Research in Veterinary Science 209 (2026) 106276

Contents lists available at ScienceDirect

Research in Veterinary Science

journal homepage: www.elsevier.com/locate/rvsc

Evaluation of doppler indexes of the lateral palmar digital artery in lame sport horses

Mariaelena de Chiara [a], Andrea De Matteis [a], Chiara Del Prete [a,*], Dario Costanza [b], Chiara Montano [c], Luigi Auletta [d], Valeria Gaia Marinelli [a], Francesco Buono [a], Maria Pia Pasolini [a]

[a] Department of Veterinary Medicine and Animal Production, University of Napoli Federico II, Via Federico Delpino 1, 80137 Napoli, Italy
[b] Interdepartmental Centre of Veterinary Radiology, University of Napoli Federico II, Via Federico Delpino 1, 80137 Napoli, Italy
[c] Department of Veterinary Medical Sciences DIMEVET, University of Bologna, Via Tolara di Sopra 43, 40064, Ozzano dell'Emilia, Bologna, Italy
[d] Department of Veterinary Medicine and Animal Science, University of Milan, Via dell'Università 6, 26900, Lodi, Milan, Italy

ARTICLE INFO

Keywords:
Digital blood flow
Echo-doppler
LPDA
Horse
Lameness

ABSTRACT

Although lateral palmar digital artery (LPDA) flow velocity does not differ between forelimbs, horses with lameness typically reduce loading of the affected limb during the weight-bearing phase.

This study aimed to assess whether Pulsed-Wave (PW) Doppler indices of the (LPDA) blood flow differ between the two forelimbs in horses with unilateral forelimb lameness, and whether these differences correlate with lameness severity. Twenty-seven lame and 15 healthy horses were enrolled. All Doppler ultrasonographic examinations were performed by a single operator, blinded to both the presence or absence of lameness and its location, with horses non-sedated and standing squarely. Peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) of the LPDA in both front limbs were acquired. No significative differences were found between the EDV and RI in the lame group and the sound group. PSV was higher ($P = 0.024$) in lame group (32.9–123.5 cm/s) compared to the sound group (17.4–69.3 cm/s). Furthermore, considering the differences (Δ) between the lame and sound limbs, ΔPSV was significantly higher ($P = 0.002$) in lame horses (15.3 cm/s; range 3.7–78.3 cm/s) compared to sound horses (2.1 cm/s; range 0.53–7.4 cm/s). No correlation between Doppler indexes and the degree of lameness was found. Reduced load on affected limbs may increase PSV values in lame limbs in most, though not all horses, thereby widening the difference between the PSV of lame and sound limbs. However, PSV values do not appear to reliably reflect lameness severity. Further research could identify additional factors influencing LPDA, beyond reduced weight bearing.

1. Introduction

Orthopaedic disorders are a common cause of pain and lameness in sport horses (Davidson, 2018). In sound horses, the forelimbs bear approximately 58% of the body weight, evenly distributed between left and right limbs. Studies on weight distribution in lame horses show substantial deviations from this pattern. Lame horses typically demonstrate compensatory load redistribution, reducing weight on the affected limb and shifting it to the other limbs (Merkens and Schamhardt, 1988; Hood et al., 2001; Weishaupt, 2005).

After emerging from the medial artery's bifurcation, the lateral and medial palmar digital arteries run abaxially to the proximal sesamoid bones in the fetlock area (Fogaça et al., 2023). The palpation of the lateral palmar digital artery (LPDA) is a useful tool for assessing orthopaedic conditions, allowing the detection of increase in pulse amplitude and frequency in limbs affected by distal diseases causing lameness (Ross, 2003). Clinically, an increased digital pulse is often interpreted as an indirect indicator of increased blood flow secondary to inflammation within the hoof or distal limb structures (Ross, 2003). However, this assessment is inherently subjective and characterized by low sensitivity and inter-observer variability, highlighting the need for more objective and reliable methods to evaluate digital vascularisation (Baxter, 2020). A quantitative assessment of digital blood flow could improve the identification of the lame limb, provide insights into the underlying pathophysiological mechanisms, and allow longitudinal monitoring of disease progression or response to treatment. Several

* Corresponding author.
E-mail address: chiara.delprete@unina.it (C. Del Prete).

https://doi.org/10.1016/j.rvsc.2026.106276
Received 12 March 2026; Received in revised form 17 May 2026; Accepted 26 May 2026
Available online 27 May 2026
0034-5288/

techniques have been proposed to evaluate vascularisation, including scintigraphy, contrast angiography, and laser Doppler flowmetry; however, these techniques are either invasive or not easily performed in clinical practice (Aguirre et al., 2013; Cochard et al., 2000). According to many authors, Pulsed-Wave (PW) Doppler ultrasonography represent a non-invasive, sensitive, cheap, and easily performable exam for routine evaluation of the horse limb's blood flow (Aguirre et al., 2013; Cochard et al., 2000; de Chiara et al., 2024; Fogaça et al., 2023; Hoffmann et al., 2001; Menzies-Gow and Marr, 2007; Pietra et al., 2004; Russ et al., 2023; Vieira et al., 2016; Wongaumnuaykul et al., 2006).

PW Doppler ultrasonography has proven to be a valuable tool for evaluating digital vascular dynamics in horses, particularly in conditions such as systemic inflammatory response syndrome (SIRS), where haemodynamic changes are systemic and no inter-limb differences have been reported, and laminitis, in which blood flow velocity and arterial diameters typically increase (Aguirre et al., 2013; Wongaumnuaykul et al., 2006).

No differences were observed in blood flow between the forelimbs of healthy horses (Pietra et al., 2004; de Chiara et al., 2024), whereas the weight-bearing state has a significant impact on the blood flow characteristics of the LPDA, leading to higher flow velocity in non-weight-bearing limbs (Hoffmann et al., 2001; Pietra et al., 2004).

The aims of this study were to evaluate whether peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) of the LPDA, as measured by PW Doppler ultrasonography in both forelimbs of sport horses with unilateral forelimb lameness while weight-bearing, showed measurable changes, and to determine whether these indexes correlated with lameness severity. By comparing data between a lame group and a healthy control group, the authors hypothesized that Doppler indexes differ between the two forelimbs in lame horses, reflecting disparities in weight distribution.

2. Material and methods

2.1. Ethical statement

This study was approved by the Ethical Animal Care and Use Committee ____. Informed consent for the collection and publication of data was obtained from the owners of the horses included.

2.2. Animals

Sport horses with unilateral forelimb lameness were recruited from multiple farms based on referral by attending veterinarians familiar with each case. In all cases, the diagnosis had been previously established by experienced practitioners (≥10 years of experience) through a complete orthopaedic examination, supported by diagnostic analgesia and imaging techniques as required.

Horses with concurrent hindlimb lameness, a previous diagnosis of laminitis, or suspected systemic inflammatory response syndrome (SIRS) were excluded. Using the same criteria, non-lame control horses were selected from the same farms based on the referring veterinarian's report indicating no evidence of lameness.

All horses underwent Doppler ultrasonographic examination performed by a veterinary ultrasonographer who was fully blinded to the clinical status of the animal, in order to confirm the presence of lameness.

Following the ultrasonographic assessment, a standardized clinical and orthopaedic evaluation was performed by the investigators in order to confirm the diagnosis. This evaluation included examination at rest and dynamic assessment in a straight line and on a circle, allowing assignment of a lameness score.

2.3. Data collection

Data were collected from February to April in the region of ___. Ambient temperature was recorded prior to the clinical examination using a smartphone weather application (iPhone 15 Pro, Apple Inc.). All evaluations were performed without sedation to prevent pharmacologically induced alterations in blood flow, and the horses were gently restrained by their grooms. General history and signalment data were recorded for each horse in a medical record before the ultrasound examination and subsequently entered into an electronic spreadsheet (Microsoft Excel ver. 16.53 2, Microsoft Corp.). Weight was evaluated using weight tape (Carroll and Huntington, 1988), while heart rate was measured by cardiac auscultation. Both the clinical evaluation and ultrasound were performed by the same author, a veterinarian with over five years of experience. Doppler evaluations were carried out in the wash stall located close to the horses' boxes, and the horses were brought directly from their stalls for examination, having walked only a short distance and without any prior exercise, structured physical activity, or prolonged warm-up before the assessment.

During all the ultrasound examination, horses stood squarely and distributed their weight evenly on all four limbs. All examinations were performed using a portable ultrasound device (Esaote MyLab30 VET Gold Cardiovascular) with a 6–18 MHz multifrequency electronic linear transducer, model LA435. The fetlock area was trimmed, cleaned with soap, rinsed with tap water and moistened with alcohol prior to the probe being applied. After massaging acoustic coupling gel onto the skin and applying it to the probe, a silicone standoff pad was installed. The limb to begin the examination was chosen at random by tossing a coin, as the veterinary sonographer was blinded — that is unaware of the presence or absence of the lameness at the time of the ultrasonographic assessment, which was performed before the lameness evaluation. The ultrasonographic probe was positioned over the neurovascular bundle, located on the palmaro-lateral aspect of the fetlock joint, at the level of the lateral palmar articular recess (Fig. 1) (Menzies-Gow and Marr,

Fig. 1. Probe placement for the lateral palmar digital artery's evaluation.

2007).

The identification of the LPDA was performed using transverse scan. The probe was then rotated 90° and all the measurements were acquired in longitudinal scan, to avoid refractive artifacts, according to Pasolini et al. (2019) and Costanza et al. (2021) (Fig. 2).

Light pressure was applied during examinations to prevent compression of the LPDA walls. Colour Doppler in Duplex mode was used to differentiate the LPDA from the homonymous vein. Then, using a sample width of 1–2 mm, Pulsed Wave Doppler in triplex mode was applied to the artery. A wall filter and the lowest possible pulse repetition frequency were used to ensure an aliasing-free flow display. A fixed Doppler angle adjustment of 70° was used, aligning the cursor with the long axis of the artery. At least three consecutive similar waveforms were recorded in the Doppler spectrum and chosen for analysis.

Following picture capture, the operator used the ultrasound device's "resistive index" function to assess the following parameters: peak systolic velocity (PSV, cm/s); end-diastolic velocity (EDV, cm/s); resistive index (RI), which is computed as RI = (PSV − EDV)/PSV. For each limb, three measurements were performed. These measurements were stored on the ultrasound device, preserved in a picture archiving and communication system (dcm4chee-arc-light version 5.11.1, http://www.dcm4che.orghttp://www.dcm4che.org) and recorded in an electronic spreadsheet.

2.4. Lameness evaluation

Following the ultrasound examination, lameness-specific information was collected to document each horse's clinical condition. Owners were questioned regarding the onset of lameness, when present, to classify it as acute or chronic, and to assess its progression over time. Lameness persisting for more than three months was classified as chronic (Ross, 2003). The orthopaedic examination was performed by the attending veterinarian, who had more than 10 years of experience in this field. The veterinarian adhered to the following standardized protocol during the orthopaedic examination: horses were assessed while standing squarely, observing weight distribution across the four limbs to identify any load-bearing abnormalities. The digital pulse was then assessed to determine its intensity, and the hoof temperature was evaluated through palpation. Finally, a dynamic evaluation was performed, first at walk and then at trot, along a straight line and on a circle. Lameness was graded using the American Association of Equine Practitioners (AAEP) scale, ranging from 0 to 5, where 0 indicated a sound horse.

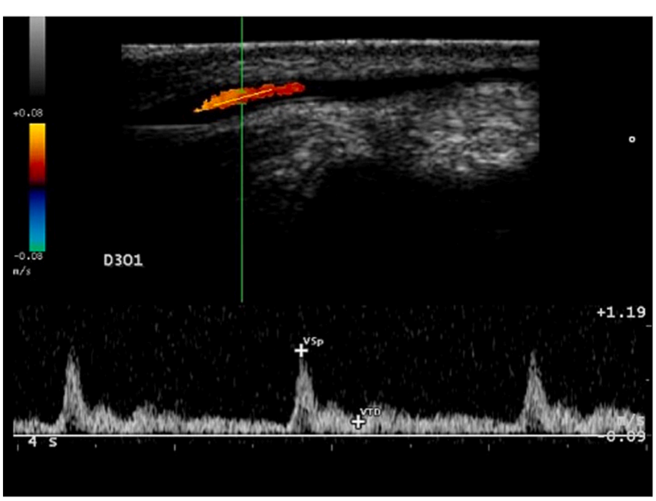

Fig. 2. Ultrasonographic examination of the LPDA using a longitudinal scan. The red-orange colour identifies the LPDA's blood flow. The Doppler waveform in the lower image shows a systolic peak, followed by diastolic peaks and an end-diastolic plateau. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.5. Data analysis

Data were recorded into an electronic spreadsheet (Microsoft Excel ver.16.53 2, Microsoft Corp., Redmond, WA, USA) before being imported into a dedicated statistical analysis software (SPSS 29.01 for Windows, SPSS Inc., Headquarters, Chicago, IL, USA). Normality was assessed using Shapiro-Wilk's W test, and results were reported as mean ± standard deviation for normally distributed data or as median (range) for non-normally distributed data. Power analysis was performed a posteriori with dedicated software (G*POWER version 3.1.9.2). Comparisons of PSV, EDV, RI, weight, age and sex between lame and healthy groups were performed using a Student's or a Mann-Whitney's U and Pearson's Chi-squared test, as appropriate. To minimize individual variability, differences between measurements (Δ) obtained from the lame and healthy limbs were evaluated within both lame and sound groups. Absolute values of Δ were considered. Since PSV was the only variable that differed between the groups, Spearman's r was used to assess the correlation between PSV and the degree of lameness. Moreover, the difference in PSV between the four lameness degrees were compared with Kruskal-Wallis test. Finally, an Ordinal Logistic Regression was used to predict the impact of PSV on the lameness severity. The proportional odds assumption was tested with the Score / Wald test of parallel lines. Linearity of the continuous predictor on the logit scale was assessed using the Box–Tidwell approach by testing the interaction between PSV and its natural logarithm. Model adequacy and risk of overfitting were evaluated by assessing the events-per-parameter ratio and the stability of model estimates. The ordinal logistic regression model was not affected by overfitting, with a favorable events-per-parameter ratio (27 observations for 1 predictor) and stable coefficient estimates.

3. Results

The ambient temperature recorded prior to the clinical examination was 16.7 ± 4 °C. A total of 42 Saddlebred riding horses, including 21 geldings and 21 females, were enrolled in the study, leading to a study power of 98%, with respect to the PSV values. The median age was 16 years (range 4–30). After the clinical examination 27 horses were considered lame and enrolled in the lame group. The other 15 animals were included in the sound group. In all enrolled horses, the lameness classification established during the blinded clinical re-evaluation was consistent with the initial classification provided by the referring veterinarians, and no discrepancies between assessments were identified. Of the 27 horses in the lame group, 6 presented with acute lameness, while the rest exhibited chronic lameness. Lameness ranged from grade 1 to 4, and the distribution of lameness grades among the horses is reported in Table 1.

The analysis indicates that the groups were homogeneous with respect to age, weight, and sex. The median age was 15 (range 6–24) years in the sound group and 17 (range 4–30) years in the lame group,

Table 1
Distribution of horses according to the type of lameness (acute vs. chronic) and the AAEP lameness grade. The table reports the number of horses in each grade (1 to 4) according to the AAEP scale, with percentages shown relative to the total for each grade (row percentages) and relative to the overall study population (column percentages in parentheses).

Lameness Grade (AAEP)	Acute	Chronic	Total
Grade 1	2 (25%;7.4%)	6 (75%; 22.22%)	8 (29.63%)
Grade 2	0 (0%;0%)	8 (100%;29.63%)	8 (29.63%)
Grade 3	3 (42.9%;11.1%)	4 (57.1%;14.81%)	7 (25.93%)
Grade 4	1 (25%; 3.70%)	3 (75%; 11.11%)	4 (14.81%)
Total	6 (22.22%)	21 (77.78%)	27 (100%)

with no significant difference ($p = 0.309$). Similarly, the median weight was 477 kg (range 454-512 kg) in the sound group and 471 kg (range 384-570 kg) in the lame group, ($p = 0.843$). The lame group included 16 females and 11 males, whereas the sound group included 5 females and 10 males ($p = 0.198$). The mean values of EDV and RI did not differ significantly between the two groups (Fig. 3A and B). The median PSV

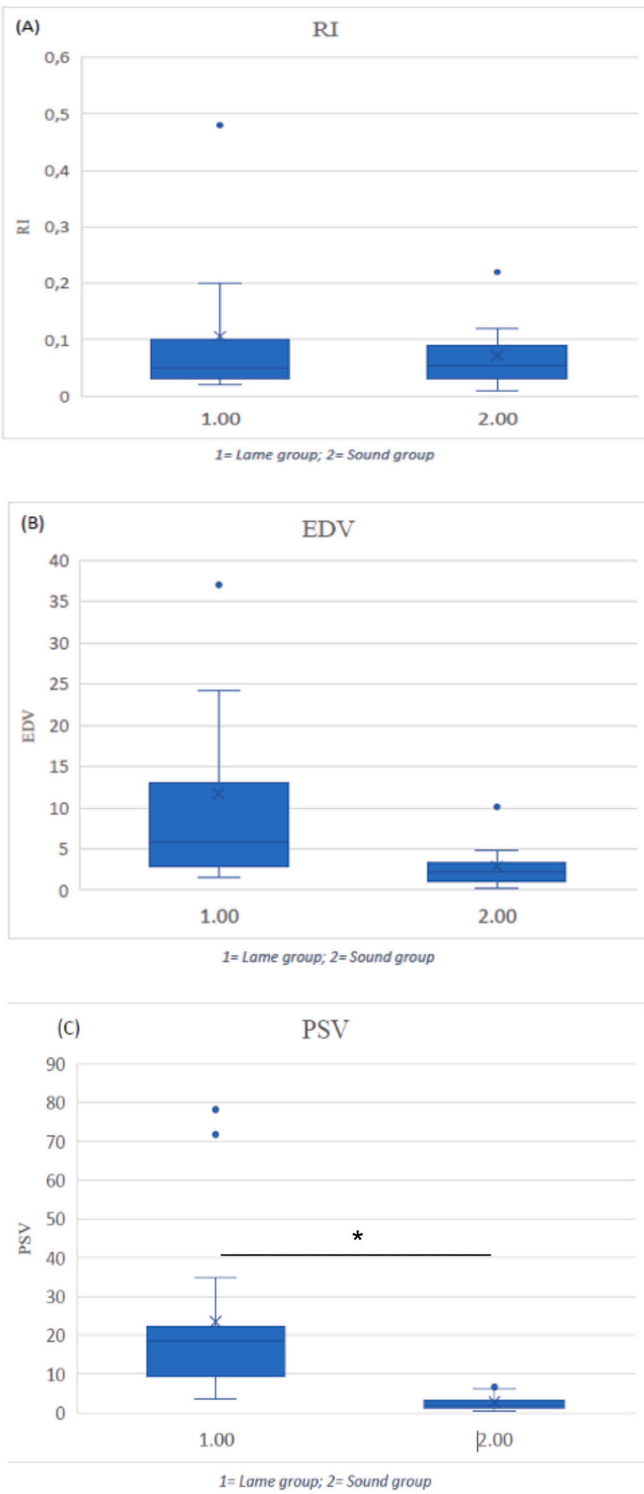

Fig. 3. Graphic representation of delta in resistive index (RI) (A), end-diastolic velocity (EDV) (B), peak systolic velocity (PSV) (C) in lame and sound groups. * indicates a statistical difference in the delta PSV (C) values between the lame group (1) and the sound group (2).

value was significantly higher in the lame group (78.0 cm/s; range 32.9–123.5 cm/s) compared with the sound group (45.0 cm/s; range 17.4–69.3 cm/s; $p = 0.024$). Notably, in 7 cases, PSV values were higher in the contralateral sound limb compared to the lame limb. A retrospective review of the clinical history revealed that, in all these horses, lameness had been present for approximately one year, thus being consistent with a chronic condition.

There were no significant differences between lame and sound groups in terms of Δ EDV ($p = 0.202$) and RI ($p = 0.673$). However, Δ PSV was significantly higher in the lame group (15.3 cm/s; range 3.7–78.3 cm/s) than in the sound group (2.1 cm/s; range 0.53–7.4 cm/s) ($p = 0.002$) (Fig. 3C).

Additionally, no significant correlation coefficient revealed no significant correlation between PSV values and the degree of lameness ($r = -0.029$, $p = 0.886$), suggesting that the values were not directly associated with the severity of lameness. The PSV values did not differ between different degrees of lameness (H = 2.48; $p = 0.48$). The proportional odds assumption was not violated ($\chi^2 = 0.21$, df = 2, $p = 0.90$), supporting the use of an ordinal logistic regression model. No evidence of deviation from linearity was observed for PSV on the logit scale ($\beta(\text{PSV} \times \ln(\text{PSV})) = -0.00795$; SE = 0.05112; Wald $\chi^2 = -0.156$; p = 0.88). In the ordinal logistic regression model, PSV was not associated with lameness severity (p = 0.90). PSV was entered as a continuous predictor in an ordinal logistic regression model (proportional odds, logit link), with lameness grade (1–4) as the outcome variable. Estimates are reported as odds ratios with 95% confidence intervals and refer to the odds of being in a higher lameness grade for a one-unit increase in PSV as reported in Table 2.1. The thresholds represent the estimated intercepts separating adjacent levels of the ordinal outcome (lameness grades 1–4). These parameters define the boundaries between outcome categories and are not effects of the predictor, results of the threshold evaluation from the ordinal logistic regression are reported in Table 2.2.

4. Discussion

The findings of this study confirm the absence of differences in LPDA blood flow parameters in sound horses and support the hypothesis that unilateral forelimb lameness is associated with differences in blood flow between the two forelimbs, as reflected by differing LPDA PSV values. However, no correlation was identified between Doppler indexes and lameness degree, suggesting that PSV is not a reliable predictor of lameness severity.

The Doppler examination is a non-invasive and easy-to-perform method, which can also be reliably carried out by veterinarians with limited experience. In addition, its repeatability and feasibility under standardized conditions have been previously demonstrated (de Chiara et al., 2024), supporting the reliability of the measurements obtained in the present study.

Doppler ultrasound has emerged as a valuable tool for examining peripheral vascularization in horses, allowing a non-invasive visualization of arteries, veins, and blood flow patterns (Cochard et al., 2000; Hoffmann et al., 1999). In healthy horses, the Doppler waveform typically shows a systolic peak, followed by diastolic peaks and an end-diastolic plateau (Hoffmann et al., 2001). Alterations in peripheral blood flow have been associated with various equine diseases, particularly laminitis (Aguirre et al., 2013; Wongaumnuaykul et al., 2006). However, to the authors' knowledge, no studies have assessed Doppler differences in horses with lameness unrelated to vascular diseases affecting the peripheral circulation.

Table 2.1
Ordinal logistic regression analysis of PSV as a predictor of lameness grade.

Predictor	β	SE	95% CI (β)	OR	95% CI (OR)
PSV	−0.00159	0.01333	−0.0277; 0.0245	0.998	0.973–1.025

Table 2.2
Thresholds (cut-points) of the ordinal logistic regression model.

Threshold	Estimate	SE	95% CI
Grade 1 / 2	−0.955	0.870	−2.661; 0.750
Grade 2 / 3	0.214	0.316	−0.406; 0.833
Grade 3 / 4	0.318	0.352	−0.371; 1.007

The primary aim of this study was to characterize variations in blood flow in lame horses, without reference to the specific underlying cause of lameness. Horses affected by conditions such as laminitis or SIRS were excluded, as these disorders are known to have a direct effect on peripheral circulation through mechanisms such as the release of cytokines and other inflammatory mediators, as reported in the literature (Aguirre et al., 2013; Wongaumnuaykul et al., 2006). In the horses included in the present study, although the specific cause of lameness was not recorded, all cases were of orthopaedic origin. Any potential effects on peripheral circulation are therefore likely related to factors different from those involved in horses affected by laminitis or SIRS (Aguirre et al., 2013; Wongaumnuaykul et al., 2006).

Blood flow to the foot is influenced by weight-bearing conditions (Hoffmann et al., 2001). In the present study, measurements were obtained under static conditions, with the horse standing still; however, weight redistribution associated with lameness may occur both during stance and locomotion, potentially influencing vascular dynamics. Δ PSV was significantly higher in the lame group compared to the sound group. This finding provides insight into the vascular adaptations that occur during lameness in horses. As horses tend to avoid loading the lame limb, various compensatory biomechanical mechanisms are employed to reduce stress on it, which may in turn influence the hemodynamic of both the affected and unaffected limbs (Hoffmann et al., 2001; Pietra et al., 2004). In both forelimb and hindlimb lameness, horses redistribute weight to other limbs, primarily those concurrently loaded (Weishaupt, 2005). Horses with induced weight-bearing forelimb lameness demonstrate four primary compensatory biomechanical mechanisms to reduce structural stress on the affected limb: reducing total vertical impulse per stride, decreasing diagonal impulse in the lame diagonal, shifting impulse within diagonals, and prolonging stance phase (Weishaupt, 2005). Similar compensatory patterns occur in hindlimb lameness, with impulse redistribution limited to the contralateral hindlimb (Weishaupt et al., 2006). Blood flow in the equine foot is also influenced by the weight-bearing status, with significantly higher blood flow velocities observed under non-weight bearing compared to weight-bearing conditions (Aguirre et al., 2013).

However, the mechanism by which lameness influences blood flow in the distal limbs remains unclear and requires further investigation suggesting that factors other than weight-bearing conditions may also be involved. In evaluating individual data, we observed that 7/21 horses, described by their referring vet as chronically lame, exhibited higher PSV in the healthy limb compared to the lame limb. This finding suggests that the load removal alone may not fully account for the complex, multifactorial variations in Doppler indices. Other anatomical, pathological, and hemodynamic factors, potentially influenced by the aetiology and duration of lameness, may also affect Doppler parameters. Furthermore, no significant correlation between PSV and the degree of lameness was found in this study. This indicates that PSV is not a reliable marker for assessing the severity of lameness and supports the idea that Doppler ultrasound may not serve as a consistent diagnostic tool for this purpose. It is possible that compensatory mechanisms, such as alterations in blood flow patterns due to pain or structural changes in the limb, may influence Doppler parameters independently of the degree of lameness. Based on these observations, it is evident that the absolute values of PSV alone are not sufficient parameters for classifying the degree of lameness in horses. Some difficulties were encountered during the ultrasound examination, as some horses tended to shift their weight between limbs. This behaviour could be attributed either to the pain causing lameness or to the individual temperament of the horse. Recent studies have focused on creating objective tools for pain assessment in horses, with composite pain scales and facial expression-based scales showing potential as effective methods (Van Loon and Van Dierendonck, 2018). Weight shifting has been recognized as a valid marker to differentiate between horses in pain and those pain-free, with notable differences observed by Nowak et al. (2024) between the pain groups as well as before and after the administration of analgesics. However, the connection between lameness, pain, and gait asymmetry is intricate. Anyway, since the subjects of this study were sport horses and therefore accustomed to being handled, sedatives were not necessary and were not used, as their administration could alter the palmar digital flow, as reported by Leise et al. (2007).

During the examination, several sources of variability may have influenced the results in both groups. Factors such ambient temperature, biological differences between the horses (age and sex), ultrasonographic technique, the ultrasound device used, and the specific vessel examined could all affect vascular responses and blood flow patterns (Aguirre et al., 2013: Chester et al., 2013; Hoffmann et al., 2001; Menzies-Gow and Marr, 2007; Vera et al., 2021). Outside temperature significantly influences peripheral blood flow in animals and humans, as demonstrated by various studies (Berry et al., 1984; Podrug et al., 2023; Upadhyay et al., 2014). To date, no specific studies have been conducted on horses, but the authors hypothesize that their blood flow may also be subject to environmental variations. In this study, data were collected between late winter and early spring in a mild-climate region, which does not exhibit excessive temperature variation. During the study period, ambient temperatures (16.7 ± 4 °C) remained within the equine thermoneutral zone (TNZ), which for adult horses is typically defined between 5 °C and 25 °C (Morgan, 1997; Kang et al., 2023). Within this range, horses can maintain their core body temperature without requiring significant thermoregulatory vascular adjustments or alterations in peripheral blood flow (Palmer, 1983). According to Vera et al. (2021), age is associated with a thickening of the arterial wall, which can occur in older horses. In our study, however, the two groups did not differ in age, suggesting that age-related vascular changes exerted their effects similarly in both groups. Regarding sex, in human medicine, the study by Chester et al. (2013) found that female participants showed a greater difference between central systolic blood pressure (cSBP) and peripheral systolic blood pressure (pSBP) compared to males. To date, this difference has not been described in horses and in this study no differences between male and female distribution were found. In any case, the comparison of Δ values between healthy and lame horses, which did not differ in biological factors and were examined under the same environmental conditions, helped minimize the influence of these variables on the results and reduced the risk that PSV values were affected by these sources of variability (Jones, 2016). Furthermore, the examinations were performed in horses at rest, which were led to the wash area close to the stall so that the influence of physical exercise was also minimized. Thus, the differences in PSV observed in lame horses, but not in healthy horses, were likely related to lameness.

To reduce the variability and increase the reliability of the results, all Doppler indexes were recorded using the same device and settings. Additionally, the recordings were conducted by the same operator, ensuring uniformity in technique and approach. The LPDA is a superficial vessel, requiring operators to apply a Doppler angle correction of 70° (de Chiara et al., 2024). While an angle correction greater than 60° can introduce an error of up to 20–30% in the calculation of PSV and EDV (Polak and Kremkau, 2021; Tola and Yurdakul, 2006) this study ensured consistency by repeating measurements on the same vessels and subjects at the same location, always applying the same correction angle. This approach minimized any potential variability.

The absence of an etiological diagnosis of lameness represents a limitation of this study. The objective of the present study was not to perform a diagnostic assessment of lameness. Rather, the aim was to assess inter-limb differences in Doppler indices, focusing on relative asymmetry ΔPSV instead of absolute PSV measurements. Moreover, only 6 of 27 horses exhibited acute lameness, while the majority of them were affected by chronic lameness, as reported by their referring vet. Therefore, future research should prioritize precise lameness diagnosis and consider the broader physiological context to enhance understanding of the relationship between blood flow and lameness in equine patients.

Another limitation of this study is the subjective assessment of lameness. However, having the lameness evaluated by the same highly experienced operator reduced the intra-rater disagreement, improving the consistency of the lameness scoring. The interpretation of the present findings should also consider the intrinsic limitations of correlating a continuous hemodynamic parameter, such as PSV, with an ordinal lameness score. Because scoring relies on subjective human assessment, the resulting association may be partly conditioned by the nature of the clinical grading system itself (Keegan et al., 2010, 2013). This consideration highlights the value of integrating objective, digitized gait-analysis technologies in future investigations. Continuous, sensor-based locomotor metrics could provide a more robust analytical framework for exploring the relationship between Doppler ultrasonographic parameters and locomotor function, thereby reducing observer-related bias and strengthening the validity of such correlations. Objective systems, which have been shown to be associated with greater consistency and reliability of lameness evaluation (de Chiara et al., 2026; McPeek et al., 2025), could further enhance the accuracy and reproducibility of these assessments. Further studies with larger populations and more homogeneous lameness characteristics (e.g., acute versus chronic cases) are required to establish the diagnostic and therapeutic utility of the Doppler LPDA examination. For example, longitudinal evaluations performed before and after therapeutic interventions could help determine whether ΔPSV changes over time and whether it may serve as a marker for monitoring disease progression or treatment response. Furthermore, the relationship between PSV asymmetry and hindlimb lameness, including its potential role in differentiating true hindlimb lameness from compensatory head-nodding patterns, could be explored.

5. Conclusion

In conclusion, this technique was well tolerated by all the horses. The results confirm a significant difference in blood flow, with an increase in Δ PSV in horses with unilateral forelimb lameness compared to healthy horses, while no significant correlation was found between Doppler indexes and the degree of lameness. This suggests that various lameness-related factors, such as anatomical, pathological, and hemodynamic variables, likely contribute to variations in the LPDA's blood flow. Furthermore, despite the consistency of evaluations performed by an experienced operator, the subjective nature of the AAEP scale may have influenced the results. In particular, the lack of correlation observed between lameness grade and hemodynamic parameters warrants further investigation and should be validated using more objective, quantitative methods of lameness assessment.

Further research is needed to clarify the complex relationship between lameness and Doppler ultrasound indexes, which may ultimately implement diagnostic and therapeutic approaches for equine lameness.

CRediT authorship contribution statement

Mariaelena de Chiara: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Andrea De Matteis:** Methodology, Investigation. **Chiara Del Prete:** Writing – review & editing, Methodology, Conceptualization. **Dario Costanza:** Writing – review & editing, Investigation. **Chiara Montano:** Writing – review & editing, Investigation. **Luigi Auletta:** Investigation. **Valeria Gaia Marinelli:** Methodology, Investigation. **Francesco Buono:** Writing – review & editing, Investigation. **Maria Pia Pasolini:** Writing – original draft, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to express our sincere gratitude to the participating stables (Borgo Appio, Scuderia del Borgo, Angolo del Cavaliere, Grifondoro, Alla Fenice) for their support and for granting us access to their horses. Their cooperation was essential to the successful completion of this study.

References

Aguirre, C.N., Talavera, J., Fernández Del Palacio, M.J., 2013. Usefulness of Doppler ultrasonography to assess digital vascular dynamics in horses with systemic inflammatory response syndrome or laminitis. J. Am. Vet. Med. Assoc. 243, 1756–1761. https://doi.org/10.2460/javma.243.12.1756.

Baxter, G.M. (Ed.), 2020. Adams and Stashak's lameness in horses. John Wiley & Sons.

Berry, J.J., Montgomery, L.D., Williams, B.A., 1984. Thermoregulatory responses of rats to varying environmental temperatures. Aviat. Space Environ. Med. 55, 546–549. https://doi.org/10.2460/javma.243.12.1756.

Carroll, C.L., Huntington, P.J., 1988. Body condition scoring and weight estimation of horses. Equine Vet. J. 20, 41–45. https://doi.org/10.1111/j.2042-3306.1988.tb01451.x.

Chester, R., Sander, G., Fernandez, C., Chen, W., Berenson, G., Giles, T., 2013. Women have significantly greater difference between central and peripheral arterial pressure compared with men: the Bogalusa Heart Study. J. Am. Soc. Hypertens. 7, 379–385. https://doi.org/10.1016/j.jash.2013.05.007.

Cochard, T., Toal, R.L., Saxton, A.M., 2000. Doppler ultrasonographic features of thoracic limb arteries in clinically normal horses. Am. J. Vet. Res. 61, 183–190. https://doi.org/10.2460/ajvr.2000.61.183.

Costanza, D., Pasolini, M.P., Greco, A., Mennonna, G., Auletta, L., Lamagna, F., Meomartino, L., 2021. Ultrasonographic measurement of kidney-to-aorta parameters in Whippets. Vet. Radiol. Ultrasound 62, 476–482. https://doi.org/10.1111/vru.12958.

Davidson, E.J., 2018. Lameness Evaluation of the Athletic Horse. Vet. Clin. North Am. Equine Pract. 34, 181–191. https://doi.org/10.1016/j.cveq.2018.04.013.

de Chiara, M., Montano, C., Costanza, D., Coluccia, P., Auletta, L., Greco, A., Pasolini, M. P., 2024. Doppler ultrasonographic measurements of the lateral digital palmar artery in pregnant mares. Vet. Radiol. Ultrasound 65, 279–287. https://doi.org/10.1111/vru.13356.

de Chiara, M., Montano, C., De Matteis, A., Guidi, L., Buono, F., Auletta, L., Del Prete, C., Pasolini, M.P., 2026. Agreement between subjective gait assessment and markerless video gait-analysis in endurance horses. Equine Vet. J. 58, 60–67. https://doi.org/10.1111/evj.14516.

Fogaça, J.L., Castiglioni, M.C.R., Vettorato, M.C., Melo, G.B., Mazzante, G.M.N., Albuquerque, A.C.A., Machado, V.M.V., 2023. Study of digital palmar and plantar arteries of horses and mules by B-mode and Doppler ultrasonography. Arq. Bras. Med. Vet. Zootec. 75, 571–590. https://doi.org/10.1590/1678-4162-12776.

Hoffmann, K.L., Wood, A.K.W., McCarthy, P.H., Griffiths, K.A., Evans, D.L., Gill, R.W., 1999. Sonographic observations of the peripheral vasculature of the equine thoracic limb. Anat. Histol. Embryol. 28, 281–289. https://doi.org/10.1046/j.1439-0264.1999.00206.x.

Hoffmann, K.L., Wood, A.K.W., Griffiths, K.A., Evans, D.L., Gill, R.W., Kirby, A.C., 2001. Doppler sonographic measurements of arterial blood flow and their repeatability in the equine foot during weight bearing and non-weight bearing. Res. Vet. Sci. 70, 199–204. https://doi.org/10.1053/rvsc.2001.0461.

Hood, D.M., Wagner, I.P., Taylor, D.D., Brumbaugh, G.W., Chaffin, M.K., 2001. Voluntary limb-load distribution in horses with acute and chronic laminitis. Am. J. Vet. Res. 62, 1393–1398. https://doi.org/10.2460/ajvr.2001.62.1393.

Jones, G.R., 2016. Average of delta: a new quality control tool for clinical laboratories. Ann. Clin. Biochem. 53, 133–140. https://doi.org/10.1177/0004563215581400.

Kang, H., Zsoldos, R.R., Sole-Guitart, A., Narayan, E., Cawdell-Smith, A.J., Gaughan, J.B., 2023. Heat stress in horses: a literature review. Int. J. Biometeorol. 67, 957–973. https://doi.org/10.1007/s00484-023-02467-7.

Keegan, K.G., Dent, E.V., Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Norris, T., 2010. Repeatability of subjective evaluation of lameness in horses. Equine Vet. J. 42, 92–97. https://doi.org/10.2746/042516409x479568.

Keegan, K.G., Wilson, D.A., Kramer, J., Reed, S.K., Yonezawa, Y., Maki, H., Lopes, M.A., 2013. Comparison of a body-mounted inertial sensor system–based method with subjective evaluation for detection of lameness in horses. Am. J. Vet. Res. 74, 17–24. https://doi.org/10.2460/ajvr.74.1.17.

Leise, B.S., Fugler, L.A., Stokes, A.M., Eades, S.C., Moore, R.M., 2007. Effects of Intramuscular Administration of Acepromazine on Palmar Digital Blood Flow, Palmar Digital Arterial Pressure, Transverse Facial Arterial Pressure, and Packed Cell

Volume in Clinically Healthy, Conscious Horses. Vet. Surg. 36, 717–723. https://doi.org/10.1111/j.1532-950x.2007.00325.x.

McPeek, J.L., Menarim, B., Sponseller, B., McClendon, M., Adam, E.N., Adams, A.A., Page, A.E., 2025. Agreement between veterinarians and three objective evaluation systems in naturally occurring equine lameness. Equine Vet. J. https://doi.org/10.1111/evj.70116.

Menzies-Gow, N.J., Marr, C.M., 2007. Repeatability of doppler ultrasonographic measurement of equine digital blood flow. Vet. Radiol. Ultrasound 48, 281–285. https://doi.org/10.1111/j.1740-8261.2007.00243.x.

Merkens, H.W., Schamhardt, H.C., 1988. Distribution of ground reaction forces of the concurrently loaded limbs of the Dutch Warmblood horse at the normal walk. Equine Vet. J. 20, 209–213. https://doi.org/10.1111/j.2042-3306.1988.tb01501.x.

Morgan, K., 1997. Effects of short-term changes in ambient air temperature or altered insulation in horses. J. Therm. Biol. 22, 187–194.

Nowak, M., Martin-Cirera, A., Jenner, F., Auer, U., 2024. Time budgets and weight shifting as indicators of pain in hospitalized horses. Front. Pain. Res. 5, 1410302. https://doi.org/10.3389/fpain.2024.1410302.

Palmer, S.E., 1983. Effect of ambient temperature upon the surface temperature of the equine limb. Am. J. Vet. Res. 44, 1098–1101.

Pasolini, M.P., Spinella, G., Del Prete, C., Valentini, S., Coluccia, P., Auletta, L., Greco, M., Meomartino, L., 2019. Ultrasonographic assessment of normal jugular veins in Standardbred horses. BMC Vet. Res. 15, 343. https://doi.org/10.1186/s12917-019-2104-5.

Pietra, M., Guglielmini, C., Nardi, S., Gandini, G., Cipone, M., 2004. Influence of weight bearing and hoof position on Doppler evaluation of lateral palmar digital arteries in healthy horses. Am. J. Vet. Res. 65, 1211–1215. https://doi.org/10.2460/ajvr.2004.65.1211.

Podrug, M., Šunjić, B., Bekavac, A., Koren, P., Đogaš, V., Mudnić, I., Jerončić, A., 2023. The effects of experimental, meteorological, and physiological factors on short-term repeated pulse wave velocity measurements, and measurement difficulties: a randomized crossover study with two devices. Front. Cardiovasc. Med. 9, 993971. https://doi.org/10.3389/fcvm.2022.993971.

Polak, J.F., Kremkau, F.W., 2021. The 60° Doppler Angle Correction Paradigm: Reality or Myth? (an Uncomfortable Truth?). J. Ultrasound Med. 40, 2227–2233. https://doi.org/10.1002/jum.15603.

Ross, M.D.S., 2003. In: Dyson, S., Ross, M.W. (Eds.), Diagnosis and Management of Lameness in the Horse, 1st edn. W.B. Saunders, St Louis, p. 71.

Russ, M.K., Lafata, N.M., Robertson, S.H., Samei, E., 2023. Pulsed wave Doppler ultrasound: accuracy, variability, and impact of acquisition parameters on flow measurements. Med. Phys. 50, 6704–6713. https://doi.org/10.1002/mp.16774.

Tola, M., Yurdakul, M., 2006. Effect of Doppler Angle in Diagnosis of Internal Carotid Artery Stenosis. J. Ultrasound Med. 25, 1187–1192. https://doi.org/10.7863/jum.2006.25.9.1187.

Upadhyay, R.C., Kumar, P., Kumar, Y., Devi, R., Singh, A.K., 2014. Physiological Changes and Blood Flow in Murrah Buffaloes during Summer and Winter Season. J. Buf. Sci. 3, 63–69. https://doi.org/10.6000/1927-520X.2014.03.02.6.

Van Loon, J.P.A.M., Van Dierendonck, M.C., 2018. Objective pain assessment in horses (2014–2018). Vet. J. 242, 1–7. https://doi.org/10.1016/j.tvjl.2018.10.001.

Vera, L., Muylle, S., Van Steenkiste, G., Segers, P., Decloedt, A., Chiers, K., van Loon, G., 2021. Histological and biomechanical properties of systemic arteries in young and old Warmblood horses. PloS One 16, e0253730. https://doi.org/10.1016/j.tvjl.2018.10.001.

Vieira, L., Rajão, M., Nogueira, K., da Silva Leite, C., da Cunha Barreto-Vianna, A., de Lima, E., 2016. Doppler parameters of lateral digital palmar artery in endurance horses. Online J. Vet. Res. 20, 742–748.

Weishaupt, M.A., 2005. Compensatory load redistribution in forelimb and hindlimb lameness. In: Proceedings of the Annual Meeting American Association of Equine Practitioners, 51, pp. 126–129.

Weishaupt, M.A., Wiestner, T., Hogg, H.P., Jordan, P., Auer, J.A., 2006. Compensatory load redistribution of horses with induced weight-bearing forelimb lameness trotting on a treadmill. Equine Vet. J. 171, 135–146. https://doi.org/10.1016/j.tvjl.2004.09.004.

Wongaumnuaykul, S., Siedler, C., Schobesberger, H., Stanek, C., 2006. Doppler sonographic evaluation of the digital blood flow in horses with laminitis or septic pododermatitis. Vet. Radiol. Ultrasound 47, 199–205. https://doi.org/10.1111/j.1740-8261.2006.00128.x.