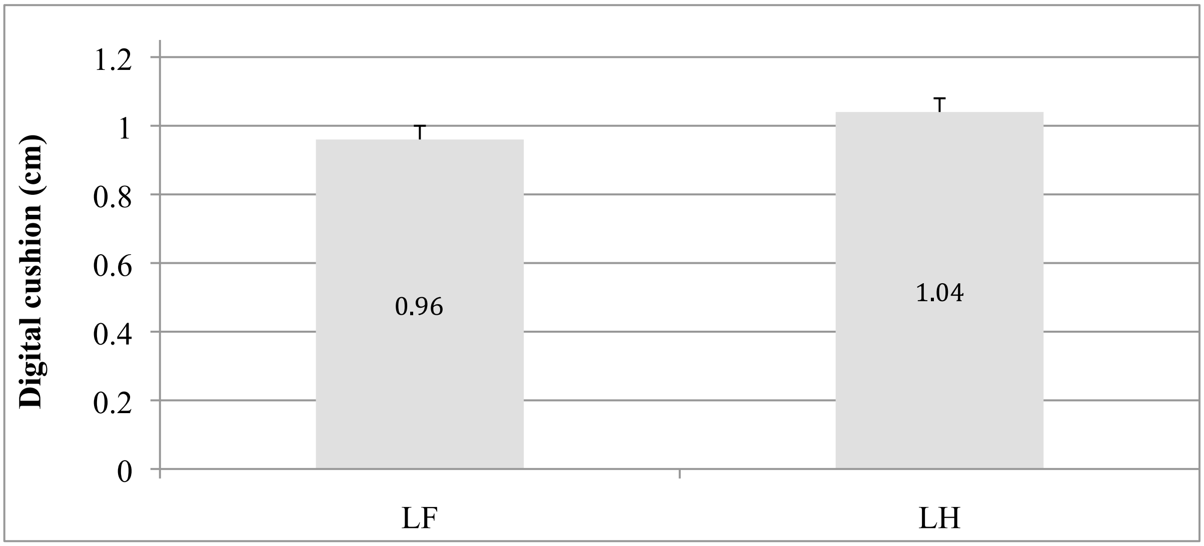

Figure 4.1. Digital cushion thickness for left fore and left hind as measured by ultrasound.

With the horse's forelimb supporting 60-65% of the weight (Baxter, 2011), digital cushion thickness was hypothesized to be greater in the fore foot as the foot gradually changes and adapts to the forces applied to it (Bowker et al., 1998). Additionally, previous research has demonstrated that hind foot digital cushions differed in composition when compared to the fore foot, where it was composed primarily of adipose and elastic tissue (Bowker et al., 1998). Composition change does not guarantee a change in digital cushion thickness and this altered composition may explain how the horse adapts to increased weight distribution on the forelimbs. Composition in the current study was not examined, but supports the hypothesis that changes in digital cushion composition allow for adaptation to weight bearing as opposed to changes in thickness. As this was a preliminary study, further investigation of the differences between fore and hind digital cushions are needed before making definitive conclusions.

Shod vs. Unshod

When comparing digital cushions of shod vs. unshod horses, unshod horses had a mean digital cushion thickness of 0.99 cm while shod horses had a mean value of 0.87 cm (Figure 2). There was no difference between the two groups ($p = 0.13$; Figure 2). Although no difference was seen between the digital cushions in shod and unshod horses, it is important to note that the sample size for this comparison is very small (n=6). A larger sample size may move the values towards significance, as previous research suggests that there are changes in pressure in the digital cushion when a horse is shod (Dhyre-Poulsen et al., 1994).

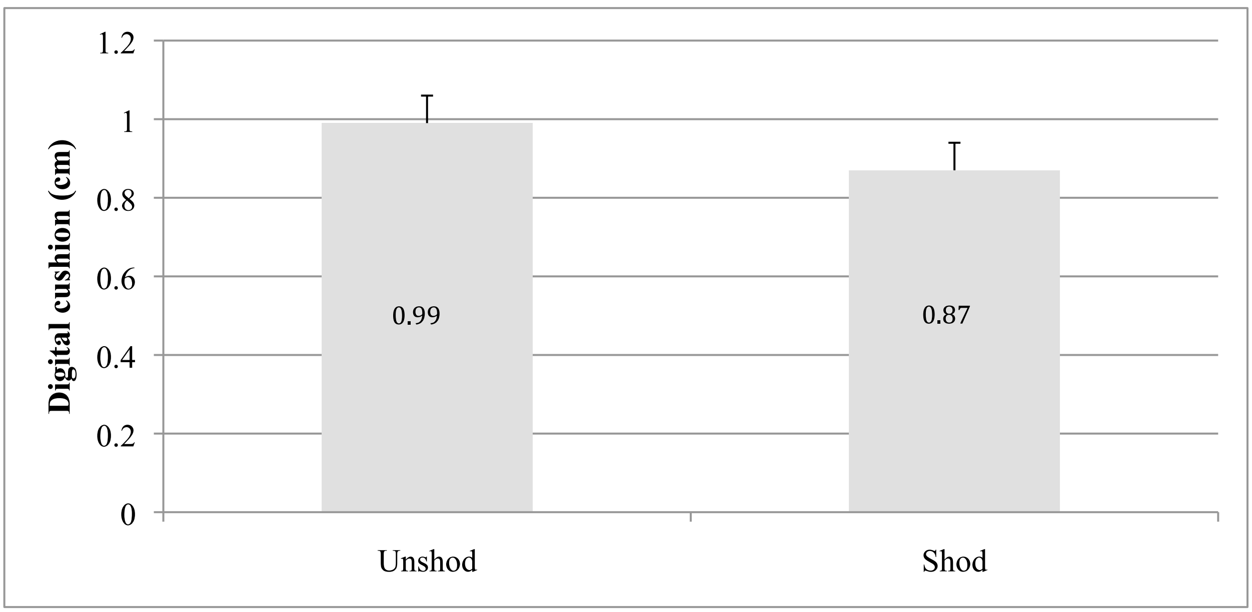

Figure 4.2. Digital cushion thickness for shod horses and unshod horses as measured by ultrasound.

As previously mentioned, the foot gradually changes and adapts to the forces applied to it (Bowker et al., 1998); and if restriction of the foot during a loading period is present, preventing it from adapting to its fullest, there is potential for the foot to have reduced strength. Dyhre-Poulsen (1994) reported that the nailing and adhesion of a shoe in a loaded hoof could impede the expansion of the hoof wall, recorded by a large change in pressure. It has been reported in other research that the attachment of a shoe reduces expansion of the hoof capsule but does not affect the expansion of the heels (Colles, 1989). Without shoes, the hoof wall moves more freely. Therefore, a shoe may restrict hoof wall expansion during the stance phase, altering energy dissipation throughout the hoof, and requiring adaptation to the applied forces.

Implications

Digital cushion thickness can be measured through the use of an ultrasound, and with baseline values established, further research investigating the digital cushion of the horse is possible. Many variables such as age, breed, weight, and concussive forces on the ground have the potential to affect the digital cushion. There was no difference seen between horses that were shod versus those that were unshod, although with a small sample size, further verification could alter the results. Previous research reports changes in digital cushion pressure as the hoof is loaded, as well as when a horse is shod, suggesting that alterations in digital cushion thickness or structure could occur. Future research focusing on understanding the variables that affect digital cushion thickness in horses is needed, with an ultimate focus on the digital cushion and its relation with lameness.

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CHAPTER 5. GENERAL CONCLUSIONS

Results from these studies serve horse owners, veterinarians, and those involved in the equine industry. The studies contribute to our understanding of health issues and economic expenses that are of the top concern to North Dakota horse owners, along with supplying verification of an ultrasound technique to measure the digital cushion in horses (Chapter 3). With the ultrasound technique verified, baseline values of digital cushion thickness were established, which will aid in future studies investigating the digital cushion, and ultimately allow further research examining if the digital cushion is associated with lameness and the economic cost it presents for horse owners.

Overall, in Chapter 2, the North Dakota Horse Health Survey indicates that horse owners spend an average of $500 or less on veterinary expenses per horse per year; with the majority (69%) of owners only using a veterinarian two times per year or less. Farrier use was found to be more frequent with 45% of horse owners using a farrier every 4-8 weeks. The top ranked health concern was lameness, followed by colic. These results are similar to what was reported in previous national studies. Therefore, future education and research efforts should be focused on the value of routine veterinary care as well as issues relating to lameness and colic.

In Chapter 3, the use of ultrasound proved to be a viable technique for viewing and obtaining measurements of digital cushion thickness in horses using a transcuneal approach. By using equine cadaver limbs, a validated procedure was completed and described in detail to allow for further use in research and clinical settings.

Once validation of the ultrasound technique was achieved, baseline values of digital cushion thickness in mature, stock-type horses of varying age, height, and weight were established. Although only a preliminary study, it was beneficial to establish baseline values, which allows for future comparison to other variables such as breed, age, and body condition score. Additional variables, such as shoeing and trimming technique, lameness conditions, and management practices would also be of interest. The horses used in this current study had no history of chronic lameness conditions, and further research is necessary to examine the changes that may occur in the digital cushion of horses with a chronic lameness condition.

Values of digital cushion thickness in shod and unshod horses were collected, with no difference observed between them. This could be due to sample size, as only six horses were imaged. A larger sample size has potential to move this towards significance. Shoeing a horse can effect hoof wall expansion as well as energy dissipation throughout the hoof as it is loaded; however, further investigation is needed determine if this alteration results affects the digital cushion. Regardless of the conclusions made, horse owners can benefit from further education on the horse's hoof allowing an educated decision on whether a horse should be shod or remain unshod.

Future Directions and Implications

The present data have suggested that there is a need for education and further information related to health and lameness in horses. Looking specifically at the North Dakota horse health survey, we found that there are similar results to national studies. This survey overall provides North Dakota horse owners with local information to become more aware of horse health concerns and expenses in their area. However, there are some limitations that come with this survey, which include lack of information in some subjects; geographic location of participants, the type of veterinary work North Dakota horse owners are doing themselves, in what way North Dakota horse owners spend their money at veterinary clinics.

In the future, asking additional questions could strengthen this survey. These additional questions could require participants to identify which county they are located in to gather information on geographic location of survey participants. Furthermore, participants could identify where the closest vet clinic is to their horses, which would allow us to determine differences that might occur in rural versus urban clinic settings. Knowing this information could provide further understanding for the average use of a veterinarian and associated expenses. Participants could supply additional information on the type of veterinary work they do themselves, since it was found in this current study that a larger percent identified doing the work themselves. Although there is a lack of veterinary use represented in this survey, this could indicate horse owners having accident free and healthy horses.

With the validation of the ultrasound procedure established, the equine digital cushion can further be studied and possible correlations made. The digital cushion is one area where research is limited yet the potential is promising. Research in dairy cattle has correlated the digital cushion with lameness, yet this same association has not yet been made in horses. Compositional changes in the equine digital cushion have been described, as well as changes in pressure in the digital cushion as the hoof is loaded; yet the effects of thickness and strength in the horse's hoof are open for investigation.

One possible approach for future research would be through a long-term study investigating the changes in digital cushion thickness in chronically lame horses, specifically those with conditions that affect the distal portion of the horse's limb. Another beneficial study would compare management strategies and digital cushion thickness, such as horses housed in a stall versus horses that are out on pasture. Differences in digital cushion thickness in horses that are shod versus those that are unshod should be examined with a stronger sample size. These studies have the potential to provide earlier identification for lameness conditions and provide information to help guide management decisions.

APPENDIX. NORTH DAKOTA HORSE HEALTH SURVEY

NDSU NORTH DAKOTA STATE UNIVERSITY

North Dakota Horse Health Survey

Dear Participant:

My name is Mattia Gunkelman. I am a graduate student in the Animal Sciences Department at North Dakota State University, and I am conducting a research project to improve welfare for horses, as well as improving economic losses for horse owners. It is my hope that with this research, I will be able to obtain information on North Dakota horse owners top horse health concerns as well as economic costs associated with horse health care.

You are invited to take part in this research project. The only criteria for participating in the study is that you must be 18 years of age or older. Your participation is entirely your choice, and you may change your mind or quit participating at any time. There is no penalty for opting not to participate; however, your assistance would be greatly appreciated in making this a meaningful study.

It should take less than10 minutes to complete the short online survey. No identifying information will be collected, so your answers will be completely anonymous. Your information will be combined with information from other people taking part in the study, and we will write about the combined information that is gathered. You will not be identified in any way in these written materials.

If you have any questions about this project, please contact: Mattia Gunkelman at mattia.gunkelman@ndsu.edu or contact my advisor, Dr. Carrie Hammer at carolyn.hammer@ndsu.edu.

You have rights as a research participant. If you have questions about your rights or complaints about this research, you may talk to the researcher or contact the NDSU Human Research Protection Program at 701.231.8908, toll-free at 1-855-800-6717, by email at ndsu.irb@ndsu.edu, or by mail at: NDSU HRPP Office, NDSU Dept. 4000, P.O. Box 6050, Fargo, ND 58108-6050.

Are you 18 years of age or older?

Yes	No
○	○

Are you a North Dakota resident?

Yes	No
○	○

How long have you been involved in the horse industry?

- <1 year
- 1-5 year(s)
- 6-10 years
- 11 years or more

How many horses do you own?

- 0
- 1-3
- 4-6
- 7-10
- 11 or more

If you care for outside horses, horses other than your own, please indicate the total number of horses normally in your care.

- I don't take care of horses owned by others
- 1-3
- 4-6
- 7-10
- 11 or more

What is your involvement in the horse industry? Please select all that apply.

- Hobby/Pleasure
- Breeding
- Show
- Rodeo
- Racing
- Barn manager
- Lessons/Training
- Working (ranch horse)
- Farrier
- Veterinarian
- Other

On average, how often do you use a veterinarian?

- Never to rarely
- Only when an emergency
- 1-2 times per year
- 3-6 times per year
- Monthly

If you answered "only when an emergency" or "never to rarely" for questions 7, why do you choose not to use a veterinarian?

- Too expensive
- Not one available in my area
- I do the work myself
- Other

What is the average cost for veterinary expenses that you spend on each horse per year?

- $0-100
- $101-500
- $501-1000
- $1001 or more

On average, how many times do you use a farrier?

- Never to rarely
- 1-3 times a year
- 4-5 times a year
- Every 4-8 weeks

If you answered "never to rarely" for question 10, why do you choose not to use a farrier?

- Too expensive
- Not one available in my area
- I do the work myself
- Other

What horse health issues concern you? Please drag the options below ranking them in order from top (highest concern) to bottom (lowest concern).

Respiratory problems

Lameness issues

Colic

Parasites

Reproductive problems

Nutrition issues

Other

Which of these health issues represent the highest veterinary expense for you as a horse owner? (pick only one)

- Respiratory problems
- Lameness issues
- Colic
- Parasites
- Reproductive problems
- Nutrition issues
- Other

Any comments you would like to share regarding any of the questions or answers provided.