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Original article

Effect of shoeing horses with eggbar shoes and shoes with wedge pads on blood flow parameters in the lateral digital artery in the Doppler ultrasound

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Abstract

A sound knowledge of horseshoe impact on blood flow parameters is required for making shoeing decisions and selecting the most appropriate types of shoes. The aim of this study was to determine the effect of horse shoeing with egg bar shoes and shoes with wedge pads on blood flow parameters in the lateral palmar digital artery measured by Doppler ultrasound. The study was conducted on 16 horses divided into two groups. Horses from group 1 were shod with egg bar shoes. Horses from group 2 were shod with shoes with wedge pads. Doppler ultrasound parameters of the lateral palmar digital artery at the level of the metacarpophalangeal joint were evaluated. Doppler tests were performed before and after shoeing within a monthly interval. The results of the study indicate that egg bar shoes have a greater impact on blood circulation in the distal part of the equine limb than shoes with wedge pads. However, the only parameters to have changed substantially after shoeing with egg bar shoes were end-diastolic velocity (EDV) and mean velocity (Vmn) in the lateral palmar digital artery. A low-resistance blood flow pattern was noted before shoeing. After shoeing in group 1, it remained unchanged in 5 horses, whereas a high-resistance pattern was observed in 3 animals. A low-resistance blood flow pattern was noted in all group 2 horses after shoeing. The difference between the analyzed shoeing techniques could be attributed to increased pressure in the heel bulb area in horses shod with egg bar shoes. Wedge pads shift the load away from the heel bulbs, which might reduce the pressure on the palmar digital vessels and exert a smaller influence on the parameters measured in the Doppler ultrasound test.

Keywords: distal limb, Doppler ultrasound, egg bar shoes, equine, wedge pads

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Introduction

Horseshoeing has various purposes, and one of the main aims is to support the treatment of orthopedic diseases (Turner 1986) and to relieve the affected structures. In the past, egg bar shoes and shoes with wedge pads were commonly used in the treatment of navicular syndrome (Rogers and Back 2003). Currently, greater emphasis is placed on easing brakeover, which is achieved by rolling the front of the shoe (Van Heel et al. 2006). However, the load on lesion-prone structures could also be decreased with the use of egg bar shoes and shoes with wedge pads, with or without rolling. Blood flow in the foot has to be controlled, and non-age related degenerative vascular changes in the dorsal aspect of the deep digital flexor tendon (DDFT) are observed in both lame and clinically healthy horses, but are more severe in horses with palmar foot pain (Blunden et al. 2006). Doppler ultrasound has been used in horses to evaluate blood flow in peripheral vessels (Raisis et al. 2000, Hoffmann et al. 2001) and metacarpal arteries before and after sedation with acepromazine (Walker and Geiser 1986), in the limbs of non-sedated horses (Cochard et al. 2000), in lateral palmar digital arteries with and without limb loading (Hoffmann et al. 2001), and to check the repeatability of Doppler ultrasound measurements in equine limbs (Menzies-Gow and Marr 2007).

The aim of this study was to determine the effect of horseshoeing with egg bar shoes and shoes with wedge pads on blood flow parameters in the lateral palmar digital artery measured with Doppler ultrasound. To the best of the authors' knowledge, the effect of shoeing on blood flow above the palmar digital artery has never been measured using the Doppler ultrasound method. The results of the study could support early detection of circulatory disorders, speed up treatment and prevent ischemic processes in the hoof.

Materials and Methods

The study was conducted on 16 client-owned horses, including 11 mares and 5 geldings. The animals for the study were selected from a population of 57 horses in two stables.

Due to the fact that the study used client-owned horses and the study was not associated with invasiveness, at the time of the study the consent of the bioethical commission was not needed.

The horses were regularly trimmed by the same farrier. The animals were aged 5 to 8 years (mean 6.37), they weighted between 430 and 570 kg (mean 450 kg) and represented the following breeds: Wielkopolska (7 horses), Polish Halfbred (6 horses) and Małopolska (3 horses). According to the owners, none of the animals had a history of lameness associated with distal limb pathology. The examined horses had been barefoot for at least one year. A straight hoof-pastern axis was one of the main inclusion criteria in the study. All horses underwent physical and orthopedic examinations which included evaluations in standing position and in motion, flexion tests, and radiography of the distal limb. Lateromedial radiographs focused on the distal interphalangeal joint, proximal interphalangeal joint and the fetlock. Oxspring (dorsoproximal-palmarodistal oblique) radiographs of the navicular bone were also acquired. Lameness examinations and radiographs were performed before and after shoeing. Radiographs were assessed based on the position of the coffin bone in the hoof capsule and signs of bone rotation. None of the horses displayed such symptoms. The animals were also examined for symptoms of osteoarthritis in distal and proximal interphalangeal joints and the fetlock. The navicular bone was examined for chronic changes at the attachments of navicular ligaments and the number of synovial invaginations within the bone. Increased ossification of the palmar processes of the distal phalanx bone was not observed in any animals. Radiographs were repeated after one month to reassess the mentioned structures and to check for acute pathological changes such as hoof abscess or laminar inflammation. No changes were found in any of the horses, and all animals were included in the study. The horses were examined approximately 10 days after hoof trimming. During this 10-day period, the horses were examined for sole sensitivity, and the pulse was monitored above the digital palmar arteries to rule out inflammation. At the beginning of the study, all hooves were quite similar in terms of toe length and heel height. They were regularly trimmed to minimize differences between the animals.

The results of horse the evaluations and Doppler ultrasonography were assessed by two of the authors (M.M., P.H.). Each horse included in the study was clinically healthy, without symptoms of lameness or radiographic changes. The horses were randomly divided into two groups:

Group 1 - healthy horses shod with egg bar shoes, without a history of thoracic limb disease (8 horses). The first Doppler ultrasound test was performed before shoeing. The horses were trimmed before shoeing to maintain a straight hoof-pastern axis. Steel graduated egg bar shoes with frog support and one front clip were used in the study. They were cold-fitted, without rolling the toe. The end of the shoe was positioned exactly under the heel, where the line drawn along the third metacarpal bone touched the ground at a right angle. The shoe was fitted with three nails on each side,

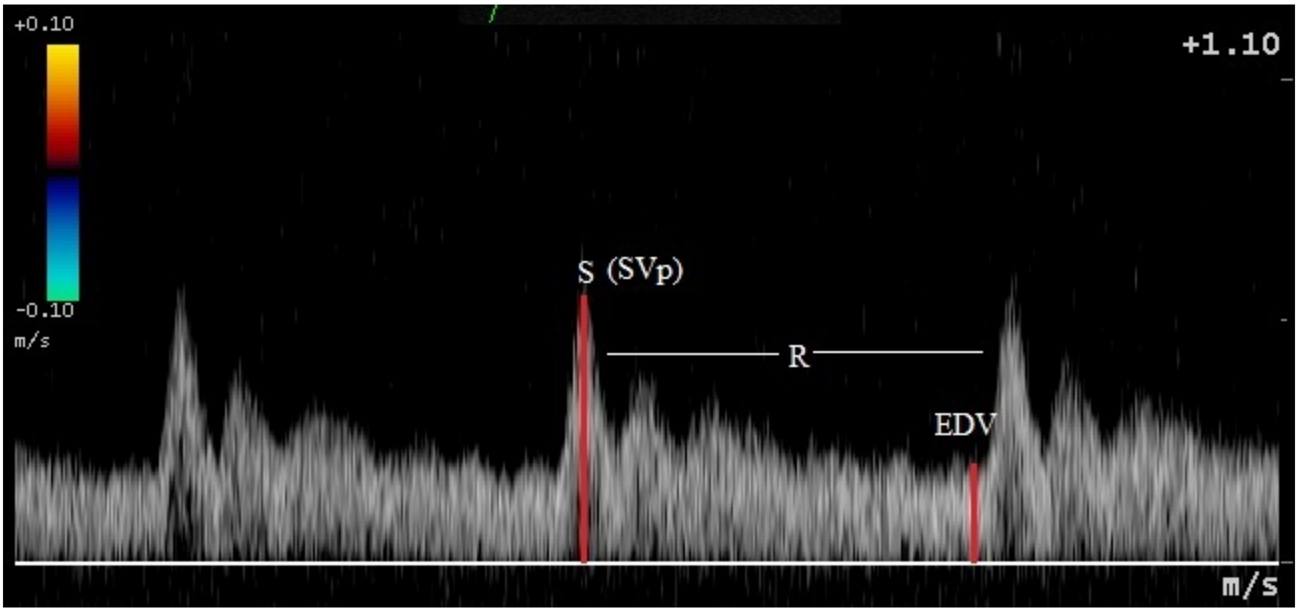

Fig. 1. Low-resistance flow measured in the horse lateral palmar digital artery before shoeing. A systolic peak (S) and the location where systolic velocity (SVp) was measured, followed by two diastolic peaks and a diastolic wave (R), as well as a diastolic peak and the location where end-diastolic velocity (EDV) was measured, are shown.

with the last one inserted cranially at the widest point of the sole. After a monthly adaptation period, physical and orthopedic examinations and radiography were repeated. All horses were found to be clinically healthy, and Doppler ultrasonography was repeated.

Group 2 - healthy horses without a history of thoracic limb disease (8 horses) were shod with wedge pads. The first Doppler ultrasound test was performed before shoeing. Half wedge pads lifted the heels by 10 mm. Open pads were used without packing between the hoof and the pad. They were cold-fitted between the hoof and the shoe with three nails without rolling the toe. The last nail was inserted cranially at the widest point of the sole. The following procedure was identical to that applied in group 1. After a monthly adaptation period, physical and orthopedic examinations and radiography were repeated. All horses were found to be clinically healthy, and the second Doppler ultrasonography was performed.

Doppler ultrasound test

A small area of coat hair was shaved (4 cm x 4 cm) near the metacarpophalangeal joint to facilitate the ultrasound test and improve the accuracy of blood flow measurements. The horses were not sedated. The Doppler ultrasound test was performed with the use of an Esaote MyLab 30 Gold ultrasound machine equipped with a 7.5-12 MHz linear array transducer. To improve the repeatability of the measurements, the transducer was positioned directly below the distal border of the metacarpophalangeal joint recess. Most scans were performed at a frequency of 7.5 and 10 MHz. All scans were performed by the same operator (M.M). During the test, the load was equally distributed between the four limbs. Ultrasound gel was used to facilitate transmission between the probe and the skin. The probe was placed near the metacarpophalangeal joint to visualize blood vessels in the cross-section in B-mode. The orientation marker was positioned cranially and on the left side of the screen. The color flow imaging option was activated, where red denoted blow flow in the lateral palmar digital artery in the direction of the probe, and blue represented blood flow in the lateral palmar digital vein in the opposite direction. The probe was rotated relative to the longitudinal axis of the vessel with the probe marker pointing dorsally. In the continuous wave mode (CW), red corresponded to arterial flow and blue represented venous flow. A sample volume (SV) of 1 mm was set in the central part of the vessel. The insonation angle was set at 60° by exerting minor pressure on the probe and changing the ultrasound settings (D-steer option and insonation angle). The flow velocity scale was set to avoid aliasing. During each Doppler ultrasound scan, arterial blood flow was measured three times, and the middle result was used in statistical analysis (Fig. 1, Table 1). The scan was conducted under similar conditions to minimize the influence of external factors. Horses were kept for 12 hours in a stable before the test, and scans were performed in the morning.

Statistical analysis

The following parameters were calculated to describe quantitative variables: median, mean, standard devia-

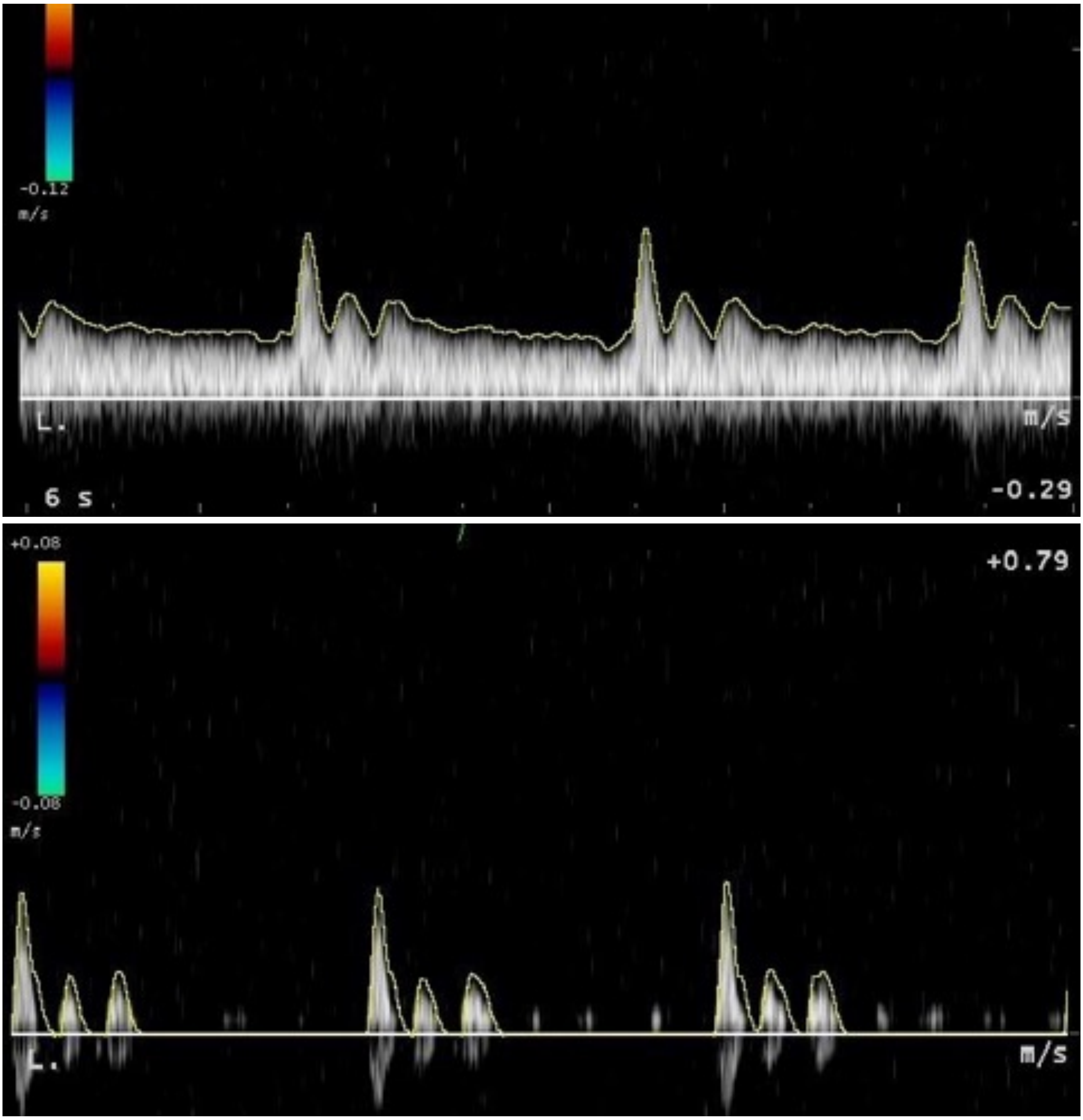

Fig. 2. Two Doppler ultrasound scans of blood flow in the lateral palmar digital artery of a 6-year-old Małopolska gelding. (a) Low-resistance flow was diagnosed before shoeing. Arrows point to the sites where systolic velocity (SVp) and end-diastolic velocity (EDV) were measured. (b) After shoeing with egg bar shoes, the blood flow pattern changed to high-resistance flow with periodic disappearance of the pulmonary venous diastolic wave. After shoeing, SVp decreased from 49.2 cm/s to 23.7 cm/s, EDV decreased from 21.6 to 0 cm/s, PI increased from 1.37 to 12.14, and RI increased from 0.56 to 1.01.

Table 1. Doppler parameters and short definitions.

Parameter	Meaning
FVI (m)	Flow Velocity Integral
SVp (cm/s)	Peack Systolic Velocity
EDV (cm/s)	End Diastolic Velocity
Vmn (cm/s)	Mean Velocity
PI	Systolic Velocity−Diastolic Velocity/ Mean Velocity
RI	Systolic Velocity−Diastolic Velocity/ Systolic Velocity

Table 2. Blood flow parameters measured in the Doppler ultrasound test in horse group 1, before and after shoeing with egg bar shoes. FVI – flow velocity integral, SVp – peak systolic velocity, EDV end-diastolic velocity, Vmn – mean velocity, PI – pulsatility index, RI – resistivity index.

	N	Median Barefoot/Shod	Mean Barefoot/Shod	Standard deviation Barefoot/Shod	Minimum Barefoot/Shod	Maximum Barefoot/Shod	p value
FVI (m)	8	0.47/0.4	0.53/0.34	0.2/0.15	0.25/0.05	0.8/0.51	0.116
SVp (cm/s)	8	48.57/40.07	52.48/40.5	10.58/10.83	42.55/23.6	67.2/55.8	0.173
EDV (cm/s)	8	23.52/16.67	24.36/14.72	7.95/7.77	13.35/0.0	36.55/22.05	0.046
Vmn (cm/s)	8	28.17/20.92	28.96/17.8	10.22/7.87	14.65/2.5	42.9/23.6	0.046
PI	8	0.88/1.44	1.07/2.96	0.53/4.1	0.68/0.83	2.1/11.29	0.173
RI	8	0.52/0.63	0.52/0.68	0.09/0.25	0.43/0.47	0.69/1.18	0.116

Table 3. Blood flow parameters measured in the Doppler ultrasound test in horse group 2, before and after shoeing with wedge pads. FVI – flow velocity integral, SVp – peak systolic velocity, EDV – end-diastolic velocity, Vmn – mean velocity, PI – pulsatility index, RI – resistivity index.

	N	Median Barefoot/Shod	Mean Barefoot/Shod	Standard deviation Barefoot/Shod	Minimum Barefoot/Shod	Maximum Barefoot/Shod	p value
FVI (m)	8	0.48/0.36	0.52/0.43	0.3/0.2	0.04/0.25	1.16/0.82	0.441
SVp (cm/s)	8	52.3/41.15	50.89/42.23	19.48/12.15	19.85/26.75	88.85/62.45	0.139
EDV (cm/s)	8	19.55/17.35	23.32/19.06	14.12/8.09	0.15/8.25	53.15/35.3	0.441
Vmn (cm/s)	8	26.9/18.6	27.06/21.82	14.41/9.0	2.35/14.00	57.2/40.4	0.374
PI	8	1.01/1.12	1.89/1.17	2.53/0.35	0.63/0.68	8.6/1.8	0.767
RI	8	0.54/0.57	0.58/0.56	0.18/0.11	0.4/0.36	1.02/0.77	0.767

tion, minimum and maximum values. Frequency tables were developed for categorical variables. Data distribution was evaluated using the Kolmogorov-Smirnov test. Values for which $p>0.05$ were analyzed using the Mann-Whitney U test at a significance level of 0.05. Values for which $p<0.05$ were analyzed using the Wilcoxon signed-rank test at a significance level of 0.05.

Results

Group 1

An analysis of the values measured before and after shoeing with egg bar shoes revealed significant ($p<0.05$) differences in the end-diastolic velocity (EDV) and mean velocity (Vmn). After shoeing, median EDV decreased from 23.52 cm/s to 16.67 cm/s ($p=0.046$), and median Vmn decreased from 28.17 cm/s to 20.92 cm/s ($p=0.046$). A low-resistance blood flow pattern was noted before shoeing. After shoeing, it remained unchanged in 5 horses, whereas a high-resistance pattern was observed in 3 animals. Measurement results are shown in Table 2, and they are presented graphically in Fig. 2.

Group 2

The results of measurements are shown in Table 3, and they are presented graphically in Fig. 3. After shoeing, a minor decrease was noted in blood flow parameters and PI values, and a minor increase was observed in RI values. Significant differences in Doppler ultrasound measurements were not observed after shoeing with wedge pads. A low-resistance blood flow pattern was noted both before and after shoeing.

Discussion

Study design

The examined horses were aged 5 to 8 years. In humans, blood flow in the lower limbs decreases with age due to a progressing decrease in the content of fat-free mass (Dinenno et al. 2001). Similar changes are not observed in the distal part of the equine limb, but age-related changes in vascular elasticity and blood flow in the equine digit have never been investigated, which is why mature horses were not qualified for the study. Sedation is not recommended before Doppler

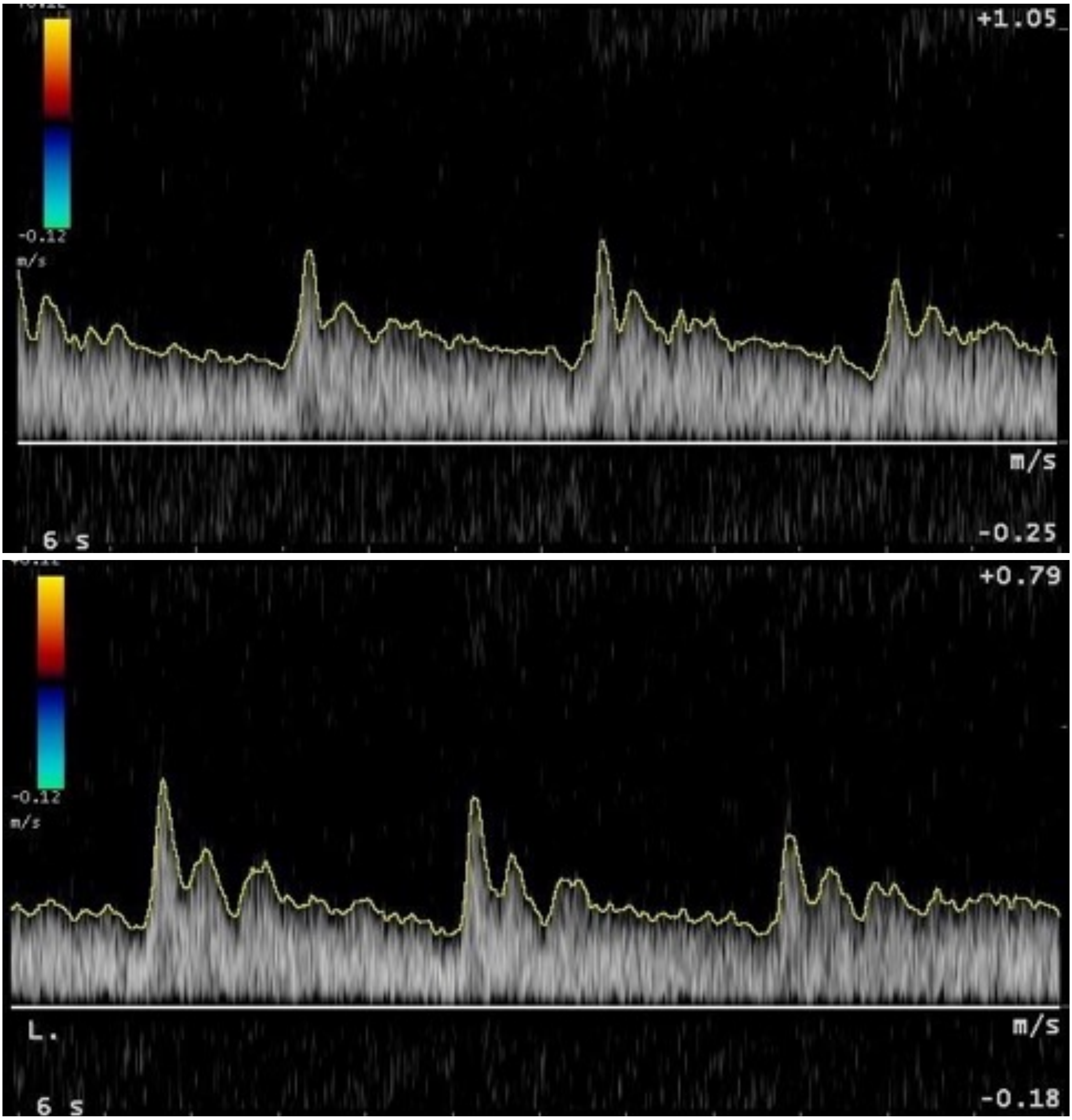

Fig. 3. Doppler ultrasound scan of blood flow in the lateral palmar digital artery of the thoracic limb in an 8-year-old Wielkopolska mare. (a) Low-resistance flow before shoeing is presented in the top image. (b) Low-resistance flow seen after the application of wedge pads is shown at the bottom. Low-impedance is visible in both cases. Minor changes in blood flow parameters were observed after shoeing: Vmn increased from 24.9 cm/s to 37.8 cm/s, PI increased from 1.18 to 1.37, and RI increased from 0.58 to 0.61.

ultrasonography because alpha-2 agonists, which are most often used to induce sedation in equine patients, interact with alpha-1 adrenergic receptors of peripheral vessels and stimulate vascular contraction (Hall and Clarke 1992). It could distort measurements and blood flow parameters measured in the Doppler ultrasound test.

Chochard et al. (2000) analyzed the parameters measured in only one limb to develop reference values for blood flow in thoracic limbs. The cited authors based their observations on the work of Bernstein (1985) who did not report differences in blood flow between the right and left limb in humans. In our study, the values measured in both thoracic limbs were analyzed. No significant differences were noted between the right and left limb; therefore, the average values from the measurements performed in both thoracic limbs were used in statistical analysis. Blood flow was measured in the lateral palmar digital artery at the level of the metacarpophalangeal joint. A comparison of the above results with the parameters measured in the area of the pastern or the median artery should be performed with great caution because the measured values can differ at various heights of the thoracic limbs (Cochard et al. 2000). Blood flow can change at different times of the day and after physical exercise, therefore, horses were not used, and they were not left in the pasture immediately before the test. Limb loading leads to changes in blood flow velocity, therefore, load was equally distributed between the four limbs during the test (Hoffmann 2001).

One of the aims of the treatment for navicular syndrome is to improve hoof mechanics with the use of orthopedic shoes (Leach 1993, Willemen et al. 1999). The use of wedge pads and 1° heel elevation cause 4% less pressure at the navicular bone and relief of the DDFT (Eliashar et al. 2004, Willemen et al. 1999). Navicular syndrome can also be managed with egg bar shoes which increase the palmar extension to support the navicular apparatus (Ostblom 1984). Based on the above consideration, egg bar shoes and shoes with wedge pads were used in this study. It should be noted, however, that shoeing has many side effects, and it is not a physiological process. It is generally assumed that wedge pads raise heels, which clearly increases the load on the superficial digital flexor tendon and the interosseous muscle (Willemen et al. 1999). However, according to a more recent study (Hagen et al. 2018), heel elevation produces similar effects on SDFT and DDFT, where an elevation of 20° can relax both structures, with a somewhat smaller impact on DDFT. Despite the above, prolonged shoeing, in particular with wedge pads, contributes to a steeper toe angle and overloading of the dorsal lamellae in the front of the hoof. According to Thomason et al. (1992) an increase in the hoof angle results in a higher load on the dorsal lamellae of the hoof. Blood flow may be constricted, and chronic pressure on the circumflex artery inhibits blood flow to laminar tissue.

This study analyzed the use of the Doppler ultrasound test for evaluating blood flow in distal parts of the thoracic limb in healthy horses. Other authors evaluated the integrity of equine digital vessels with the use of other methods, including laser Doppler flowmetry (Adair et al. 2000), computed tomography angiography (Collins et al. 2004), venography (D'Arpe and Bernardini 2010) and scintigraphy (Ritmeester et al. 1998). These methods are highly useful in diagnosing vascular perfusions of the hoof, but they are invasive and often not available in routine field practice. The main advantage of the Doppler ultrasound examination is that this technique is non-invasive and generally more accessible. Equipment costs and the cost of the examination are relatively low, which greatly increases the availability of this diagnostic tool (Laissy et al. 1996). Despite the above, the method applied in this study does not support direct evaluations of blood flow in the hoof which could provide information about increased flow impedance and could be indicative of impaired circulation in the area below the ultrasound probe.

Effect of horseshoeing on blood flow parameters

Blood flow measurements in the Doppler ultrasound test performed in group 1 and group 2 horses before shoeing were indicative of arterial flow under physiological conditions and were similar to those reported by other authors (Aguirre et al. 2013, Cochard et al. 2000). In this study, arterial blood flow was characterized by low impedance in all animals before shoeing. In contrast, Cochard et al. (2000) reported high-impedance flow in 4 out of the 9 analyzed healthy horses. Wongaumnuaykul et al. (2006) observed low-impedance flows as well as high-impedance flows with low EDV or retrograde blood flow in healthy control horses. The high-impedance flow spectrum was attributed to chronic stenosis or vascular blockage with collateral circulation. In this study, high-impedance flow was observed in 3 horses from group 1 after shoeing with egg bar shoes.

In the literature, the average blood flow values in the lateral palmar digital artery of thoracic limbs in horses without degenerative changes in distal parts of the limb, measured at the level of the metacarpophalangeal joint, were similar to the results of our study. Clear differences were noted in the maximum value of PI which reached 8.6 in this study, but only 2.56 in the work of Cochard et al. (2000) and 2.22 in the study by Aguirre et al. (2013). The values of PI ranged from 0.63 to 2.34 and were similar to those reported by other authors, but the mean value of PI was determined at 8.6 in one group 2 horse before shoeing. After shoeing, the PI in that horse dropped to 0.71. The causes of the observed increase in PI were not identified. The shape of the hoof capsule was within the norm, the horse was clinically healthy and had no history of lameness. This case should be probably analyzed in view of other factors that could influence measurement results.

In horses shod with egg bar shoes, systolic velocity decreased in all animals, but significant differences were noted only in the values of mean velocity and decreasing end-diastolic velocity which decreased in all group 1 horses after shoeing. In contrast, arterial flow parameters did not change significantly in horses shod with wedge pads. The difference between the analyzed shoeing techniques could be attributed to increased heal pressure in horses shod with egg bar shoes (Hüppler 2016). Wedge pads shift the load away from heels, which could reduce the pressure on palmar digital vessels and exert a smaller influence on the parameters measured in the Doppler ultrasound test. The latter could change in consequence of long-term shoeing, whereas wedges generally cause underrun heels (Hagen et al. 2018). The above could lead to the palmar vessel compression, which can affect Doppler blood flow parameters. Doppler tests should be performed regularly in the long term to confirm such risk. In a study by Ritmeester et al. (1998) dorsal laminar perfusion in horses with laminitis increased after shoeing with egg bar-heart bar shoes. However, these observations were made in horses with chronic laminitis with rotation of the distal phalanx and coronary ischemia caused by the compression of the dorsal coronary corium by the extensor process. Therefore, changes in the position of the distal phalanx could alter blood flow parameters. In the cited study, solar blood flow decreased. The above findings appear to be more consistent with our results. However, in the current study, blood flow parameters decreased despite the fact that the position of the distal phalanx remained unchanged in horses shod with egg bar shoes.

Limitations of the study

The main limitation was that there was no control group consisting of horses shod with plain shoe, and also there was no barefoot group where the Doppler ultrasound was repeated. We based our results and conclusions only on the change in the Doppler parameters before and after shoeing. General results can be distinctly affected by toe modifications, shoe position, length and width of the bar, height of the wedge pad and kind of packing. We were only focused on two particular types of shoeing, when is why, when using other types of shoes, results might be different.

Conclusions

The use of egg bar shoes decreases end-diastolic velocity (EDV) and mean velocity (Vmn) in the lateral palmar digital artery. In horses shod with wedge pads, significant differences in blood flow parameters measured in the lateral palmar digital artery during a Doppler ultrasound test were not observed before and after shoeing. Our results suggest that egg bar shoes have a greater impact on blood circulation in the distal part of the equine limb than shoes with wedge pads.

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