Influence of weight bearing and hoof position on Doppler evaluation of lateral palmar digital arteries in healthy horses

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Objective—To describe the pulsed-wave Doppler tracing of the equine lateral palmar digital artery and its modification in relation to standardized changes in posture.

Animals—17 healthy Saddlebred horses.

Procedures—Pulsed-wave Doppler examinations of left and right lateral palmar digital arteries of the horses were performed. The baseline examination was performed on each forelimb while horses were standing squarely with the body weight equally distributed among the 4 limbs (BED position). For each forelimb, the examination was repeated during 3 standardized modifications of the horse's posture (non–weight-bearing [NWB] position, full weight-bearing [FWB] position, and a position involving hyperextension of the distal interphalangeal joint [HE position]). In each position, mean values of systolic peak velocity, first and second diastolic peak velocity, end-diastolic velocity, mean velocity, and resistive index were calculated. Data obtained in each different posture were compared statistically.

Results—No significant differences in blood flow variables were detected between the left and right forelimbs. However, significant differences were detected in values of first diastolic velocity, second diastolic velocity, mean velocity, and resistive index between the NWB position and FWB position. Also, end-diastolic velocity in the NWB position was significantly different from that recorded in the HE position.

Conclusions and Clinical Relevance—The pulsed-wave Doppler tracing of the equine lateral palmar digital artery was modified considerably with changes in posture. This suggests that the use of a precisely standardized posture for horses is required to obtain repeatable data. (*Am J Vet Res* 2004;65:1211–1215)

Several studies[1-7] have been performed to evaluate digital blood flow in healthy horses and horses affected by inflammatory diseases that are associated with changes of arterial hemodynamics (eg, laminitis). Some of the diagnostic techniques used previously, such as scintigraphy and angiography, are not suitable for repeated daily measurements and wide field application because of their invasive approach or high cost. Conversely, Doppler ultrasonography represents a noninvasive imaging technique that is useful for routine examination of blood flow in vessels of standing nonsedated horses.[2,8] In a recent report,[8] the Doppler ultrasonographic features of blood flow in the forelimb arteries of conscious clinically normal standing horses have been described. Furthermore, the effects of feeding and weight bearing on hemodynamic aspects of equine digital blood flow have been investigated; for each condition, the systolic, diastolic, and end-diastolic velocities and the resistive index (calculated as the difference between the systolic velocity and end-diastolic velocity divided by the systolic velocity) were evaluated.[9,10] In particular, blood flow velocity in the distal part of the **lateral palmar digital artery (LPDA)** was significantly increased while the examined limb was maintained in a non–weight-bearing position, compared with values associated with the limb in a weight-bearing position.[10]

To the authors' knowledge, descriptions of the Doppler waveforms associated with digital blood flow of horses' limbs in a full weight-bearing position or after modification of the angle between the sole and the ground have not been reported before. The purpose of the study reported here was to describe the pulsed-wave Doppler tracing of the equine LPDA and its modification in relation to standardized changes in posture. Through Doppler ultrasonographic evaluation of the effect of different standardized postural conditions on blood flow of the LPDA, we hoped to establish an appropriate standard position for such examinations.

Materials and Methods

Horses—Seventeen healthy Saddlebred horses (13 geldings and 4 mares) were included in the study; the horses were 3 to 19 years old (mean age, 8.4 years) and weighed 455 to 670 kg (mean weight, 537.4 kg). All horses were determined to be free from orthopedic and cardiovascular diseases on the basis of findings of a thorough physical examination, radiographic evaluation of the limbs, and an EGC and echocardiographic examination. All horses were housed separately in box stalls and fed grass hay and commercially available grain; food was withheld for 12 hours before the experimental evaluations. The Doppler evaluations were performed in a standard temperature-controlled environment at an ambient temperature of 18° to 23°C.

Experimental protocol—The 2-dimensional ultrasonographic examinations of the left and right LPDAs were performed by use of a computed ultrasound sys-

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tem[a] with a linear transducer scanner at a frequency of 7.5 MHz. Pulsed-wave Doppler studies[a] were consistently performed at an ultrasound frequency of 5 MHz by the same operator (MC). A synchronized base-apex ECG was simultaneously recorded. A 100-Hz wall filter was used. The ultrasonographic examination was performed in horses (from which food had been withheld) at rest without sedation or restraint with a twitch. The ultrasound probe was positioned 3 cm below the lateral sesamoid bone on the palmar phalangeal region, which had been previously prepared by clipping the hair and applying coupling gel. A standoff pad, represented by a thin plastic bag containing acoustic gel, was directly applied to the surface of the probe to obtain better resolution of the near field and more parallel orientation between the ultrasound beam and the arterial blood flow. Each LPDA was insonated in a longitudinal plane for pulsed-wave Doppler studies. The sample gate of pulsed-wave Doppler evaluation was adjusted to include most of the vessel lumen (uniform insonation method), and the sample volume cursor was positioned to align the beam line with the direction of blood flow. By applying an automatic correction of velocity calculation, Doppler tracings were registered only when an angle of 45° between the ultrasound beam and the direction of blood flow was achieved. By recording 3 consecutive cardiac cycles, the mean values of the following blood flow measurements were calculated: **systolic peak velocity (P1)**, corresponding to the peak of the curve of systolic velocity; **first** and **second diastolic peak velocity** (**P2** and **P3**, respectively); **end-diastolic velocity (EDV)**; **mean velocity (MV)**; and **resistive index (RI)**, which was calculated as the difference between P1 and EDV, divided by P1.

A baseline ultrasonographic study was performed on each forelimb while the horse was standing squarely with its body weight equally distributed among all 4 limbs (designated the BED position). The forelimbs of each horse were successively reexamined after each change of the horse's posture (to modify the vertical load bearing on the hoof) while the probe was maintained in the described position. The study protocol included pulsed-wave Doppler examination of the LPDA in each forelimb during a period of full weight bearing (established by lifting the nonexamined forelimb; designated the FWB position), during a period of non-weight bearing (established by lifting the examined forelimb, with the carpus flexed and the metacarpophalangeal joint in passive extension; designated the NWB position), and during a period of full weight bearing with concurrent hyperextension of the distal interphalangeal joint (established by placing the point of the hoof of the examined limb on a 3-cm-thick board, with an approximate angle of 15° between the sole and the ground, while the nonexamined forelimb was lifted; designated the HE position).

All evaluation sessions were started after a 15-minute period of adaptation to the postural condition so that horses were quiet with a low steady heart rate during the examinations; furthermore, the sequence of applied postural conditions was randomly changed to minimize any influence that 1 postural condition could have on the Doppler recording obtained for the following postural condition.

Statistical analyses—Data analyses were carried out by use of a commercial statistical software package.[b] Descriptive statistics, including values of mean ± SD, were calculated for each Doppler measurement obtained for each postural condition. Differences between the comparative measurements of the left and right forelimbs were obtained in each postural condition and evaluated by use of a Student *t* test for paired data. The effect of different standard postural conditions on blood flow of the LPDA was investigated by use of a 2-way ANOVA. In addition, to analyze which condition contributed to the effect, a Tukey honestly significant difference test for multiple comparisons was performed. Significance was always set at a value of $P < 0.05$.

Results

The LPDA was easily identified in both forelimbs of all horses via 2-dimensional ultrasonography. The vessel was located at a depth of 4 to 6 mm under the skin of the base of the proximal phalanx. A repeatable pulsed-wave Doppler tracing, with a standard angle of 45° between the beam line and the vessel, was obtained from the right and left LPDA of each horse. All of the postural conditions were well tolerated by the study horses with the exception of the HE position; in some evaluations of horses (no more than 20%), positioning of the forelimb to establish conditions of full weight

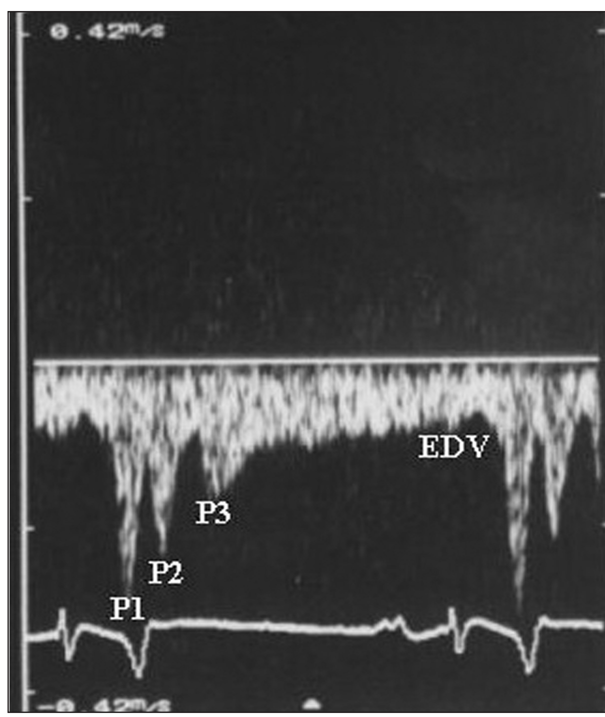

Figure 1—Doppler ultrasonographic waveforms recorded from the left lateral palmar digital artery in a horse that was standing squarely with weight equally distributed on all 4 limbs. Notice that the Doppler waveform includes a systolic peak velocity (P1), followed by 2 peaks of decreasing amplitude in early diastole (P2 and P3), and an undulating tail trace that corresponds to the end-diastolic velocity (EDV).

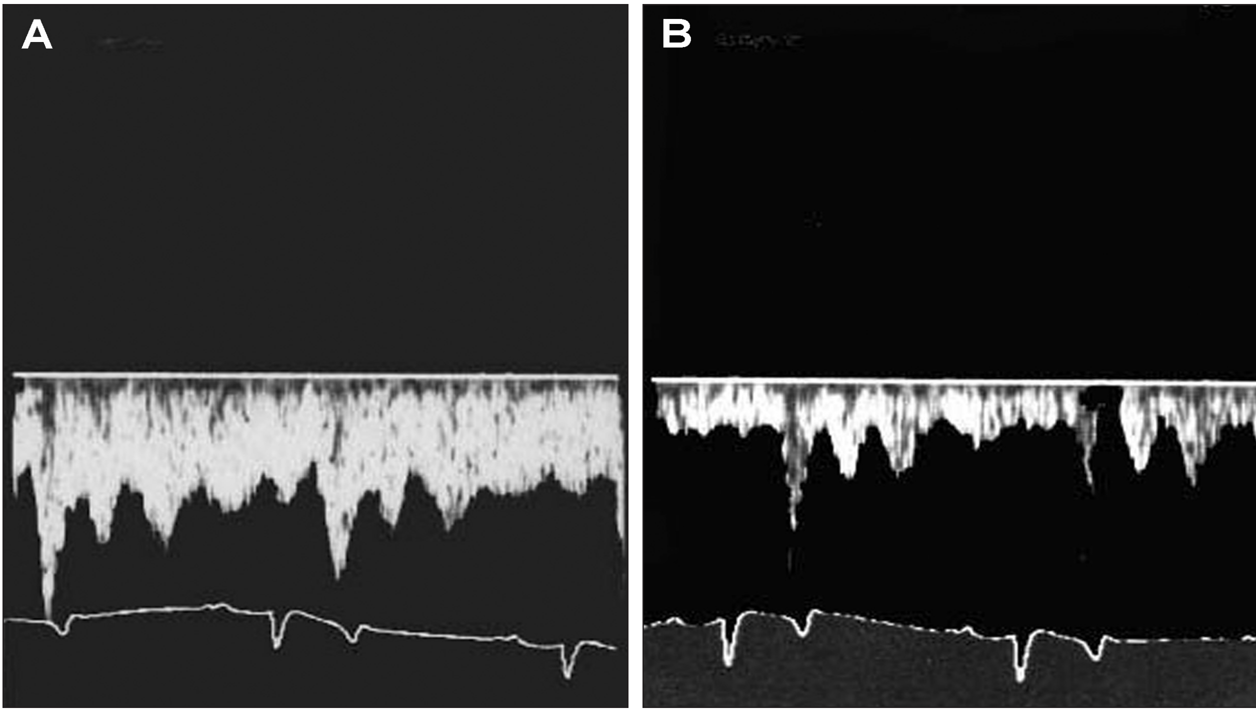

Figure 2—Pulsed-wave Doppler waveforms recorded from the left lateral palmar digital artery in a horse during non–weight-bearing (A) and full weight-bearing (B) conditions. Notice that in panel A, the tracing appears less pulsatile and the signal is broader than that in panel B.

Table 1—Mean ± SD Doppler flow variables measured in the left and right lateral palmar digital arteries of 17 healthy horses.

Position	P1 (m/s)	P2 (m/s)	P3 (m/s)	EDV (m/s)	MV (m/s)	RI
NWB	0.24[a] ± 0.13	0.19[a] ± 0.09	0.16[a] ± 0.10	0.09[a] ± 0.06	0.13[a] ± 0.08	0.64[a] ± 0.10
BED	0.22[a] ± 0.12	0.16[ab] ± 0.07	0.14[ab] ± 0.08	0.07[ab] ± 0.05	0.11[ab] ± 0.06	0.67[ab] ± 0.13
FWB	0.23[a] ± 0.14	0.15[b] ± 0.07	0.13[b] ± 0.07	0.07[ab] ± 0.04	0.10[b] ± 0.05	0.71[b] ± 0.10
HE	0.22[a] ± 0.11	0.16[ab] ± 0.06	0.14[ab] ± 0.08	0.07[b] ± 0.04	0.11[ab] ± 0.06	0.69[ab] ± 0.10

[a,b]Different superscript letters indicate a significant difference between groups.

P1 = Systolic peak velocity. P2 = First diastolic peak velocity. P3 = Second diastolic peak velocity. EDV = End-diastolic velocity. MV = Mean velocity. RI = Resistive index. NWB = Non-weight bearing. BED = Body weight equally distributed on all 4 limbs. FWB = Full weight bearing. HE = Full weight bearing associated with hyperextension of the distal interphalangeal joint.

bearing with concurrent hyperextension of the distal interphalangeal joint provoked attempts by those horses to counteract the applied load by jumping off the board.

Pulsed-wave Doppler recordings of LPDA blood flow indicated a continuous monodirectional tracing throughout the whole cardiac cycle with an evident systolic peak and 2 diastolic peaks, which were followed in some instances by an undulating tail trace above zero flow (**Figure 1**). The multipeaked spectral Doppler waveform recorded in the BED and NWB positions appeared less pulsatile and had a broader signal than that recorded in the FWB and HE positions (**Figure 2**). Descriptive statistics for each Doppler variable in each different postural condition were calculated (**Table 1**).

Statistical analysis revealed no significant difference in blood flow measurements between the left and right LPDA. Furthermore, no significant differences in values of P1 were detected among the different postural conditions. The variables P2, P3, and MV were significantly lower in the FWB position than they were in the NWB position. The variable EDV was significantly lower in the HE position, compared with that associated with the NWB position. Finally, the value of RI was significantly higher in the FWB position, compared with that detected in the NWB position.

Discussion

As a tool to evaluate digital blood flow in horses, Doppler ultrasonography is noninvasive and relatively easy to perform. However, several variables may modify arterial blood flow and, consequently, influence its evaluation by use of the echo-Doppler technique. The main sources of variability in Doppler examination of peripheral arteries are both subject and technique related. Subject-related variables include strength of myocardial contraction, status of the aortic valves, compliance characteristic of the arteries, presence of branch point bifurcation and curvature, viscosity of the blood, and resistance to flow offered by the tissue that is being perfused.[11] Technique-related variables depend on the type of sonographic equipment used and include frequency emission, beam shape, correct setting of the angle between the ultrasound beam and axis of blood flow, and rate of vessel insonation. Furthermore, administration of food or drugs, environmental temperature, CNS system influences, and weight bearing are known to be factors that can modify the resistance of the peripheral vasculature, thereby influencing the blood flow waveform of the peripheral arteries in horses.[9,10,12,13] To obtain an accurate reading and minimize errors associated with the aforementioned variables, the Doppler recordings obtained in the study of this report were consistently performed with the same instrument setting by the same operator on horses in standardized environmental and postural conditions. Furthermore, only Doppler recordings obtained with a constant angle of 45° between the beam line and blood flow were included in our analyses. Under these study conditions, the Doppler examinations of LPDAs were successfully performed in all standing nonsedated horses. Signs of mild discomfort were observed in a few horses only during the period that the limb was in the HE position. The time required to obtain correct vessel visualization was related to the tractable nature of the horse, the postural condition imposed, and the developing skill of the operator.

The Doppler tracing obtained in all the different postural conditions indicated a waveform that was above the zero line throughout the whole cardiac cycle. The Doppler tracing appeared higher and less pulsatile in the NWB position, compared with tracings in the BED and FWB positions, which suggested lower peripheral resistance associated with the NWB position.

Results of the study of this report indicated no significant difference between the left and the right forelimb for each of the LPDA blood flow variables in any of the postural conditions. These findings provide experimental confirmation of what was only supposed, but not demonstrated, in previous studies.[8,10]

In our study, the absence of a significant difference in values of P1 (corresponding to the apex of blood flow acceleration occurring during the left ventricular ejection) among the NWB, BED, and FWB positions could indicate that the P1 waveform is not influenced by the rate of pressure exerted on the foot. This finding is in contrast to that of another study[10] in which a significant reduction of P1 was detected when changing from a non–weight-bearing to a weight-bearing condition. This difference between the 2 studies may be attributable to the more distal site used for examination of the LPDA in the other study (the probe was placed at the level of coronary band), compared with the site of Doppler evaluation used in the present study.

With regard to the diastolic waves, P2 represents the peak of the curve generated by a reverse pressure wave rebounding on the aortic valve that closed at the beginning of the diastolic phase, whereas P3 and the undulating late-diastolic tail trace represent the peak of the curves produced as a consequence of multiple reflections of the cardiac impulse from sites located in the upper and lower arteries.[14] Results of the study reported here indicated a significant reduction of P2 in the LPDA associated with a postural condition in which low vertical forces were exerted on the foot (NWB position), compared with the P2 value associated with a position characterized by higher vertical forces exerted on the foot (FWB position). Furthermore, data analysis revealed that P3 and MV values were significantly higher in the NWB position, compared with those values in the FWB position. Conversely, the RI value was significantly increased in the FWB position, compared with the value in the NWB position.

Results of a study[11] in humans indicated that the lack of reverse blood flow in early diastole and the presence of end-diastolic flow that was always above zero could be considered a consequence of a distal low-resistance tissue associated with a high metabolic activity.

The modifications of the velocity tracings that were detected in the horses of this report may be attributable to a progressive increase in distal arterial resistances associated with the increased pressure exerted on the foot. In fact, when a horse is standing or walking, the compression of soft tissues and vascular structures inside the hoof results in an increase in peripheral arterial resistances[10,15] as well as an increase in digital venous pressure. This mechanism provides protection for the foot by dissipating the impact of hoof strikes, but it may also reduce the digital blood supply by increasing the arterial peripheral resistances.

In addition to postural conditions characterized by increasing vertical forces, we also evaluated the HE position by lifting the nonexamined forelimb with concurrent hyperextension of the distal interphalangeal joint. Results obtained in that position were clearly different from those recorded in the FWB position and more similar to those obtained in the BED position. Data analyses revealed a significant difference in values of EDV between the HE and NWB positions; no differences in any other variables were detected between those 2 postural conditions. These findings are consistent with lower vascular resistances in the HE position, compared with those in the FWB position, and suggest a difference in hoof pressure between the FWB and HE positions. However, the difference in EDV between the 2 positions could be the result of a small weight shift from the forelimbs to the hind limbs in the HE position, compared with weight distribution in the FWB position. In fact, in the HE position, a caudal shift of the barycenter could occur with consequent reduction in weight on the forelimbs. In our study, this hypothesis could not be further verified because of the lack of a force platform with which to exactly measure the vertical forces exerted on the foot.

The results of the study of this report have confirmed the relationship between peripheral vascular resistances and the degree of vertical forces exerted on the equine foot. Increased pressure exerted on the foot reduced diastolic velocity and increased RI in the LPDA. Because diastolic velocity and RI were significantly influenced by different postural conditions (associated with changes in the weight borne by the foot), repeated Doppler examinations of the equine digital arteries should be performed in horses in a precise standard postural condition. For example, the Doppler variables could be modified by a shift of the horse's weight from the left to the right side (as may occur in the BED position) or from the fore- to hind limbs (as may occur in the HE position). The results obtained in the FWB and NWB positions were more consistent. Thus, to minimize the influences of weight bearing and hoof position, the pulsed-wave Doppler examination of digital blood flow should be carried out in a full weight-bearing position or in a non–weight-bearing position (ie, by lifting the examined forelimb with the carpus flexed and the metacarpophalangeal joint in passive extension). Because of the constellation of variables that can modify digital blood flow, precise standardization of the pulsed-wave Doppler recording technique is mandatory to obtain an accurate and repeatable Doppler tracing; with such an approach, even early and subtle modifications of the digital circulation may be evaluated. Thus, it may be possible, for example, to diagnose laminitis in horses during the developmental phase because decreased blood flow and increased resistance in LPDAs could perhaps be detected some hours prior to the onset of clinical signs.

[a]AU560, Esaote Biomedica, Florence, Italy.
[b]Release, 8.0.0, SPSS Inc, Chicago, Ill.

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