Prerace venous blood gases and acid-base values in Standardbred horses: effects of geography, season, prerace furosemide, gender, age, and trainer using big data analytics

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OBJECTIVE
A retrospective study was conducted to establish the prerace venous acid-base and blood gas values of Standardbred horses at rest using big data analytics.

SAMPLES
Venous blood samples (73,382) were collected during seven racing seasons from 3 regional tracks in the Commonwealth of Pennsylvania. Horses were detained 2 hours prior to race time.

PROCEDURES
A mixed-effects linear regression model was used for estimating the marginal model adjusted mean (marginal mean) for all major outcomes. The interaction between age and gender, track, and the interaction between month, treatment (furosemide), and year were the major confounders included in the model. Random effects were set on individual animal nested within trainer. Partial pressure of venous carbon dioxide (PVCO2), partial pressure of oxygen (PV02), and pH were measured, and base excess (BE), total carbon dioxide (TCO2), and bicarbonate (HCO3−) were calculated.

RESULTS
Significant (P < .001) geographical differences in track locations were seen. Seasonal reductions in acid-base values started in January with significant (P < .001) decreases from adjacent months seen in June, July, and August followed by a gradual return. There were significant increases (P < .001) in BE and TCO2 and decreases in PV02 with age. Significant differences (P < .001) in acid-base values were seen when comparing genders. A population of trainers were significantly different (P < .001) from the marginal mean and considered outliers.

CLINICAL RELEVANCE
In a population of horses, big data analytics was used to confirm the effects of geography, season, prerace furosemide, gender, age, and trainer influence on blood gases and the acid-base profile.

Analysis of data collected at a Standardbred race-track showed that daily environmental temperatures, prerace administration of furosemide (FUR), gender, and age had significant effects on pH, sodium, and bicarbonate ion concentration.1

Prerace venous TCO2 concentrations in Thoroughbreds were analyzed to determine the effect on performance. This study found an association with a class of race, distance, furosemide administration, sex, cloudy weather conditions, and trainers.2 Another study3 conducted to predict the effect of transportation and excitement on prerace TCO2 concentrations found that age was associated with higher TCO2 and longer transportation time with lower TCO2 concentrations in Standardbred prerace samples. Regional differences were reported in prerace TCO2 plasma concentrations in Thoroughbreds from Australia4 and South Korea5 and Standardbreds from New Zealand6 and acid-base values in the United States.7 Standardbreds and Thoroughbreds had a common distribution of TCO2 concentrations. There was evidence of a greater degree of alkalinization in the Standardbreds compared to Thoroughbreds, which was attributed to the trainer’s administration of alkalizing agents.8
Studies in the horse have shown that acid-base balance can be influenced by the manipulation of the dietary cation-anion balance (DCAB). Administration of various substances may also alter the electrolyte concentrations and acid-base status of horses.

The administration of FUR produces an increase in bicarbonate, pH, partial pressure of carbon dioxide, and sodium, with decreases in vascular volume and loss of chloride and potassium. These changes produce a metabolic alkalosis. A population study in Standardbred horses has confirmed the presence of a metabolic alkalosis in prerace venous acid-base values in horses receiving prerace FUR. Administration of various doses of sodium bicarbonate via nasogastric, intravenous, or oral dosing syringes resulted in a metabolic alkalosis.21–24

The goal of this analysis was to use big data analytics to verify and expand on previous studies by using a larger number of horses, with additional acid-base values and blood gases collected over multiple years to investigate more variables. Venous blood-gas and acid-base data from Standardbreds racing at tracks from 3 geographical locations were collected to document, regionally, seasonal, age, gender, and trainer influence on prerace values. Horses with and without the prerace administration of FUR were included in the study.

### Materials and Methods

#### Population of Standardbred horses

Data were derived from samples routinely collected from horses competing in Pennsylvania (PA) Harness Racing Commission parimutuel races. Prerace venous blood samples were collected by the Commission Veterinary staff from horses racing at 3 tracks.

Tattoo or brand identification, date, and track were recorded. Additional information was obtained from the official race day programs, which included horses’ age, gender, and trainer. The trainer’s name was necessary to link the horse identification to a trainer, and once the data were entered into the model the trainers became anonymous.

The 3 tracks were Meadows (MD), with year-round racing and 2 seasonal tracks; Pocono Downs (PD), with racing from March to November; and Harrah’s Philadelphia (HP), with racing from April to December. Tracks were in 3 geographic regions of PA, southeastern (HP = latitude 39.85, longitude −75.349, altitude 19 m), northeastern (PD = latitude 41.277, longitude −75.82, altitude 218 m), and western (MD = latitude 40.22, longitude −80.20, altitude 340 m). The distances between tracks ranged from approximately 120 miles (HP to PD) to 320 miles (MD to PD and HP). Harrah’s Philadelphia located in the southeastern corner of PA did not have onsite stabling; therefore, horses were transported on the day of the race, primarily from PA and the adjacent states of New Jersey and Delaware. Meadows and PD had a combination of on-site stabling and horses transported for racing. The samples included in this retrospective analysis were horses below the base-excess (BE) violation threshold; thus, they were allowed to race.

### Selection of horses for prerace testing

The horses were confined to the paddock 2 hours before posttime. Drivers were instructed not to exercise the horses prior to arrival, as it would alter the acid-base status of the sample. The investigators had no control over the selection process as a minimum of 4 horses were selected on a random basis for each race. Horses selected for testing that appeared to have exercised were not sampled and subsequently sampled based on the Commission Veterinarian’s examination. All horses were released from the paddock at the same time for warm-up prior to racing and returned following warm-up.

### Collection of samples

After verification of horse identity, external jugular venous blood samples were collected in 3-mL multipurpose sterile plastic syringes (Monoject Coviden LLC, Mansfield MA). Basic guidelines for sample collection and handling were followed. Syringes were heparinized by drawing sterile neutral heparin (Sagent Pharmaceuticals, Schaumburg, IL) solution into the syringe by withdrawing the plunger followed by expelling all air and excess heparin. Heparin coating the barrel of the syringe and contained within the needle was enough to prevent clotting. This residual amount was not of sufficient volume to dilute the sample and affect the blood-gas values being measured. Upon collection of the blood sample, trapped air was immediately expelled, and syringes were recapped, mixed, placed in crushed ice, and transported to the on-site laboratory. Samples were analyzed under the 30-minute time delay considered tolerable for acid-base analysis, especially for the measurement of pH and P\textsubscript{CO\textsubscript{2}}.

In the interpretation of the results from venous samples, the gold standard for measuring changes in total body blood gases is the collection of mixed venous blood via the placement of a central venous catheter. This was impossible in this study. A study in horses showed a 0.97 correlation coefficient between mixed venous and jugular samples; this was considered acceptable and jugular blood was used.

### Calibration of equipment

All blood samples were analyzed for pH, P\textsubscript{CO\textsubscript{2}}, P\textsubscript{VCO\textsubscript{2}}, and hemoglobin (Hgb) using an on-site blood gas analyzer (800 series; Radiometer Medical, Copenhagen, Denmark) located at each of the 3 racetracks. Base excess, HCO\textsubscript{3}\textsuperscript{−}, and TCO\textsubscript{2} were calculated by the instrument software (Radiometer Medical Reference Manual). Calibration followed the procedures detailed by the manufacturer. Three machines at 3 different locations were not expected to produce identical results. To reduce the potential variability between instruments, calibration solutions, and gases, quality control (QC) samples provided by the manufacturer were used for calibration on all Radiometer instruments. All standards were traceable to...
the National Institute of Standards and Technology. The use of traceable quality control samples demonstrates reproducibility based on different QC samples and documents that all instruments fall within allowable error limits for the 4 daily QCs.

Following the initial calibration using the manufacturer’s calibration solutions and gases and verification that the 4 QCs fell within specified limits, a precision test was conducted to document variability between repeated measurements by the operator. The same blood sample was measured in triplicate. The coefficient of variation (CV%) following 3 repeated measurements of 125 representative samples for Hgb, PCO$_2$, pH, and PO$_2$ was 0.92, 0.036, 1.1, and 4.6%, respectively. All the values were well within the acceptable range for bioanalytical methods according to the 2018 FDA Guidance for Industry Bioanalytical Method Validation.

**Statistical analysis**

All analyses were conducted with Stata 16MP (StataCorp, State College TX) with 2-sided tests of hypotheses and a $P$ value of < .05 as the criterion for statistical significance. There was significant heterogeneity in the data set with a considerable number of repeated measures that precluded estimating a simple Gaussian mean. Hence, a mixed-effect model was used to control (adjust) for multiple fixed and random effects. Throughout this article, the word marginal mean(s) will be used to indicate the model-adjusted mean(s). The post hoc marginal means of venous blood concentrations of Hgb, pH, P$_{CO_2}$, P$_{O_2}$, BE, HCO$_3^-$, and TCO$_2$ were estimated by a mixed-effects linear regression model. The fixed effects for each of these models were track, year, trainer, and statistical interaction of categorical age with gender and statistical interaction between month of the year and treatment. Random effects were set on the level of individual horse. To correct for small departures from normality, robust estimation of the variance was used. Least significant difference was used to adjust for post hoc multiple comparison. Before and during the racing season, stallions may have been castrated and switched to the gelding group. This was accounted for in the statistical model. The Z score (standard score) was calculated as the difference of a trainer from the overall marginal mean estimate based on the statistical model outlined above. Trainers with Z scores significantly ($P < .05$) below −2 SD were labeled outliers below the population marginal mean, and trainers with Z scores significantly ($P < .05$) above +2 SD were labeled outliers above the population marginal mean. The 95% confidence limits (95% CL) were calculated as standard error times 1.96 and figure values were reported as marginal means ± 95% CL. The upper and lower 95% confidence interval (95% CI) were calculated as marginal mean ± 1.96* Std Err. The estimation of the likelihood of a trainer being an outlier due to the administration of prerace FUR, a multinomial logistic model was constructed (yes/no) as the only fixed effect. Results were reported as relative risk ratio in comparison to the group of trainers that were not outliers.

Horses from the 3 regional tracks, may have been sampled once or multiple times or sampled at more than 1 of the 3 tracks. Horses shipped from different geographical areas in the country for a special race were usually sampled once.

**Results**

A total of 73,382 prerace samples were collected from horses racing at the 3 Pennsylvania tracks. They represented samples from 11,479 horses trained by 1,747 trainers. Geldings contributed 40,566, females contributed 23,968, and stallions contributed 8,848 samples.

**Geographical differences**

There were statistically significant geographical differences ($P < .001$) in all venous parameters measured. The BE at PD was 7.22 mmol/L compared to HP at 6.93 and MD at 6.03 mmol/L. All values with the upper and lower 95% confident intervals are shown in Supplementary Table S1.

**Seasonal differences**

All 3 tracks showed a seasonal variation in all blood values measured except Hgb. The highest plasma concentrations for BE and TCO$_2$ were seen in the month of February with marginal means and 95% CL of 6.8 ± 0.068 and 34.1 ± 0.085 mmol/L for BE and TCO$_2$, with a gradual reduction of BE in June to 6.03 ± 0.053 mmol/L and 32.68 ± 0.064 mmol/L for TCO$_2$ in July, followed by increases through to the month of December (Figure 1). Similar reductions were seen for P$_{CO_2}$ with a high concentration in February at 50.87 ± 0.141 to a low of 48.32 ± 0.130 mmHg in July.

![Figure 1](image)

**Figure 1**—Model adjusted marginal means and ± 95% confidence limits of the seasonal variations for base excess. Values with different letters were significantly different from other months ($P < .001$).
and for HCO$_3^−$ with a high in February of 32.4 ± 0.073 to a low in July 31.20 ± 0.059 mmol/L. The increase in pH from a low of 7.422 ± 0.0009 to high of 7.426 ± 0.0006 was concurrent with the reduction of P$_v$CO$_2$ during the same period (Figure 2). These changes were significantly different ($P < .001$) for the months of June, July, and August when compared to the preceding and following month. Seasonal changes were also seen for venous P$_v$O$_2$ with a high of 37.9 ± 0.19 in February to a low of 36.5 ± 0.14 mmHg in June. No defined seasonal variations were seen for venous Hgb.

Furosemide and nonfurosemide administrations

Of the collected samples, 52% were from horses administered prerace FUR. The marginal means with and without the prerace administrations of FUR are shown in Table 1. There was a consistent ~2 mmol/L difference in the concentrations of the nonadjusted prerace samples from horses administered FUR for TCO$_2$, BE, and HCO$_3^−$. Furosemide administration had no effect on Hgb but a negative effect on venous P$_v$O$_2$ concentrations.

Gender and age differences

All 3 genders showed increases in BE with increasing age (Figure 3). The stallion and gelding curves were essentially superimposed with no significant difference. In females, BE concentrations were lower for all ages. There were significant differences ($P < .001$) in P$_v$CO$_2$ for all 3 genders but no differences for pH between stallions and females when compared to geldings (Figure 4; Supplementary Table S2). Geldings had higher venous P$_v$CO$_2$ concentrations and lower pH when compared to females and stallions. The significant increases in pH and P$_v$CO$_2$ with age were seen between the ages of 2 and 4 with plateauing beyond 4.

There was a decline in venous P$_v$O$_2$ in all 3 genders between the ages of 2 and 10, which was not gender related. Geldings declined from a marginal mean ± 95% CL of 37.70 ± 0.49 to 36.01 ± 0.46, males 38.35 ± 0.47 to 35.58 ± 0.46, and females 38.28 ± 0.38 to 34.92 ± 1.34.

Trainer influence

Eight-hundred and 72 trainers were included in the analysis of trainer influence on acid-base values. Only trainers who ran horses 6 or more times were selected, which involved 10,771 horses. The number of horses managed by each trainer ranged from the selected low of 6 to a high of 1,822, the

![Figure 2](image-url)  
**Figure 2**—Model adjusted marginal mean ± 95% confidence limits of the seasonal variations for pH (open circles) and partial pressure of carbon dioxide (solid squares) of prerace venous samples. The values above the dashed arrow for pH and below the solid arrow for pressure of carbon dioxide were significantly different from the other months ($P < .001$).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FUR</th>
<th>NFUR</th>
<th>Difference</th>
<th>FUR-NFUR</th>
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<td>pH</td>
<td>7.428 ± 0.0004</td>
<td>7.414 ± 0.0002</td>
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<td>P$_v$CO$_2$ (mmHg)</td>
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<td>49.01 ± 0.043</td>
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<td>BE (mmol/L)</td>
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<td>HCO$_3^-$ (mmol/L)</td>
<td>32.39 ± 0.046</td>
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</tr>
<tr>
<td>TCO$_2$ (mmol/L)</td>
<td>33.92 ± 0.047</td>
<td>32.26 ± 0.028</td>
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<td></td>
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<tr>
<td>Hgb (g/dl)</td>
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<td>15.43 ± 0.022</td>
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<tr>
<td>P$_v$O$_2$ (mmHg)</td>
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<tr>
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<tr>
<td>P$_v$CO$_2$ (mmHg)</td>
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<tr>
<td>BE (mmol/L)</td>
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<td>HCO$_3^-$ (mmol/L)</td>
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<td>TCO$_2$ (mmol/L)</td>
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<tr>
<td>Hgb (g/dl)</td>
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<td>P$_v$O$_2$ (mmHg)</td>
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median number was 80. Trainers managed their horses, some with or without the prerace administration of FUR. The BE ascending marginal means and 95% CL for each trainer’s horses are shown in Figure 5. The overall BE marginal mean estimated by the mixed-effects linear regression model was 6.54 mmol/L.

Figure 3—Model adjusted marginal mean ± 95% confidence limits of base excess of the increases in age for geldings (open circles), stallions (closed circles), and females (open squares). Due to the superimposed changes in the stallions and geldings, the changes in age were compared for stallions and females. Ages with different letters were significantly different (P < .001).

Figure 4—Model adjusted marginal means ± 95% confidence limits of pH (A) and the partial pressure of carbon dioxide (P\textsubscript{\text{CO}}\textsubscript{2}) (B). Geldings (open circles) pH concentrations were significantly lower (P < .001) than stallions (closed circles) and females (open squares). Significant differences (P < .001) in P\textsubscript{\text{CO}}\textsubscript{2} concentrations were seen between geldings, stallions, and females. The significant increases with age occurred between 2 and 4 years of age. The significant changes in age for pH were only shown for females and geldings, as females and stallions were not different. Ages with different letters were significantly different from one another.

Figure 5—The ascending concentrations of the model adjusted marginal means (solid line) and 95% confidence limits (whiskers) of the base excess of each of 870 trainers managing 10,771 horses that competed 6 or more times. The marginal mean (dotted line) estimated by the mixed-effects linear regression model was 6.54 mmol/L. Trainers (black whiskers) with Z statistic above +2 SD or −2 SD below the marginal mean, were significant outliers (P < .05), indicating that their estimated marginal mean was outside the 95% confidence limits of the population marginal mean. Trainers (gray whiskers) were not significantly different from the population marginal mean. The considerable variability in trainer’s 95% confidence limits indicates that a horse’s response to a trainer’s management style was variable.
The Z score analysis was used to identify outliers. Trainers overlapping the marginal mean (gray whiskers) were not significantly different from the marginal mean. Trainers with Z scores ± 2 SD from the marginal mean (black whiskers) were significantly different from the marginal mean \((P < .05)\) and considered outliers.

A multinomial logistic was used to compare trainers not labeled as outliers (gray whiskers) to trainers above the upper 95% CL limit labeled as outliers (black whiskers). These trainers above (black whiskers) had a 6-fold higher likelihood of being outliers when a proportion of their horses were treated with FUR, and they had a relative risk ratio (RRR) of 6.1 \((P < .001)\). Trainers below the lower 95% CL limit were also considered outliers. In contrast, they had a 90% likelihood of not having been treated with FUR with a RRR of 0.1 \((P < .001)\).

**Discussion**

This retrospective study included data from 7 racing seasons of prerace on-site venous acid-base and blood gas measurements from 3 geographically separate Standardbred racetracks in the Commonwealth of Pennsylvania. This represents the largest study to date of venous acid-base and blood gas values in horses at rest and the various factors that influence these values. The data set had significant heterogeneous data with a considerable number of repeated measures that precluded estimating a simple Gaussian mean. Due to the differences in venous blood values seen at all 3 tracks and to present the results in a comprehensive form that represented the changes seen at all 3 tracks, a mixed-effect model was used to control (adjust) for multiple fixed and random effects. Despite these adjustments, significant differences were seen in the 3 geographical regions, as well as between seasons, genders, age, prerace furosemide, and trainer influence.

The primary advantages of a large dataset include identifying changes that might not have been exposed in a smaller dataset and diminishing the effects of outliers, and it allows a more precise estimate that the changes seen are real and to generalize the results with greater certainty. The complexity of the model depends on the size of the dataset through the degrees of freedom. The more data the more complicated and somewhat flexible models can be explored. Since the power of the analysis also depends on the numbers, larger datasets can capture smaller effects (uncovering changes) while using multiple confounding variables. Nevertheless, and besides all the benefits from big data studies, the fact that this study confirms some of the previous findings is of considerable benefit, especially because the so-called “power failure” leads to the inability of scientists to replicate the findings from previous studies and may not represent a true effect.\(^{31}\)

The regulatory threshold for BE was established when the prerace program started in 1994, and it is of significant importance to the racing industry that the current study offers proof that these previously determined thresholds were valid and reasonable.

**Regional differences**

Factors that might account for regional differences include possible differences in the composition of regional fresh grass, hay, grain, and a different population of trainers. As seen in Supplementary Table S1, the difference in values between HP and PD was less, which may be due to the eastern location of both tracks, a lesser distance in transportation between tracks, and greater exchange of horses when compared with MD located in the more distant western PA location. Despite the eastern location of HP and PD, differences were seen. Regional differences have been seen in countries with national databases compiled from locations separated by greater distances.\(^{1,7}\) Our data were gathered from a smaller region and demonstrated that even short distances between locations may affect acid-base and blood gas values. Prerace onsite analysis required equipment at the 3 sites. Some variability between instruments is unavoidable. This variability was minimized by the use of identical instruments, calibration solutions, and calibration methods outlined in Materials and Methods.

**Seasonal variation**

The gradual reduction in venous BE, TCO\(_2\), and \(P\text{\textsubscript{\text{CO}}}_2\) with an increase in pH occurred during the summer months coincided with increases in ambient temperature. The greatest increases in environmental temperature in the 3 regions of PA were during the months of June, July, and August with the peak occurring in July. The dew points for the 3 regions were also the highest during these 3 months.

During the summer months, there was a gradual reduction of \(P\text{\textsubscript{\text{CO}}}_2\) shifting the carbonic acid equation to the left reducing the concentration of \(H^+\) and \(HCO_3^-\) ions resulting in the decrease in BE, TCO\(_2\), and \(HCO_3^-\), with an increase in pH. These changes were likely due to an increase in the horse's ventilation caused by the increasing environmental temperature and humidity. In exercise studies,\(^{32,34}\) resting and postexercise respiratory rates increased in hot-humid conditions compared with cool and dry conditions. In drier regions with low humidity year round, cool or hot temperatures did not affect heart and respiratory rates in resting horses.\(^{35}\)

Our observations support and extend previously reported\(^{4}\) variation in pH, sodium, and \(HCO_3^-\) with changes in daily ambient temperature, and the results of a study\(^{6}\) that showed an association between TCO\(_2\) and weather conditions. These prior studies had no explanation or statistical evaluation for these changes based on the limitation of the measurements of all acid-base values. Our study had a complete profile of acid-base and blood gas values with repeatable results over a number of years.

**Age and gender differences**

The racing longevity of the Standardbreds allows the incorporation of age in this study. The differences
in the marginal means between the gender groups of Standardbreds were consistent with changes in age. Significant differences in pH were seen between males and females even after accounting for other variables, such as region, furosemide, and seasonal changes due to the statistical power of a large database. The significant differences between females and stallions when compared to geldings (Figure 4; Supplementary Table S2) are puzzling. Differences seen in P$_{\text{CO}_2}$ between females and males parallel the changes noted in BE, TCO$_2$, and HCO$_3^-$ between the genders as P$_{\text{CO}_2}$ has a major influence on these parameters.

The changes in venous acid-base values plateaued between 4 and 5 years of age followed by a decline at 9 years of age. There are limitations on the interpretation of this change in the older group of horses due to the smaller number of horses in the older pool compared to the younger population. Many of the older horses still racing were repeat samplings of the same horses.

There are limitations in generalizing these age changes to all horses in that no nonracing control population was available for comparison. The plateau at age 4 to 5 may be related to the maturing of horses. The rise at 7 and 8 years of age was unexplained but could be related to a change in the management of an older group of horses. Trainer management had a considerable effect on acid-base values, and whether age was a specific consideration in the management of older horses could not be determined.

**Venous oxygen concentrations**

A decrease in venous oxygen tension seen between the age of 2 and 10 years reported in this study was not gender related. Studies in racehorses ranging from 2 to > 6 years of age have shown a reduction in PaO$_2$, linked to inflammatory airway disease and exercise-induced pulmonary hemorrhage. The changes in blood gases in these were linked to the severity of the disease and not the age. The lower P$_{\text{O}_2}$ concentration measured with the prerace administration of FUR was surprising. Reviews of the effect of FUR did not mention gas changes in arterial, venous, or mixed-venous samples due to the administration of FUR.

Studies on the horse have reported significant and rapid FUR-induced changes in plasma volume and interstitial shifting of fluids. This resulted in a decrease in right atrial pressure, pulmonary arterial pressure, and stroke volume, which will affect cardiac output and peripheral perfusion in resting adult horses. These effects were within the time frame of the administration of FUR and blood sampling prior to the allowed warm-up and may explain the lower venous P$_{\text{O}_2}$.

**Trainer influence**

Trainers had no control over the regional, seasonal, age, and gender influences on prerace blood gas values. They did control the management and diet days or hours prior to the race and whether their horses receive prerace FUR. Once the model accounted for all other confounders, the variability in the blood gas values seen among horses reflects the trainer’s specific management practices. The trainer’s manipulation of the dietary cation-anion balance (DCAB) will influence acid-base values. Low DCAB diets (addition of calcium chloride, ammonium chloride) or high DCAB diets (addition of sodium bicarbonate, potassium citrate) nutritionally shift acid-base values toward a metabolic acidosis or alkalosis, respectively.

Sorting trainers by BE using the marginal means revealed the range of values in horses managed by each trainer. The marginal means across all trainers for BE and TCO$_2$ were 6.54 and 33.48 mmol/L, respectively. In Figure 5, the curved line was the ascending marginal mean for each trainer who ran at least 6 horses, and the gray and black vertical whiskers indicate the 95% CI for 2 groups of trainers. Of the 870 trainers included, the 310 above and 30 below the marginal mean (black whiskers) based on their Z scores were outliers and significantly different from the marginal mean. The trainer’s management strategies for their horses (gray whiskers) overlapping the marginal mean did not result in significant departure for most trainers.

Prerace FUR is allowed in North America with certain conditions. If approved, the intravenous administration of FUR for every race must be administered 4 hours prior to race time and be within 100 to 500 mg, IV. Multinomial analysis was used to describe the effect of FUR on the likelihood that a trainer will be above the marginal means and an outlier. The administration of FUR resulted in a 6-fold increase (600%) in the likelihood that a trainer was in the outlier category, above the 95% CI of the population mean generated from all horses managed by the 872 trainers in the dataset.

Furosemide produces a metabolic alkalosis shown by increases in the concentration of BE, an indicator of changes in the metabolic component of acid-base values. Dietary management and the administration of FUR have contributed to the increased likelihood that a given animal will exhibit values of BE above the population mean. This does not exclude horses that can be above the population mean due to dietary management alone.

The large variation associated with specific trainers was certainly associated with differences in the dietary and treatment regimens that a specific trainer used to manage the horses in their care. In dietary studies in horses on a mixed alfalfa-hay and oats, a diet with commonly used supplements did not result in blood gas differences from the control diet, and others have suggested that normally recommended amounts of supplements should not affect DCAB. There is no evidence that a high-alkaline diet alone will result in a violation of racing rules, but this study suggests that a high-alkaline diet and the administration of FUR were more likely to produce a metabolic alkalosis as shown in Figure 5.

Using the largest database available to date, which includes data from 11,479 horses, this study...
confirmed the presence of regional, gender, age, seasonal variations, prerace furosemide, and trainer influence on acid-base and blood gas values of prerace blood samples collected from Standardbred horses. The study directly benefits the racing industry by supporting established procedures. The effects described in this study can be applied to the general equine population with some limitations. Future studies using big data analytics are needed to verify the uniformity of these findings in the general equine population. Studies using acid-base data report values prior to the investigation as normal or control data and are interpreted as normal for the general population of horses. In this study, certain factors such as region, season, gender, and age are beyond the control of the owner/trainer and do affect acid-base values. What is under the control of the owner, trainer, or investigator are specific diets and management, which are used to maintain requirements for various activities, including minimal activity, pleasure riding, dressage, and racing.

Acknowledgments

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References


**Supplementary Materials**

Supplementary materials are posted online at the journal website: avmajournals.avma.org