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Original Research

Correlation of Blood Pressure With Splenic Volume in Horses, Daily Variation in Blood Pressure, and "White Coat Hypertension"

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ABSTRACT

The objectives were to describe the associations between splenic reservoir mobilization and pharmacological changes in blood pressure (BP), the normal daily variability of BP, and the variation in BP between measurements obtained at a veterinary hospital and at home. A group of horses from a research herd (research group) and a group of healthy client-owned horses presented to a hospital (hospital group) were studied. Invasive BP and splenic volume were measured in the research group while hyper- and hypotension were induced by phenylephrine and acepromazine, respectively. Noninvasive blood pressure (NIBP) and ultrasonographically estimated splenic volume (by 2 observers) were measured on three consecutive days in research group horses. Noninvasive BP was measured in the hospital and the home environment in the hospital group at three time points. The change in splenic volume was highly correlated with the change in systolic BP after phenylephrine administration ($r = -0.97$, $P \leq .001$), and there was no significant change in splenic volume or correlation with changes in BP after acepromazine administration. Noninvasive BP had low daily variability (coefficient of variation [CV] = 9%–11%), and splenic volume had high daily variability (CV = 30%–32%) but was reproducible between observers (intraclass correlation coefficient = 0.70). Horses in the hospital group repeatedly had higher systolic NIBP in the hospital (140.0 ± 14.0) than at home (133.8 ± 14.8, $P = .01$). Variation in BP after administration of phenylephrine, but not after administration of acepromazine, is related to the change in splenic volume. BP does not change significantly in consecutive days; however, splenic volume does and is reproducible between observers. Blood pressure in horses is higher in hospital than that in home.

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1. Introduction

Blood pressure (BP) varies with autonomic tone, environmental stimuli, and disease processes such as cardiovascular or renal disease. While there have been recent efforts to find a consensus in BP monitoring methods, devices, and protocols in veterinary medicine [1], controversies and lack of knowledge exist in many aspects of BP measuring and in the clinical relevance of abnormal results in horses.

The size of the equine splenic reservoir, an average of 12 L of blood with a packed cell volume (PCV) of 80%, is not matched by any other domestic animal [2]. The quantitative relevance of the mobilization of this enormous reserve provides unique aspects to equine hemodynamics [3–6]. There have been studies evaluating the effects of the splenic contraction and its influence in BP and

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Conflict of interest statement: The authors declare no conflicts of interest.

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oxygen-carrying capacity particularly in the field of exercise physiology [7–9]. Information from these elegant studies is hard to apply to the resting or ill horse due to the complexity of the changes associated with exercise. Changes in splenic size associated with changes in hemodynamic variables have been described in dehydrated horses and after administration of phenylephrine [10,11], but formal studies about its association with BP are lacking. In addition to the potential importance of a large increase in blood volume, the concept that the splenic capsule is a marker of activity of the capacitance vasculature has been proposed [5].

Blood pressure measurements in horses are commonly performed in the intensive care unit for the evaluation and monitoring of hypotension. An increase in BP is less commonly identified in horses and it can be present as a sequela of laminitis, other causes of chronic pain, equine metabolic syndrome, or chronic renal failure [12–14]. White coat hypertension in veterinary medicine is defined as an increase in BP caused by the measurement process which resolves when the stressful stimulus is removed [1]. White coat hypertension can cause target organ damage in humans [15], and the "white coat" effect is more severe in nonhealthy cats when than that in normal individuals [16,17]. To the best of our knowledge, the presence of a "white coat effect" in horses has not been previously studied.

The study presented here was designed to investigate the relationships of BP, splenic volume, and excitement ("white coat effect"). The study was divided in three steps to test three hypotheses: (1) the changes in BP after administration of an α-1 adrenergic agonist (phenylephrine) and a tranquilizer with α-1-antagonist (acepromazine) properties are correlated with the changes in splenic volume; (2) spleen volume and BP measurements are repeatable in healthy horses when measured in consecutive days in the same environment; and (3) BP measured in an equine hospital is higher than that in the home environment.

2. Materials and Methods

2.1. Animals

The study population consisted of healthy horses in a research group (RG) and a group of client-owned horses presented to a university hospital for preventative medicine evaluation (hospital group). The RG was composed of 8 warmblood mares 11.6 ± 1.5 year old and weighing 568 ± 62 kg. The hospital group consisted of 23 geldings, 15 mares, and 2 stallions (29 warmbloods and 11 Arabians) 10.5 ± 3.6 year old and weighing 515.6 ± 92 kg.

2.2. Protocol

The mares from the RG were placed in the stalls at least 15 minutes before being instrumented, and a general physical examination was performed. A 13 G indwelling catheter was placed in the jugular vein using standard aseptic technique, and all drugs were administered through this catheter. For invasive blood pressure (IBP) monitoring, a 20 or 22G over-the-needle catheter was placed in the facial or transversal facial artery, after aseptic preparation, and secured with cyanoacrylate glue and tape. The catheter was connected via nondistensible heparin-saline–filled tubing to a disposable BP transducer, which was positioned and zeroed to the level of the heart base and connected to a monitor (Datex Ohmeda, S3, GE, Datex-Ohmeda Division, Helsinki, Finland). Catheter placement was attempted in the awake horse, yet, if necessary, xylazine (Xylasol, Graeub AG, Bern, Switzerland) 0.5 mg/kg was administered intravenously (IV). Invasive blood pressure recordings were performed a minimum of 30 minutes after xylazine administration. Hypertension was induced with an IV phenylephrine (Phenylephrine HCL, Dr. G. Bichsel AG, Interlaken, Switzerland) infusion (3 μg/kg/min diluted in 1 L 0.9% NaCl solution over 15 minutes) and hypotension with IV acepromazine (Prequillan, Fatro S.p.A., Ozzano Emilia, Italy) (0.05 mg/kg).

Splenic volume was estimated by ultrasound using a previously described method [6] at baseline, immediately after the phenylephrine infusion, 35 minutes after phenylephrine infusion to ensure the pressures normalized to baseline, and 30 minutes after acepromazine to ensure maximal drug effect, by unblinded observers. One milliliter of blood was taken into ethylenediaminetetraacetic acid tubes for PCV and total protein (TP) measurement at the same time points. This was analyzed with microcentrifugation and refractometry, respectively. Time points were chosen based on previously described timing of maximal effects of acepromazine and phenylephrine on BP [11,18,19]. Noninvasive blood pressure (NIBP) measurements were obtained simultaneously and used for a parallel study determining the accuracy and precision of the NIBP monitor and were reported elsewhere [20].

An oscillometric monitor (Cardell Veterinary Monitor 9402; CAS Medical Systems, Inc., Branford, CT), with a cuff bladder width to tail girth ratio of 0.4–0.6 (according to manufacturer's recommendations), was centered over the coccygeal artery around the base of the unclipped tail and used for NIBP measurements in the RG on three consecutive days. To correct readings to the level of the heart base, the vertical distance between the base of the heart, as estimated by the point of the shoulder, and the base of the tail was measured, and a correction factor of 0.77 mmHg/cm was applied [21]. Non-invasive blood pressure was measured six to eight times. As recommended by American College of Veterinary Internal Medicine guidelines for device validation in small animals, the first measurement was discarded, and the average of three to seven consecutive readings was calculated [1,20]. At the same time, the splenic volume was measured as previously described by putting the measurements into a modified ellipsoid formula, uniquely designed for the equine spleen [6]. This was done by two observers blinded from each others measurements as well as previously recorded measurements on those horses.

Non-invasive blood pressure was measured in the hospital group, as described previously, in an equine hospital and home environment by the same observer on consecutive days. This was done 3 separate times throughout the year, approximately 3 months apart. Only NIBP obtained when the HR was below 48/min was included in the comparison of clinic and home environment BP.

2.3. Statistical Analysis

A Shapiro–Wilk test was used to evaluate normality. Data were presented as mean ± SD. Because all data were normally distributed, *t*-tests were used to determine differences in hematocrit and splenic volume from baseline to hypo- and hypertension phases, and Pearson correlation coefficient (R) was calculated to assess the correlation between IBP, splenic volume, and hematocrit for each phase (normo-, hypo- and hypertensive). Coefficient of variation (CV) was used to assess interday variation of NIBP and splenic volume (standard deviation/mean). Coefficient of variation was interpreted as follows: very low variability CV<5%, low variability as 5%–15%, moderate variability as 15%–25%, and high variability as >25% [22]. The intraclass correlation coefficient (ICC) was calculated using data from a repeated measures analysis of variance ("horse" and "observer" used as sources) to evaluate the interobserver variation in splenic volume. In addition, interobserver agreement in splenic volume measurements was quantified using the Bland and Altman method for repeated measurements [23]. The bias was reported as the mean difference between the measurement obtained by observers 1 and 2. The limits

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