Universiteit Utrecht

BODY CONDITION SCORE INFLUENCES FORELIMB HOOF KINETICS IN SHETLAND PONIES WITH IMPRINT SHOES

A comparison of forelimb hoof kinetics of obese Shetland ponies and normal Shetland ponies before and after the application of Imprint First® shoes

Research project of the Faculty of Veterinary Medicine at Utrecht Univerity

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PREFACE

In the final part of the study Veterinary Medicine at the University of Utrecht, all students are required to contribute to a scientific study. The practical experience of contributing to research will increase the students' understanding of scientific research. Research in the department of Equine Science is performed under supervision of a team including (academic) professors, teachers and PhD students.

Studies focus on laminitis as this is a common disease in the equine world with major welfare implications. More knowledge is gathered concerning both the pathophysiology and the therapy of laminitis.

This study was performed in the period of the 14th of September 2015 to the 8th of November 2015. This report is the final product of my experimental research and focuses on hoof kinetics in obese Shetland ponies compared to the normal control group. A mouldable glue-on heart-bar shaped (Imprint First®) shoe as part of the treatment for acute laminitis is considered, as the pressure distribution of the front hooves was measured in obese and normal Shetland ponies with and without Imprint First® shoes. The Imprint First® shoes will be reported in more detail by my co-worker Robin ten Have.

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ARTICLE INFORMATION

Keywords:
Horse;
Equine Metabolic Syndrome;
Obesity;
Veterinary Treatment;
Shoeing;
Pressure plate;
Force Plate;
Gait analysis;
Hoof kinetics;
Pressure distribution.

ABSTRACT

Obesity, Equine Metabolic Syndrome (EMS) and hyperinsulinemia are associated with episodes of dorsal hoof wall pain and laminitis. This occurs most likely through insulin regulated palmar vascular dysfunction and a relatively heavy weight load on the front feet. An early supportive treatment using mouldable glue-on heart bar shaped shoes (Imprint First®) is claimed to reduce the (toe)pain in the affected hooves and thus would increase the chance of full recovery. Therefore, the aim of this study was to compare forelimb hoof kinetics of obese Shetland ponies and normal Shetland ponies before and after the application of these Imprint® shoes. Shetland ponies were suitable for this study as they represent a large group within both EMS and laminitic cases. 5 obese Shetland ponies and 5 normal Shetland ponies were selected from a group healthy, sound ponies without clinical signs of current or previous laminitic episodes. A combined pressure- and force plate system was used to measure multiple kinetic variables at walk and trot after hoof trimming (T0), immediately after shoeing (T1) and 72 hours after shoeing (T2). At each time point, five valid trails per forelimb at walk and trot were collected. A linear Mixed Model operating at a significance level of $P<0.05$ was used for statistical analysis. At walk the stance duration(ST), normalized vertical impulse(nVI) and normalized vertical impulse of the toe region (nVI toe) were significantly reduced in the obese Shetland ponies compared to the normal group($P<0.05$). At T0, the normalized peak vertical force (nPVF) occurred significantly earlier in the stance phase and at T2, nPVF was significantly smaller in the obese ponies ($P<0.05$). The relative toe-heel loading of the ST was smaller at both walk and trot in the obese group, and at T0 and T1 during walk and at T0 during trot too ($P<0.05$), meaning a prolonged stance time in the heel zone when compared with the toe zone in the obese ponies. At trot, also the relative toe-heel loading of the nVI and the nPVF was reduced in the obese ponies compared to the normal group($P<0.05$). Furthermore the nVI and nPVF were significantly reduced in the obese ponies at T2 at trot ($P<0.05$). Most differences between the obese Shetland ponies and the normal Shetland ponies were observed before application of the Imprint First® shoes. The observed difference between groups suggests that at first the obese ponies were less comfortable compared to the normal ponies. The decrease in difference after application of the shoes suggests a beneficial effect of the glue-on, heart bar shoes to the comfort level of the obese ponies.

INTRODUCTION

Awareness of equine obesity and laminitis related conditions

Amongst equine veterinarians, obesity in the equine population is increasingly recognised as a major health issue (1). Owers and Chubbock alert that obesity is becoming the norm, as horse owners tend to underestimate the overweight of their equines (2). In a study in Australia, owners considered weight loss as a major health concern, but only 1% of horse owners considered weight gain to be an issue (3). Obesity amongst equines has been estimated to be 31,2% (4).

Obesity will never be named as cause of dead, however the challenge is to raise awareness about the linked life-threatening diseases (2). Equine Metabolic Syndrome (EMS) is described as complex of metabolic abnormalities including insulin resistance, characterised by hyperinsulinemia.

Furthermore EMS cases often display signs of increased adiposity in either regions (including a cresty neck) or general obesity and an increased risk of laminitis (5). EMS is mostly linked with physical inactivity and an excessive diet, and is increasingly diagnosed in horses (6).

Indicated risk factors of equine obesity are non-regular or no exercise. Certain breeds like draught types, cob types and Welsh breeds are more prone to develop obesity and EMS (4). Multiple studies recognise similar risk factors for laminitis; a high body condition score (BCS) (7-11), a high cresty neck score (CNS) (7-11), pony breeds (7-10,12) and low exercise rate (10). Lastly, EMS characterized as hyperinsulinemia has proven to be a risk factor for pasture associated laminitis. The link between hyperinsulinemia and acute laminitis is proven in both field studies (11,13,14) and experimental research (15).

Higher serum insulin (11,14-16) and leptin (11) concentrations have been observed in ponies prior to pasture-associated laminitic episodes. Interestingly, glucose, free fatty acids and cortisol serum levels remained normal (14). The high glucose demand of the hoof lamellae has been studied in relation to laminitis (15,17). However, later studies reveal that glucose uptake in the hoof occurs independently of insulin (15), making the glucose-related theory less relevant. Insulin or other factors of pasture-associated laminitis lead to activation of matrix metalloproteinases (18), elevation on thromboxane A2 activity (8) and COX-2 expression (19) marking inflammation and tissue degeneration. Insulin has vasoregulatory actions and vascular dysfunction is nowadays believed to be the most plausible mechanism for laminitis in relation to obesity, EMS, insulin resistance and hyperinsulinemia (5,15,16,20). Lastly, also rapid hindgut-fermentation due to carbohydrate overload leads to a series of events seemingly causing pasture-associated laminitis (16).

Another, less highlighted possible risk factor for laminitis due to equine obesity can be presented by supporting limb laminitis. Supporting limb laminitis occurs after prolonged unilateral weight bearing and results in severe lameness (21,22). It is hypothesised that supporting limb laminitis results directly from mechanical overload leading to arterial occlusion in combination with constant loading of the deep digital flexor tendon (21). Supporting limb laminitis mostly occurs within 4-100 days after injury and is commonly seen in forelimbs (23). Studies have proven that overweight laminitic horses tend to develop more severe signs than horses with a normal weight (24,25). As degree of lameness and lamellar degeneration are connected (26,27), it might be suggested that the forelimb load of approximately 58% of the body weight (28) can trigger or at least provoke the laminitic process in overweight horses (16,25). Laminitis cases associated both with EMS and supporting limb laminitis tend to express more extensive degeneration of the lamellae (22).

Prevalence, pathophysiology and treatment of laminitis

In a survey amongst horse owners in northern Britain, laminitis was scored as the second most important disease, as well as the second common cause of permanent or recurrent disease within horses (29). Frequency rates of laminitis in the equine population are described between 0,5% and 17,1 % within different equine groups in the UK (24,30,31). Laminitis rates up to 33,8% have been observed in an closed herd in North Virginia of Welsh and Dartmoor pony's (13). Not surprisingly, as laminitis is the close second reason for euthanasia after colic, it is classified as most debilitating disease of the equine species (22).

Laminitis is known to have a complex aetiology of vascular, inflammatory, metabolic or mechanical origin (16,32). Acute laminitis has been defined as the onset of clinical signs which includes increased hoof temperature, an increased digital pulse amplitude, lameness and/or shifting of weight due to inflammation and pain but without displacement of the distal phalanx (21,22,25,32). During this phase, the tissue at the lamellar interface fails, leading to a weak link between the distal phalanx and the inner hoof wall (16).

In the course of the disease, irrespective of its origin, the lamellar degradation leads to a loosening of the distal phalanx of the inner hoof wall. As a consequence of the weight acting on the distal phalanx and the pulling force of the deep flexor tendon the distal phalanx rotates in relation to the hoof capsule (7,27,32,33). The structural damage of acute laminitis in the laminae is largely irreversible (26). However, if the degradation is minimal, the patient can recover (26,27). Consequently, it is important to limit the damage of the pathological process by limiting any activity that places stress on the weakened lamellae (16), as the damaged tissue is then most likely to be able to recover (22,25,27). Today's clinical treatment of acute laminitic cases aims to reduce further lamellar damage, provide analgesia and monitor the progression (21,22). The patient should be limited to walk minimally, and the affected hoof should be mechanically supported to stabilize the structural components (22). Stall rest and supportive shoeing is usually prescribed (22).

Therapeutically shoeing options by acute laminitis

Shoeing options during an acute laminitic episodes include pads, wedged cuffed shoes, wooden shoes, foot casts, glue-on shoes, reverse shoes, Egg-bar shoes and heart bar shoes and combinations of these options (22,34-38). Supporting the foot in such a way that contact surface area increases by supporting the frog and/or the sole leads to a shift of centre of gravity, unloading the hoof wall (33,35,38). Also trimming the hoof is such a way that the toe is bevelled can reduce stress on the dorsal hoof wall, especially during break over (21,22,33). Wedged heels are used in order to decrease forces of the deep digital flexor tendon and increase relative weight bearing of the heel region (37,39). However, the effectiveness of elevated heels in reducing the tension in the deep digital flexor is questioned in a more recent study (40). Normal shoes need to be removed in laminitic cases, as these concentrate the weight-bearing forces on the hoof wall (21,39).

The Imprint Equine Footcare System is developed by orthopaedic farrier Andrew Poynton and the Imprint First® shoes are presumed to be a suitable aid in the treatment of acute laminitic cases. The system is based on a heart-bar shoe design, but instead of nailing the shoes it uses completely mouldable plastic. The plastic has two advantages as it probably allows more natural hoof movements and it is applied non-traumatically. By supporting the frog and caudal hoof, the shoe aims to unload the hoof wall and stabilizes the third phalanx (41). Personal and anecdotal experiences with the positive effect of the Imprint® shoe on the comfort level of laminitic cases serves as the background for this study.

Experimental measurements have indicated that histopathological changes in the laminae occur before clinical signs of laminitis are evident (26,42). It suggests that laminitis might be a slowly progressing expression of suboptimal conditions of the equine hoof including a more or less asymptomatic developmental phase (22). Given the fact that literature suggest histopathological changes in the laminae occur prior to clinical signs of laminitis and signs of laminitis develop parallel to the weight burden on the hoof wall (25-27), the use of Imprint First® shoes might also be interesting for the horses with an increased risk of laminitis, such as obese and non-exercising ponies and horses with equine metabolic syndrome and insulin resistance.

AIM OF THE STUDY

Taking into account the practical and ethical concerns of walking laminitic ponies repeatedly over the combined pressure- and force plate system, the effect of the Imprint® shoes was measured in 10 (5 control and 5 obese) healthy and sound Shetland ponies, part of the research herd of the Utrecht university. This study measured the effect of body condition score on forelimb hoof kinetics at walk and trot before and after the application of the Imprint First® shoes by using control and obese Shetland ponies. The hypothesis of this study was that the application of Imprint® shoes will redistribute the forces acting on the forelimb hoof wall to the palmar area of the foot. By redistributing the forces acting on the forelimb hoofs, the Imprint® shoe will also reduce the pressure on the sole in the toe area and improve the break over of the foot in sensitive laminitic ponies. Furthermore, the measured effects are expected to be larger in the obese Shetland ponies compared to the non-obese control group, as they are expected to be more uncomfortable while walking. These findings theoretically would explain the positive effect of the Imprint® shoes on the comfort level of laminitic ponies.

MATERIALS AND METHODS

Ponies

Shetland ponies are suitable for this study as they represent a large group within both EMS and laminitic cases. Given the fact that the pressure- and force plate system has a limited (2m x 0,4 m) surface, using ponies will increase the chance of the hooves fully contacting the measurement area. Shetland ponies of the faculty's research herd of the Equine Clinic of Utrecht University were used. The ponies were part of a larger research on the epigenetic effects of equine metabolic syndrome in horse embryos. Consequently all ponies were mares and were already divided in an obese group and a control group. Of each group 5 Shetland ponies were included in this study. All ponies were healthy, unshod, had equal forelimb hooves and had no clinical signs of current or previous laminitic episodes. The obese Shetland ponies had a mean ±SD in age (5 ±1.8 years old), body mass (245 ±28 kg), height at withers (1.00 ±0.04 m), body conditions score (8.7 ±0.4) (43) and cresty neck score of (3.8 ±0.3)(44) versus an age of (4 ± 1.5 years old), body mass (185 ±14 kg), height at withers (0.99 ±0.02m), body condition score (5.6 ±0.9)(43) and cresty neck score of 2±0.0 (44) of the control group. The body mass of the ponies was registered before the start of each measuring session. The study was approved by the Ethical Committee of Utrecht University (approval number DEC 2014. III. 02.021).

Trimming procedure

The trimming procedure was instructed by the developer of the Imprint® shoes Andrew Poynton to an experienced farrier prior to the study (41). Key proceedings of the trimming and shoeing procedure are illustrated in figure 1. Before the control measurement T0, the ponies were trimmed. A small plank with chalk was used to assure the forelimb hooves were balanced correctly. Ideally, the heels were trimmed to the widest point of the frog. Directly after trimming, T0 measurements at walk and trot were performed. Subsequently, the Imprint® shoes were fitted to the hooves. Imprint first® shoes sizes 3,25"-4,25" were used. The dorsal part of the Imprint® shoes were melted in a container with boiling water, while the shoe part of the Imprint® shoe stayed solid through a supporting element (illustration at cover) . Extra plastic was melted if necessary to shape extra material to support a small frog. Before

Figure 1. Trimming and shoeing procedure

A: Trimming the forelimb hooves totally even, ideally with the heels to the widest point of the frog.
B: Creating indentations which will serve as key to the plastic
C: Applying adhesive on the dorsal hoof wall
D: Positioning the Imprint First© shoes centred on the frog, moulding to the foot and filling the indications
E: Cooling the shoe with imprint shoe freezer
F: End result after application of the Impint First© shoes

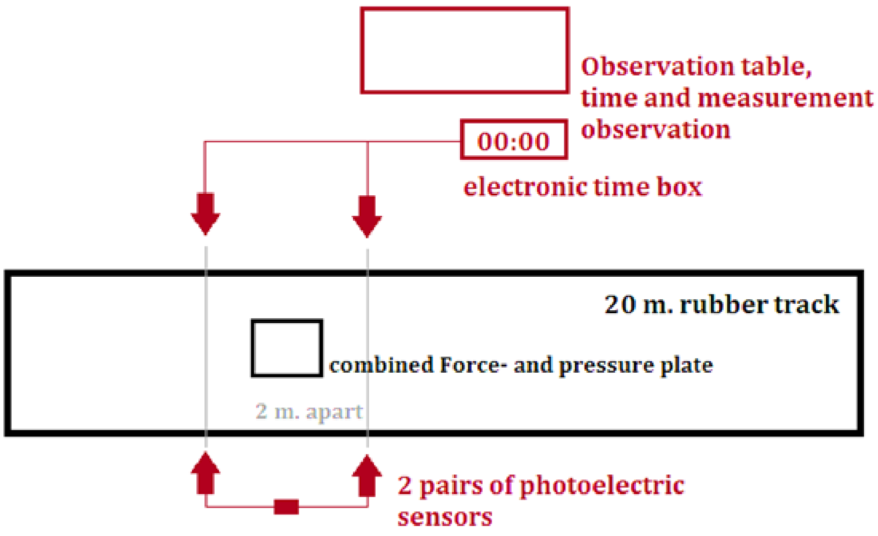

Figure 2. Schematic overview of the experimental setup, the pressure- and force plate system was positioned under the rubber track.

application of the glue-on heart bar shaped shoes, the farrier created 3 indentions at both sides of the hoof in the hoof wall, in order to strengthen the attachment of the glue shoes to the hooves. Also, the hooves were cleaned using a metal brush to remove loose material and further roughen the surface. Adhesive was applied on the hoof wall. To handle the half-melted shoes, the farrier put on plastic gloves and kept these gloves moisture, as the melted plastic will stick to the heat of human skin. The Imprint First® shoes were positioned centred on the frog and moulded to the foot in order to fill the indications. The Imprint® shoes were cooled using Imprint shoe freezer. After a period of 5 minutes weighting to secure a strong attachment of the glue-on shoes, measurements T1 and after 72 hours measurements T2 were performed.

Measurement system and data collection

Measurements were preformed using a pressure plate (Footscan 3D 1m-system, RSScan international) and force plate (Z4852C, Kistler) in a combined pressure- and force plate system setting with a spatial resolution of 2.6 sensors/cm^2 and a pressure range of 0–200 N/cm^2, covered with a 20 meter long rubber track (NR/SBR, De Mulder Rubber and Plastics) with a shore hardness of 65 ± 5. Two pairs of photoelectric-sensors (WE260- S270. Sick AG) connected to an electronic timing box (Timer Interval Meter K3HB-P, Omron Corporation) recorded the average velocity and were placed 2 meter apart perpendicular to the track, with the first pair of sensors 0.20 m in front of the measuring surface. Although acceleration was not measured directly, the length of the track ensured that the effect of acceleration and deceleration at the start and end of each trail was minimized over the central measuring area. This experimental setup has been used in previous equine gait analysis studies (45,46). A schematic drawing of the experimental setup is presented in figure 2.

The pressure- and force plate were calibrated before each measuring session according to the manufacturer's specifications using the Footscan Scientific Gait 7 software (RSscan International) and with the assistance of a person weighing 65 kg, without the rubber covering. Subsequently, the rubber covering was placed over the measuring area and the threshold of the pressure plate was adjusted according to the offset-screen. The force plate and the pressure plate were manually reset before each set of measurements.

After a warm-up period of 5 minutes at walk (45,47), the ponies were led over the pressure- and force plate system by an experienced handler at walk and subsequently at trot. At both gaits a number of five valid measurements were collected for each forelimb hoof (45,47). A trail was considered valid if the pony looked straight forward, maintained a constant pace over the pressure- and force plate system, a complete print of one front foot was recorded, the force- and pressure plate measurements showed no abnormalities, and if velocity was within a pre-set range of 0.8/1.4 m-s at the walk and 2.5/3.5 m-s at the trot (45,48-51). Control measurements (T0) were performed directly after trimming of the forelimb hooves by an experienced farrier (figure 1). After T0, imprint First® shoes were applied (figure 1) to the forelimb hooves by one experienced farrier. A second and third set of measurements was done immediately after application of the Imprint® shoes (T1) and 72 hours after shoeing (T2).

Data processing and statistical analysis

The following timing and limb loading variables were calculated for all valid trails at both walk and trot: **1-** the velocity, being recorded over 2 metre and reported in milliseconds (ms); **2-** mean stance duration (ST), calculated as total stance phase and expressed in milliseconds (ms); **3-** mean normalised vertical impulse (nVI) as well as the mean vertical impulse of the toe and heel regions, calculated by time integration of the force-time curves (N s) and corrected per pony for their bodyweight; **4-** mean normalised peak vertical force (nPVF), calculated as the maximal vertical force divided by the contact area in Newtons per cm2 (N/cm^2) and corrected per pony for their bodyweight; **5-** mean time to peak vertical force (TPVF), as time at which the maximal force occurs as percentage of stance (%); and **6-** relative toe-heel loading percentages of the ST, nVI and nPVF, as described hereafter how to be calculated. Hoof prints were divided manually in a toe and heel region by a line through the maximal hoof width as described in previous papers (45,46,52). The manual division of the hoof is illustrated by figure 3. The corresponding vertical forces or stance time (VF) were sampled at 250 Hz and the relative toe- heel loading of the forelimb hooves was calculated as

$$\text{Toe}-\text{heel balance} = \frac{VF_{Toe} - VF_{Heel}}{0.5(VF_{Toe} + VF_{Heel})} \times 100\%$$

(46,53). At this calculation, 0% represents perfect balance in vertical ground reaction force between the regions, while possible values ranging from -200% to 200% indicate relatively higher loading of the heel and toe region respectively.

The raw data was prepared for analysis using Microsoft Office Excel 2007. IBM SPSS Statistics 22 and custom made Matlab scripts (Matlab R2015a) were used for processing the data. All data was checked for normality and if necessary a natural log transformation was applied. A linear mixed model was used with pony as subject and a random intercept. The fixed factors measuring time point, body condition score (BCS), limb and interaction between measuring time point and BCS were tested and the best model was chosen based on the lowest AIC score. A P-value <0,05 and a power of 80% was used to indicate acceptable statistical significance. The asymmetry variables were not normally divided , therefore an independent samples Kruskall-Wallis test was applied with multiple comparisons performed if a statistical significance between groups was found. Unless otherwise stated, data is presented as mean ± SD.

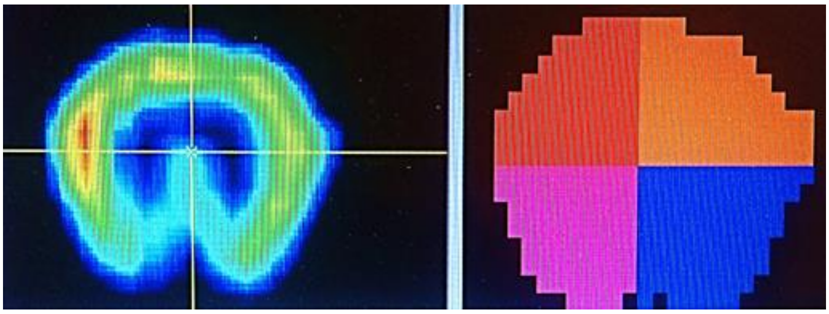

Figure 3: A representative hoof print and the manual division of het hoof in a toe, heel, media land lateral section.

RESULTS

Over a period of 4 weeks, 600 measurements of full-contacted forelimb hoof prints were collected. A typical hoof print of a right forelimb hoof with and without the glue-on heart-bar shoes at the different times of measurements are presented in figure 4. Measured timing and limb loading variables are presented in table 1, significant results are marked with a (*) for P<0,05 and (**) for P<0,005. Data of the relative toe-heel loading of the stance duration is presented in detail in figure 5A for walk and figure 5B for trot. Raw data can be found in the attachment of the report.

At walk, there were no significant differences between the nVI of the heel region and between the relative toe-heel loading of the nVI and nPVF. A limb asymmetry between the left and right forelimbs was observed at the nVI of the heel region when the right and left limbs of all ponies were compared. Statistical analysis has shown this did not influence any other parameters significantly, besides there were no statistical significant relevant data collected of the nVI of the heel region at walk. The obese Shetland ponies walked slower during T0 than the normal control group (P=0,010), however all the measurements were within the pre-set range of 0.8/1.4 m-s, the marginal significance difference in speed was most likely caused by the small variability and did not influence the other parameters significantly. Combined results of T0, T1 and T2 at walk found a significantly smaller ST, relative toe-heel loading of the ST, nVI and nVI of the toe zone in the obese Shetland ponies compared to the normal group (P=0,002, P=0,000, P=0,017 and P=0,016 respectively). Only the ST stayed significantly different between the two groups at T0, T1 and T2 when the time points were compared separately (P=0,000, P=0,001 and P=0,044 respectively). At T0, the TPVF, and the relative toe-heel loading of the ST were smaller in the obese Shetland ponies (P=0,033 and P=0,039 respectively), meaning these ponies had a prolonged stance time in the heel zone when compared with the toe zone. At T1 the relative toe-heel loading of the ST was smaller in the obese Shetland ponies (P=0,048). At T2 the nPVF was significantly smaller in the obese ponies(P=0,025). These results indicate that the obese Shetland ponies, while walking within the same range of velocity, did had a shorter stride duration, lower normalised vertical impulse and loaded their heel region more compared to the normal ponies.

At trot, the speed did not differ significantly between any comparison of the groups. Furthermore the ST, nVI, nVI of the toe and heel regions and the TPVF were not significantly different between the obese Shetland ponies and the normal Shetland ponies during any time point. A limb asymmetry between the left and right forelimbs was observed at the nVI of the toe region when the right and left limbs of all ponies were compared. Statistical analysis has shown this did not influence any other parameters significantly, besides there were no statistical significant relevant data collected of the nVI of the toe region at trot. Combined results of T0, T1 and T2 at trot

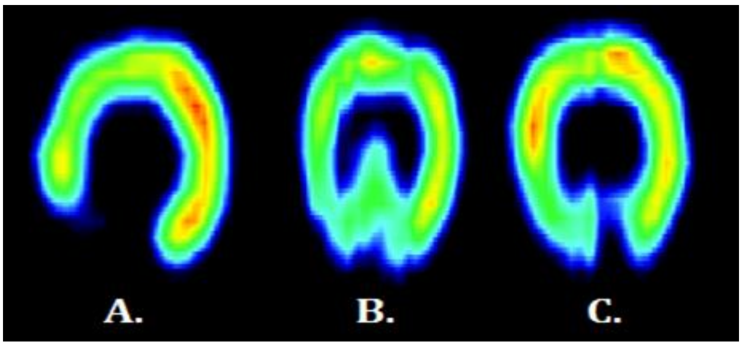

Figure 4: A typical representation of a right forelimb hoof print image of the pressure plate, A: at T0, B: at T1, C: a T2.

Table 1: Mean ± SD for multiple variables, combined left and right limb measurements of the obese ponies and the control group at walk and trot.

	Obese ponies				**Control group**			
Variable	T0	T1	T2	Combined	T0	T1	T2	Combined
Walk								
Velocity (m s)	**1,21±0,02***	1,18+0,02	1,15±0,01	1,18±0,01	**1,11±0,03***	1,13±0,02	1,17±0,02	1,14±0,01
Stance duration (ms)	**551±13,6****	**558±15,9****	**585±18,6***	**565±9,41****	**668±11,0****	**659±5,89****	**638±16,7***	**655±7,09****
Vertical impulse (N s)	2,05±0,15	1,71±0,11	2,26±0,16	**2,01±0,09***	2,51±0,16	2,30±0,09	2,87±0,09	**2,56±0,08***
nVI of the toe region (N s)	1,27±0,09	1,17±0,07	1,55±0,10	**1,33±0,06***	1,88±0,17	1,64±0,10	2,00±0,10	**1,84±0,08***
Peak vertical force (N/cm² kg)	5,29±0,31	4,49±0,27	**5,58±0,24***	5,12±0,17	5,40±0,31	5,15±0,23	**6,57±0,25***	5,71±0,19
Time to PVF (%SD)	**384±11,1***	396±10,9	411±12,6	397±6,76	**432±8,09***	432±9,03	421±16,6	429±6,67
Relative toe-heel loading of the ST	**8,80±0,67***	**9,35±0,55***	8,93±0,65	**9,03±0,35****	**14,1±1,08***	**14,1±1,09***	13,4±1,31	**13,9±0,65****
Trot								
Vertical impulse (N s)	1,03±0,10	1,01±0,09	**1,13±0,06***	1,06±0,05	1,18±0,10	1,24±0,09	**1,49±0,04***	1,30±0,51
Peak vertical force (N/cm² kg)	7,53±0,52	7,33±0,52	**8,50±0,21****	**7,79±0,26***	8,61±0,52	8,75±0,48	**11,0±0,34****	**9,47±0,33***
Relative toe-heel loading of the ST	**12,0±0,59***	11,7±0,44	12,2±1,05	**12,0±0,41****	**17,0±0,70***	15,3±1,04	15,4±1,02	**15,9±0,54****
Relative toe-heel loading of the nVI	39,4±12,8	56,3±12,5	52,6±14,3	**49,5±7,47***	77,0±8,99	78,9±10,1	70,0±11,4	**75,3±5,74***
Relative toe-heel loading of the nPVF	31,6±11,4	45,5±12,1	41,6±14,1	**39,6±7,09***	60,7±9,05	65,4±9,99	56,2±11,2	**60,8±5,68***

* **Significance P<0,05; **significance P<0,005**

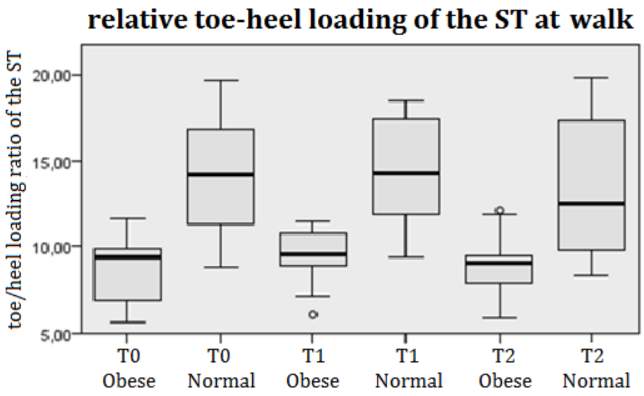

Figure 5A: relative toe-heel loading of het ST at walk

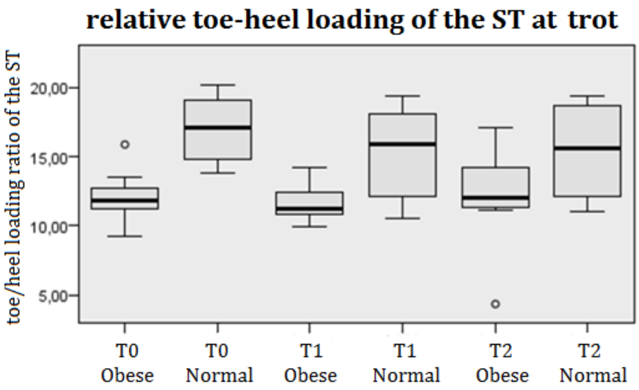

Figure 5B: relative toe-heel loading of het ST at trot

revealed a lower nPVF and lower relative toe- heel loading of the ST, nVI and nPVF for the obese Shetland ponies compared to the normal group (P=0,020, P=0,000 P=0,007 and P=0,026 repsectively). At T0, the relative toe-heel loading of the ST was smaller in obese Shetland ponies (P=0,008) and at T2 the nVI and the nPVF were smaller in the obese group compared to the normal control group (P=0,028 and P=0,002 respectively).

DISCUSSION

The aim of this study was to objectively compare the hoof kinematics of control and obese ponies before and after the application of the the Imprint First® shoes. This study is one of the first studies to focus on a comparison of the hoof kinetics of ponies and laminitic predisposed ponies. Frog support in relation to the possibilities of treating laminitis has been studied in vivo using several materials such as foam at stance (38), egg-bar shoes with the use of markers (37) and other shoeing has been studied in vitro (35). A combined pressure- and force plate system is a relatively new experimental setup, and has not been used to evaluate laminitic treatments options before.

The study design was set up with a combined pressure- and force plate system. Earlier performed studies have proven that a calibrated pressure place provides detailed measurements on hoof contact and limb loading variables (45,48,53-55). Pressure plate measurements can be dynamically calibrated using simultaneous force plate measurements (54). However, a pressure plate can also be used solitary, as long as the results are not compared with force plate measurements (46,54). The combined pressure- and force plate system has been previously used in studies comparing different shoeing (45), different surfaces (53) and fore- and hindlimb variation in ponies and horses (48).

Alternative experimental setups could have been an instrumented treadmill, as described by Weishaupt et al (56) or instruments mounted between the hooves and shoes (57). However, treadmill locomotion has a slight deformation of the overground locomotion values, as the treadmill itself has compliance values. Measurements from a treadmill measurement might not be directly translated to solid ground locomotion (58,59). Also the use of an instrument mounded between the shoes and the hooves seems less precise as the material is applied between the hoof and the shoe (57). As the Imprint® shoes are flexible, the volume of the instruments might redistribute the forces unevenly ,leading to less accurate measurements. Besides, the weight of the instruments might influence the gait parameters and the method cannot be used barefoot, measurements 'before' shoeing is thus impossible.

EMS and laminitic predisposed obese ponies have been correctly selected for this study, given the breed (7-10,12), body condition score (7-11), and crusty neck score (7-11). The used experimental setup with combined pressure- and force plate system resulted in consistent results with a characteristic biphasic pattern of the ground reaction force curve at walk and peaks at the beginning and end of the stance phase at trot, as described in earlier literature (50,55).

During this study, most profound differences between the obese ponies and the control group were observed at walk, being the significant shorter stance duration of the obese ponies during T0, T1 and T2 and their significant smaller relative toe-heel loading of the stance duration during T0 and T1. From these parameters can be concluded that the obese ponies, while walking within the same pre-set range of speed, had a shorter stance phase and carried relatively even weight on the toe and the heel, whereas the control group carried more weight at the toe region of the hooves. Typically, the significant differences of the stance duration and relative toe-heel loading of the ST became less significant during T1 and T2, even leveling the relative toe-heel loading of the ST to a non-significant difference at T2. Conclusive, the differences between the groups were being most obvious at T0.

The results at trot show the same trends, but were not sufficiently consistent to draw any more conclusions from. Possibly, handling the ponies biased the results to a greater extend at trot, as the handlers experienced more difficulties to correctly lead the ponies. This can also be seen in the greater variability of the velocity results at trot. Although Water et al studied biases such as handler influences, there is a chance this group of ponies was less trained and thus weren't able to reach the same level of significance (60).

More researchers and measurement biases could be introduced by the division of the hoof prints. Previous set-up guidelines has been used by dividing the hoof prints (45,46,52), however the division still is manually and subjective to the researcher. Also, the prints could not be outlined, and slightly turned prints will never have been divided totally correctly according to the guidelines. Moreover, the ponies have been selected for symmetrical hooves at this study as described in other studies such as Oosterlinck et al, 2011 (48). However the hooves did not have to meet certain standards like hoof-ground angle. It might have been possible to narrow the inter-pony differences between the hooves. Stressed must be the fact that the Imprint® shoes were not tested at laminitic ponies, therefore the same difficulties were seen as earlier research on therapeutically shoeing options for laminitic ponies (38), is which research the supportive shoeing material was suggested to wear faster over time due to the locomotion of the ponies.

Variation in subject velocity should be minimized during pressure- and force plate system analysis (49-51), although the setup was correct, the speed was consistent between the measurements. However the speed did differ significantly between the obese ponies and control group at T0. A higher walking velocity is known to lead to a shorter stance duration and because of shorter ST a decreased nVI is seen even though the nPVF increases (49,50). The increase in nPVF is most likely seen because of a shift of weight to forelimbs during increased speed (51). The higher velocity seen during T0 by the obese ponies has possibly increased the difference in stance duration, but because the nVI and nPVF did not differ significantly between the groups, the significance in velocity most likely caused no measurable significant effect on the other variables. Most likely, the small variability between the measurements caused a significant difference within minimum margin between the groups, however not creating a measurable effect on the other variables and thus not clinically relevant.

To summarize, results from this study at walk show that the obese ponies had a comparable velocity, but shorter shorter stride duration, lower normalised vertical impulse and loaded their heel region more compared to the normal ponies. Therefore the hind limbs must have carried the weight of the obese ponies to a greater extend. This clue is amplified by the relative toe-heel loading of the ST. Hoof kinetics at walk and trot compared between obese ponies and normal ponies are not described in earlier literature. Multiple explanations seem reasonable at first.

The excessive fat storage around the shoulder region in the obese ponies could have limited the movement of the front limbs. During the study, most obese ponies had less ground covering during their gaits. However the parameters became less significant during the measurements, and the level of obesity and related inhibitions did not change during the 72 hours between the measurements. Therefore, body condition alone seems to be no valid reason.

Another possibility might be slightly sensitive front hooves in the obese ponies, as they are predisposed for laminitis in multiple ways. Sensitivity of the front limbs will lead to a caudal shift of their weight to the hind limbs. During the experiment the shoes redistributed the weight from the hoof wall to the hoof wall and the frog. The obese ponies became more comfortable, and this could be drawn from the less significantly different ST and relative toe-heel loadings of the obese ponies and the control group during T2.

The aim of the Imprint® shoes is to support the foot in such a way that contact surface area increases by supporting the frog, leading to a shift of centre of gravity and unloading the hoof wall. The shoes did make the obese ponies more comfortable, as their hoof kinematics are more similar to the control group at T2 as at T0. Interestingly, the Imprint® shoes did gave a positive response in the obese Shetland ponies. As this suggest prior discomfort before the imprints, the ponies on their own are interesting too. The multiple predisposed for laminitis group of ponies, even without clinical signs of laminitis might have been sensitive at their front hooves during the experiment. The exiting part is that we have been able to monitor the differences between these ponies and their healthy controls at a pressure plate. Possibly, these model ponies could be used for further research on the topic of acute laminitis.

Conclusion

The aim of this study was to objectively compare the hoof kinematics of control and obese ponies before and after the application of the the Imprint First® shoes. This study is one of the first studies to focus on a comparison of the hoof kinetics of ponies and laminitic predisposed ponies. Most differences between the obese Shetland ponies and the normal Shetland ponies were observed before application of the Imprint First® shoes at walk. Typically, the significant differences of the stance duration and relative toe-heel loading of the ST became less significant during T1 and T2, even leveling the relative toe-heel loading of the ST to a non-significant difference at T2. The results drawn from this study indicate that the obese Shetland ponies, while walking within the same range of velocity, did had a shorter stride duration, lower normalised vertical impulse and loaded their heel region more compared to the normal ponies. Most likely the obese group shifted their weight to their hindlimbs to some extent, being most obvious at T0. The observed decrease in the measured variables after application of these shoes between the groups suggest that the obese Shetland ponies became more comfortable over time because of the Imprint® shoes. As this suggest prior discomfort of the obese Shetland ponies before the imprints, the ponies on their own are interesting too. The multiple predisposed for laminitis group of ponies, even without signs of current laminitis might have been sensitive at their forelimb hooves during the experiment. This clue needs to be confirmed by a future experiment with front hoof percussion or measurements with laminitic ponies in order to draw any definitive conclusions. This study may lead to future evidence-based early phase laminitic treatment and the effect of therapeutical shoeing in the early phase of laminitic cases. Pressure-plate analysis seems promising for quantifying the effect of therapeutic shoeing with regard to laminitis. As typical gait parameter kinematics for pre-clinical laminitis might be acknowledged in the future, pressure plate measurements can play a role in preventive or early-phase treatment of laminitic equine.

Conflict of Interest Statement

There were no financial of personal relations that could have inappropriately influenced or biased the content of the paper.

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ATTACHMENT

The descriptive statistics of this report is presented in an attached document.