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## Evaluation of maximal oxygen consumption during field exercise tests in Standardbred trotters

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### Introduction

The measurement of VO<sub>2</sub> in horses is routinely performed in some laboratories equipped with a treadmill (T<sub>m</sub>) but has only been exceptionally reported in field conditions because of the lack of adapted equipment. Recently a portable breath-by-breath gas analyser system adapted to horses (Cosmed K4B2 and Equimask®) was validated. The aim of this study was (1) to assess the feasibility of VO<sub>2</sub>max measurement on the track (T<sub>r</sub>) using the K4B2; (2) to compare the results with those obtained during a T<sub>m</sub> exercise test up to fatigue; (3) to study the relationship between VO<sub>2</sub>max and physiological parameters usually measured in field conditions (heart rate (HR) and lactatemia (LA) vs speed, ie V<sub>200</sub> and V<sub>LA4</sub>).

### Material and methods

Five Standardbred trotters were submitted to two stepwise incremental exercise tests, one on the T<sub>r</sub> and one on a high-speed T<sub>m</sub>. Speed, HR, ventilatory parameters and VO<sub>2</sub> were continuously recorded throughout the tests. LA was evaluated after each step.

### Results

VO<sub>2</sub>max (T<sub>r</sub>:156.7 ± 14.8 mL/kg/min; T<sub>m</sub>:148.1 ± 10.3 mL/kg/min), LA<sub>max</sub> (T<sub>r</sub>:6.5 ± 1.6mmol/L; T<sub>m</sub>:7.3 ± 2.9mmol/L), HR<sub>max</sub> (T<sub>r</sub>:222 ± 13 b/min; T<sub>m</sub>:229 ± 6 b/min) measured either on the T<sub>r</sub> or on the T<sub>m</sub> were not significantly different. However while V<sub>LA4</sub> and V<sub>200</sub> were similar in both conditions, speed at VO<sub>2</sub>max (VVO<sub>2</sub>max) was significantly higher on the T<sub>r</sub> (12.56 ± 0.32 m/s vs. 9.9 ± 0.24 m/s). Breathing strategy differed: tidal volume (VT) was higher and breathing rate was lower on T<sub>r</sub>. VO<sub>2</sub>max correlated with V<sub>LA4</sub> ( $r = 0.66$ ,  $P = 0.07$ ) and weakly with V<sub>200</sub> ( $r = 0.51$ ,  $P = 0.19$ ).

### Conclusion

This is the first report describing VO<sub>2</sub>max measurements in trotters in genuine track conditions. The values obtained in this condition were similar to those obtained in the laboratory, but the breathing strategy was different and VVO<sub>2</sub>max was higher.



## Comparison of the portable and fixed gas respiratory analysers in horses according to exercise intensity

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### Introduction

Several studies have evaluated the accuracy of COSMED K4b<sup>2</sup> portable metabolic gas analysis systems in humans (Pinnington HC et al. J. Sci Med Sport. 4:324-35, 2001). The objective of this study was to compare data obtained from the K4b<sup>2</sup> portable system and the fixed Quark COSMED cart for determining the validity of the K4b<sup>2</sup> unit in measuring energy expenditure during an incremental treadmill test in seven horses.

### Material and methods

The expired air was collected in consecutive sessions using the K4b<sup>2</sup> and the Quark metabolic cart in random order. Minute ventilation (VE), inspired O<sub>2</sub> and CO<sub>2</sub> fractions were measured at rest and continuously at rest and during each trial. Oxygen consumption (VO<sub>2</sub>) and carbon dioxide production (VCO<sub>2</sub>) were estimated using the Haldane Equation. According to the manufacturer's recommendations, we applied a correction coefficient of 20 to the final VO<sub>2</sub> value (VO<sub>2</sub>-correction) and also directly to the tidal volume (VO<sub>2</sub>-Haldane-correction).

### Results

Heart rate values were comparable for exercise at the same work stage during gas collection using the two systems ( $P = 0.7136$ ), indicating that the physiological stress was similar. Repeated ANOVA showed no significant difference between the applied methods (VO<sub>2</sub>-correction vs. VO<sub>2</sub>-Haldane-correction,  $P = 0.2062$ ) or the devices (K4b<sup>2</sup> vs. Quark,  $P = 0.4973$ ). Whatever the methods used (VO<sub>2</sub>-correction vs. VO<sub>2</sub>-Haldane-correction), any significant effect was observed using the Bland and Altman method to compare the K4b<sup>2</sup> and Quark VO<sub>2</sub> values.

### Conclusion

The application of the K4b<sup>2</sup> system was accurate for all VE, VO<sub>2</sub> and VCO<sub>2</sub> measurements from rest to maximum exercise levels in horses.



## **Nitric oxide synthase inhibition in healthy thoroughbred horses augments O<sub>2</sub> extraction at rest and submaximal exercise, but not during short-term maximal exertion**

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### **Introduction**

Endogenous nitric oxide (NO) release is known to modulate vascular tone and may play a role in cellular respiration via inhibition of mitochondrial enzymes. Thus, we examined the effects of NO synthase inhibition on O<sub>2</sub> extraction at rest and during incremental treadmill exercise leading to maximal exertion.

### **Material and methods**

Seven healthy, sound, exercise-trained Thoroughbred horses were studied in 2 sets of experiments, namely placebo (saline) and NO synthase inhibition (with N<sup>ω</sup>-nitro-L-arginine methyl ester [L-NAME] administration @ 20mg/kg, IV) studies, which were carried out in random order, 7 days apart. In both treatments, catheterization of the aorta and the main pulmonary artery permitted blood-gas measurements (corrected to core temperature) to be made at rest, and during an incremental exercise protocol leading to galloping at 14m/s on 3.5% uphill grade for 120s (maximal exercise).

### **Results**

In standing horses, NO synthase inhibition caused systemic and pulmonary hypertension, bradycardia, and an expansion of the arterial to mixed-venous blood O<sub>2</sub> content gradient as mixed-venous blood O<sub>2</sub> tension and saturation decreased significantly ( $P < 0.01$ ). Thus, O<sub>2</sub> extraction of standing horses increased significantly. During submaximal exercise, although NO synthase inhibition did not affect arterial blood-gas tensions, a significant ( $P < 0.05$ ) attenuation of the exercise-induced increment in hemoglobin concentration limited the rise in arterial blood O<sub>2</sub> content. However, the accompanying significantly ( $P < 0.01$  vs. placebo) large reductions in mixed-venous blood O<sub>2</sub> tension and saturation in the NO synthase inhibition study resulted in a significant ( $P < 0.05$ ) augmentation of the arterial to mixed-venous blood O<sub>2</sub> content gradient and O<sub>2</sub> extraction. In contrast with these findings, NO synthase inhibition neither affected the extent of arterial hypoxemia, hypercapnia or metabolic acidosis in maximally exercising horses, nor the mixed-venous blood O<sub>2</sub> tension and saturation. Thus, arterial to mixed-venous blood O<sub>2</sub> content gradient and O<sub>2</sub> extraction in the NO synthase inhibition experiments were not different from the values observed during maximal exertion in the placebo study.

### **Conclusion**

Our data indicate that while endogenous NO production affects O<sub>2</sub> extraction at rest and submaximal exercise, this is unlikely in Thoroughbreds performing short-term maximal exercise.



## **Evaluation of race distance, track surface and season of the year on the recurrence and severity of EIPH in flat racing Thoroughbreds in Brazil**

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### **Introduction**

This study was aimed at verifying the influence of race distance, racetrack surface and season of the year on the recurrence and severity of Exercise Induced Pulmonary Haemorrhage (EIPH) and its effects on finishing position of flat racing Thoroughbreds in Brazil. To our knowledge no similar studies have been undertaken in Brazil, which is one of the few countries in the racing community to accept the use of furosemide (FUR) as a pre race medication for bleeders.

### **Material and methods**

Two thousand one hundred eighteen post race respiratory endoscopies were analyzed with a total of 1003 different horses. The horses were randomly selected from a population of certified bleeders with ages from 2 ½ to 7 years old which had FUR administered prior to each race. Data were analyzed using both ordinary and multiple logistic regression (Genmod, SAS Inst. Inc.).

### **Results**

Our results showed that recurrence of EIPH in bleeders medicated with prerace FUR was higher in tropical winter (Odds Ratio 1,78) and long races (OR 1,41) and that severity worsened in the winter (OR 1,38) and when track surface changed due to rain (OR 1,23). Despite the use of FUR, 61.66% of the horses in this study remained EIPH positive to some extent. Horses that remained positive and those with higher hemorrhage grading tended to finish unplaced.

### **Conclusion**

Our results suggest that race distance, season of the year and racetrack surface affects the recurrence and severity of EIPH in bleeders medicated with prerace FUR and questions the benefits of FUR as an effective medication against EIPH.



## The effect of inspired gas density on pulmonary artery transmural pressure and EIPH

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### Introduction

High pulmonary artery (PA) transmural pressure (PA<sub>tm</sub>), largely as a result of high PA pressure has been clearly implicated in the aetiology of EIPH. However, the role of the airways in determining the magnitude of PA<sub>tm</sub> has received little attention. We hypothesised that horses breathing a gas of greater density than air would exhibit greater PA<sub>tm</sub> and more severe EIPH and that horses breathing a gas of lower density than air would exhibit lower PA<sub>tm</sub> and less severe EIPH, compared with horses breathing air.

### Material and methods

8 TB horses were studied in a Latin-Square design. Following warm-up, each horse exercised for 1 min at 10, 11 and 12 m/s (5) breathing air or 21% O<sub>2</sub> in helium (HE) or in argon (AR). Heart rate, respiratory rate, PA pressure and oesophageal pressure were measured during exercise. Bronchoalveolar lavage (BAL) was performed 40 min post-exercise and RBC counts were performed.

### Results

HR and respiratory rate at 12m/s on air were  $218 \pm 11$  bpm and  $125 \pm 4$  b/min, respectively, and were not different on AR or HE. Mean PA pressure was not affected by gas density, but maximum change in PA pressure increased with increasing gas density (HE  $95 \pm 7$ ; Air  $106 \pm 8$ ; AR  $115 \pm 15$  mmHg;  $P < 0.05$ ). Delta oesophageal pressure also increased with increasing gas density such that PA<sub>tm</sub> was not altered by gas density. Median (and range) BAL RBC counts were not different between HE (7.0; 1.9-31.5), air (4.5; 1.2-20.8) and AR (7.1; 3.2-25.1  $\times 10^3$  RBC/mL BAL).

### Conclusion

As alterations in PA and oesophageal pressure caused by changes in inspired gas density were of similar magnitude, PA<sub>tm</sub> remained unchanged and there was no effect on the severity of EIPH. This observation is not consistent with the observation of the efficacy of the nasal strip in reducing EIPH.



## **Pre-exercise hypervolemia is not detrimental to arterial oxygenation of horses performing a prolonged exercise protocol simulating the 2nd day of a 3 day equestrian event**

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### **Introduction**

Dehydration and hyperthermia are principal concerns in horses performing prolonged exercise, particularly in hot, humid conditions; thus, several hydration schemes have been investigated to improve endurance through better maintenance of cardiovascular/thermoregulatory functions. However, it was recently reported (Equine Vet J Suppl. 34: 425, 2002) that hyperhydration prior to prolonged moderate-intensity exercise simulating the 2nd day of a 3 day equestrian event, induced arterial hypoxemia which may be detrimental to performance. Because moderate-intensity exercise does not induce arterial hypoxemia in healthy horses in our laboratory, we examined the effects of pre-exercise hypervolemia on arterial oxygenation during a prolonged exercise protocol simulating the 2nd day of a 3 day equestrian event which incorporated a burst of short-term high intensity exercise known to induce arterial hypoxemia and desaturation of hemoglobin.

### **Material and methods**

Blood-gas studies were carried out on 7 healthy, exercise-trained Thoroughbred horses in the control and hyperhydration treatments. The sequence of treatments was randomized for each horse and 7 days were allowed between studies. Hyperhydration was induced by administering 0.425 g/kg NaCl via nasogastric tube followed by free access to water. The exercise protocol (modified from Equine Vet J 31: 31, 1999) was carried out on a treadmill set at a 3% uphill grade and consisted of walking @ 2 m/s for 2 min, trotting for 10 min @ 3.7 m/s, galloping for 2 min @ 14 m/s (which elicited maximal heart rate and EIPH), trotting for 20 min @ 3.7 m/s, walking for 10 min @ 1.8 m/s, cantering for 8 min @ 9.2 m/s, trotting for 1 min @ 5 m/s, and walking for 5 min @ 2 m/s.

### **Results**

NaCl administration induced a significant 16.1% increase in plasma volume as indicated by a significant reduction in plasma protein concentration. In either treatment, whereas arterial hypoxemia was not observed during periods of sub-maximal exercise in our protocol, short-term maximal exertion caused significant arterial hypoxemia, desaturation of hemoglobin, hypercapnia, and acidosis in both treatments. However, the magnitude of the exercise-induced arterial hypoxemia, desaturation of hemoglobin, hypercapnia, and acidosis in both treatments remained similar, and statistically significant differences between treatments could not be demonstrated.

### **Conclusion**

Significant pre-exercise expansion of plasma volume by this method does not adversely affect the arterial oxygenation of horses performing a prolonged exercise protocol simulating the 2nd day of a 3 day equestrian event.



## Effects of the equine nasal flair on indices of performance and EIPH

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### Introduction

Reports of the efficacy of the equine nasal flair on various indices of respiratory function and/or exercise-induced pulmonary hemorrhage (EIPH) are equivocal. The results of several treadmill studies suggest significant reduction in EIPH and energetic work of respirations, while contradictory results have also been reported. This study evaluated the effects of the equine nasal flair on multiple indices of physiological performance during maximal treadmill exercise.

### Material and methods

Eight Thoroughbred horses exercised on a treadmill at speeds 110% of those required to elicit in a randomized cross-over design, with (CON) or without (FLAIR) the application of an equine nasal flair. Blood samples (arterial and mixed venous) were collected pre, 30 and 90 sec during and following exercise. Ventilatory parameters were measured using an open-flow mask system sealed to the horse's face; with an esophageal catheter used to measure pleural pressures. One hour following exercise, video endoscopy and saline lavage of both the left and right lung and trachea (TTW) was done. Video images were evaluated in a 'blinded' manner, and erythrocytes (rbc) in lavage fluid were enumerated.

### Results

Visual bleeding scores and TTW rbc counts were unaffected by treatment with the nasal flair ( $2.6 \pm 0.3$  vs.  $2.5 \pm 0.4$ ,  $P = 0.29$ ; and  $3.200 \pm 850$  vs.  $3.400 \pm 680$  cells/uL, CON vs. FLAIR, respectively,  $P = 0.28$ ). Oxygen consumption, blood lactate accumulation, airway resistances, ventilatory parameters were similarly unaffected by application of the nasal flair.

### Conclusion

During treadmill exercise, the equine nasal flair did not alter the severity of EIPH, neither by visual scoring nor erythrocyte enumeration. Indices of performance were also unaffected by application of the equine nasal flair. These results suggest that the nasal flair does not improve parameters related to athletic performance and does not reduce EIPH.



## **Exercise-induced pulmonary hemorrhage (EIPH) during sub-maximal exercise**

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### **Introduction**

During maximal exercise, Thoroughbred horses experience extreme elevations in pulmonary artery pressure (Ppa) thought responsible for pulmonary capillary rupture and exercise-induced pulmonary hemorrhage (EIPH). However, the pressure differential across the blood-gas barrier (and the extent of EIPH) involves summation of negative intrapulmonary as well as positive intravascular pressures. Therefore, we tested the hypothesis that prolonged sub-maximal exercise (trotting), which results in intravascular (i.e Ppa) pressures well below, but extravascular pressures (i.e. esophageal pressure; Pes) near that measured during maximal sprinting, would cause significant EIPH.

### **Material and methods**

Five Thoroughbred horses trotted to fatigue (~25 min) at 5 m/s on a 10% incline. Ventilatory variables, Pes, and Ppa were measured (5 min intervals) and bronchoalveolar lavage (BAL) cells were enumerated (~ 45 min post-exercise).

### **Results**

BAL revealed an increased EIPH (rest:  $0.2 \pm 0.1 \times 10^6$  exercise:  $1.7 \pm 1.0 \times 10^6$  RBCs/mL BALF;  $P < 0.05$ ). The highest mean Ppa was only  $55 \pm 3$  mmHg, whilst minute ventilation ( $1197.5 \pm 77.0$  L/min), tidal volume ( $12.7 \pm 0.5$  L), breathing frequency ( $107 \pm 11$ ), and Pesmin ( $-31 \pm 6$  cmH<sub>2</sub>O) approached maximal exercise values. This highly negative Pes resulted in a peak pulmonary vascular transmural pressure of  $110 \pm 11$  mmHg (when end-inspiration is in-phase with systolic Ppa), well above the level considered causative of EIPH.

### **Conclusion**

The finding of significant EIPH during sub-maximal exercise where Ppa is well below the "EIPH threshold" ( $< 75$ - $100$  mmHg) broadens the spectrum and number of performance horses susceptible to EIPH and supports earlier studies which suggest that extravascular factors are of primary importance in the etiology of EIPH.



## Effects of hypercapnoea on fluid flux from the pulmonary vasculature at rest and during exercise in horses

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### Introduction

Specific airway diseases in horses are associated with abnormal pulmonary haemodynamics. This study was designed to determine fluid flux (JV-A L/min) across the alveolar-capillary barrier in hypercapnoeic horses before, during and after high intensity exercise.

### Material and methods

Six horses were exercised on a treadmill until fatigue without (Con) and with chronic carbonic anhydrase inhibition and associated hypercapnoea (HyCap) with administration of acetazolamide. Arterial and central mixed venous blood, as well as VCO<sub>2</sub> and VO<sub>2</sub>, were sampled simultaneously. Blood volume changes across the lung (&#8710;BV %) were calculated from changes in plasma protein, haemoglobin and hematocrit. Cardiac output (Qp) was calculated using the Fick principle. JV-A across the alveolar-capillary barrier was then quantified based on Qp and &#8710;BV. Variables were analysed using two-way repeated-measure ANOVA ( $P < 0.05$ ). A significant F ratio was further analysed using Tukey post-hoc analysis.

### Results

Hypercapnoea had a significant effect on JV-A ( $P = 0.04$ ). At rest there was no JV-A in Con ( $0.3 \pm 0.8$  L/min); in HyCap  $1.3 \pm 0.5$  L/min of fluid moved from the pulmonary interstitium into pulmonary circulation ( $P < 0.05$ ). During exercise in Con fluid moved from the pulmonary circulation into the pulmonary interstitium ( $9.4 \pm 2.4$  L/min). It remained relatively stable in HyCap ( $1.8 \pm 2.4$  L/min). Mean exercise HyCap was significantly different from Con ( $P = 0.04$ ).

### Conclusion

Altered CO<sub>2</sub> homeostasis along with acid-base changes affects JV-A in the lungs. Based on the findings of this study it can be concluded that the kinetics of the pulmonary interstitial and vascular fluid movement in horses adapt rapidly and efficiently to physiological and perhaps pathological changes at rest and during strenuous exercise.



## Effect of corticosteroid and bronchodilator therapy on bronchoalveolar lavage cytology following intrapulmonary blood inoculation

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### Introduction

Intrapulmonary blood causes an inflammatory response. Modifying this inflammatory response may be a useful method of treating Exercise Induced Pulmonary Haemorrhage (EIPH). The purpose of this study was to evaluate the efficacy of three treatments, an oral bronchodilator, an inhaled steroid, and an oral steroid in modifying the cellular response to intrapulmonary blood inoculation.

### Material and methods

Experimental design was a randomised block divided into four experimental segments of 2 weeks. Eight normal horses were randomly assigned to pairs and treatments. Autologous blood was inoculated into the lungs on four occasions over an 8 week period. For each treatment, a bronchoalveolar lavage (BAL) sample was collected on day 0 and then two randomly selected segmental bronchi (one in each lung) were inoculated with blood (50mL). BAL fluid was collected from one of these inoculated bronchi on day 3 and from the other on day 10. From BAL samples, total RBC and total and differential WBC were determined. Results for percentages and absolute cell counts were expressed as mean  $\pm$  standard error of the mean (SEM) and analysed using one, two and three way analysis of variance.

### Results

All treatments ( $P = 0.021$ ) reduced the number of erythrophages at day 3 ( $P < 0.05$ ) and oral corticosteroid lowered the relative and absolute ( $P = 0.073$ ) number of haemosiderophages in BAL compared to the other two treatments at day 10.

### Conclusion

We concluded that the treatments altered the dynamics of cell populations in BAL following blood inoculation. Possible benefits for equine lungs following episodes of EIPH remain to be determined. Further studies might include macrophage activation studies, and evaluation of cytology concomitant with pulmonary function testing to evaluate treatment efficacy.



## **Evaluation of lower respiratory tract disease in horses presented for poor performance using tracheal aspirate cytology and arterial blood gases**

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### **Introduction**

Lower respiratory tract (LRT) disease is believed to contribute to decreased performance in racehorses. The LRT can be evaluated by cytology of tracheal wash (TW) or bronchoalveolar (BAL) fluid, and degree of compromise to gas exchange can be assessed by arterial blood gas (ABG) analysis. Although TW cytology may be abnormal, its relationship to, or effect on gas exchange during exercise is unknown. The purpose of this study was to identify horses with abnormal TW cytology, and to correlate abnormal TW with impairment of gas exchange in horses presenting for evaluation of poor performance.

### **Material and methods**

Medical records of 813 horses presenting to the treadmill facility between 1998-2004 were examined. Horses were selected if they had ABG analyses and TW performed. Diagnoses, TW results as determined by clinical pathologists, and ABG results were compared. Normal ABG vs. speed was determined by linear regression using normal TB horses.

### **Results**

Two hundred nine cases had TW and ABG analyses. Seventy-seven horses had abnormal ABG. Amongst these, 30 horses had significant upper respiratory tract (URT) abnormalities (39%). In the horses without URT, 37/47 (78.7%) horses with abnormal ABG had abnormal TW cytology. In the horses with URT, 26/30 (86.7%) horses had abnormal TW cytology with abnormal ABG. One hundred thirty-two horses had normal ABG, with 36 having URT (27.3%). Horses (59/83) (71.1%) with normal ABG and no URT had abnormal TW cytology. Of the horses with normal ABG and URT, 38/49 (77.6%) had abnormal TW cytology.

### **Conclusion**

A similar distribution of horses with normal and abnormal ABG had abnormal TW, although a slightly lower percentage of horses with abnormal ABG had normal TW vs normal ABG. A higher percentage of horses with URT had abnormal ABG, suggesting a contribution of URT disease to ABG values.



## **Inflammatory airway disease in poorly performing National Hunt racehorses**

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### **Introduction**

Inflammatory airway disease (IAD) is characterised by tracheal mucus and neutrophilic inflammation of the lower airways. The condition is common in young flat racehorses and may result in reduced athletic performance. IAD in young racehorses is frequently associated with bacterial infection and the prevalence of the condition decreases with increasing age. The aim of this study was to investigate whether lower airway inflammation is a feature in an older population of poorly performing National Hunt racehorses.

### **Material and methods**

Tracheal wash (TW) and broncho-alveolar lavage (BAL) were performed, under sedation, 30–60 minutes after strenuous exercise on a high-speed treadmill.

### **Results**

Lower airway inflammation (> 20% neutrophils in TW, or > 5% neutrophils in BALF) was identified in a total of 65 out of 87 horses. There was no significant association between grade of tracheal mucus score and tracheal or broncho-alveolar inflammation. There was a significant association between the proportion of neutrophils in TW and BALF. However, 7/35 horses with tracheal inflammation had no evidence of inflammation in BALF and 30/58 had evidence of inflammation in BALF despite normal TW findings.

### **Conclusion**

No significant associations were found between lower airway inflammation and age, gender, presence of bacterial or fungal infection, presence of upper airway obstruction or exercise-induced pulmonary haemorrhage. Lower airway inflammation is a common finding in poorly performing NH racehorses. In contrast to studies in flat racehorses, inflammation does not appear to be associated with bacterial infection and does not decrease with increasing age, suggesting that other aetiological factors are involved.



## **Late-phase bronchoconstriction after cold weather exercise in horses**

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### **Introduction**

Inspired air is warmed to body temperature and fully humidified by the upper airway mucosa under normal resting conditions. This conditioning process may not be completed by the upper airways during conditions of increased minute ventilation or when the inspired air is unusually cold, resulting in cooling and desiccation of lower respiratory surfaces. Excess heat and water loss from intrapulmonary airways is believed to be the provocative stimulus for exercise-induced bronchoconstriction (occurring immediately after exercise) and associated late phase airway obstruction (occurring a few hours after exercise).

### **Material and methods**

We used eight healthy horses to test the hypothesis that exercise-induced lower airway cooling and desiccation would result in bronchoconstriction. Each horse performed a 15 min submaximal exercise challenge in a random crossover design. The independent variable was inspired air temperature during the challenge (25 or -5C). The dependent variables were total respiratory impedance, resistance, and reactance at 5 hr, 24 hr, and 48 hr post exercise challenge, expressed as a percentage of the pre-challenge baseline.

### **Results**

No significant effect of inspired air temperature was found on any respiratory mechanical parameter 5 hr after the exercise challenge. However, cold inspired air was associated with higher respiratory reactance 24 hr after the exercise challenges, and higher respiratory impedance and resistance 48 hr after the exercise challenges.

### **Conclusion**

These findings support the hypothesis that submaximal exercise while breathing subfreezing air can adversely affect respiratory mechanical properties in normal horses. However, the time course for development of abnormal respiratory mechanical properties is longer than that reported in other mammals.



## **Evaluation of the upper respiratory tract in 90 sport horses undergoing high-speed treadmill videoendoscopy**

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### **Introduction**

Videoendoscopic examination of the upper respiratory tract (URT) during high-speed treadmill exercise has proven invaluable in the assessment of poor athletic performance of racehorses. However, there has been little study of other sport horses that perform less strenuous exercise. This retrospective study aimed to evaluate the videoendoscopic findings in a mixed population of sport horses referred for investigation of poor athletic performance.

### **Material and methods**

The URT of 90 horses referred for investigation of poor performance was examined at rest and during an exercise test to fatigue on a high-speed treadmill.

### **Results**

Upper airway obstruction was diagnosed in 68 of the 90 horses examined, of which 23 (34%) had complex dynamic collapse. Palatal malfunction was observed in 36 horses, of which 16 had other additional forms of dynamic airway collapse. Dynamic laryngeal collapse was observed in 26 horses, including one of 52 horses with normal (grade 1 or 2) and 11 of 22 horses with equivocal (grade 3 out of 5) laryngeal function at rest. Other disorders included axial deviation of the aryepiglottal folds (15 horses), pharyngeal wall collapse (10 horses) and epiglottal retroversion (2 horses). In 16 cases, URT obstruction was exacerbated or was evident only when the horse was exercised with a flexed poll position. Additionally, 19 (28%) horses with URT obstruction had concurrent inflammatory airway disease.

### **Conclusion**

The findings of this study demonstrate that dynamic obstruction of the URT is a common cause of poor performance in sport horses and is frequently complex in nature. Excessive poll flexion is an important contributing factor.



## Dynamic pharyngeal collapse in racehorses

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### Introduction

Dynamic pharyngeal collapse (PC) is a condition seen in racehorses which can be career ending. The purpose of this study was to characterize PC into grading categories and to describe the effects of PC on performance.

### Material and methods

Eight hundred thirteen medical records of horses presented to the University of Pennsylvania for poor performance and placed on the high speed treadmill from 1998-2004 were reviewed. Forty-seven (6%) records were identified as horses with the primary diagnosis of PC. Forty-two tapes of video endoscopy of the pharynx during exercise were reviewed. Each video recording was assigned a number of the degree of PC using the following scale: Grade 0 = normal pharynx, Grade 1 = deviation of 1 pharyngeal wall (PW), Grade 2 = deviation of 2 PW, Grade 3 = deviation of 3 or more PW, Grade 4 = deviation of all 4 PW resulting in near full obstruction of the glottis. Earnings/race prior to diagnosis of PC to earnings/race after diagnosis of PC in Thoroughbreds (TB) was compared.

### Results

38 (81%) horses were TB, and 9 (19%) were Standardbreds (STB). Eight (17%) were females, 39 (83%) were males and the average age was 4 years. Thirty-two (68%) had a history of making upper respiratory noise. Six (14%) horses had Grade 1 PC, 16 (38%) had Grade 2 PC, 13 (31%) horses had Grade 3 PC and 6 (14%) had Grade 4 PC. A statistical difference was found comparing pre-diagnosis earnings/race (mean \$5199) to post-diagnosis earnings/race (mean \$1189) in TB  $\geq$  4 years of age with a  $P$  value = 0.02.

### Conclusion

There was a trend for more TB than STB, and more males than females to be diagnosed with PC relative to our hospital population. Racing records after a diagnosis of PC in TB showed reduced earnings/race compared to prior to diagnosis.



## **Hematological, immunological and respiratory gas changes in horses and mules**

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### **Introduction**

Exercised at Altitude (3800 m) Mules are purported to perform better than horses at high altitude. This study measured the rate and magnitude of changes in hematological, immunological and respiratory gas parameters with acute acclimation to high altitude in horses and mules under both rest and post-exercise (post-ex) conditions. An abbreviated abstract is presented.

### **Material and methods**

Resting and 1-min post-ex venous blood samples were obtained from 6 horses and 5 mules housed at 225 m (LA) and then transported to 3800 m (HA) for 13 days. The standardized exercise test consisted of trotting (3.0 m/s) up an incline (6%) for 2 km. Data were analyzed with repeated measures ANOVA and only post-ex data are presented here.

### **Results**

Exercise at HA increased HR ( $P = 0.002$ ) and PCV ( $P = 0.03$ ) in both groups, but the increase was attenuated in the mules. Mules had a lower HR than horses post-ex ( $P = 0.01$ ). DPG/Hb was increased in both groups ( $P = 0.001$ ) but was greater ( $P = 0.03$ ) in horses. Cortisol, post-ex, was elevated and was greater in mules compared to horses ( $P = 0.02$ ), but there were no species differences in WBC count ( $P = 0.23$ ) or neutrophil:lymphocyte ratio ( $P = 0.46$ ). Both groups were alkalotic compared to LA ( $P = 0.001$ ), and there were no group differences ( $P = 0.95$ ). Post-ex pO<sub>2</sub> were 12% higher in the mules ( $P = 0.034$ ).

### **Conclusion**

The lower, post-ex heart rates and PCV in mules at HA indicate a reduced metabolic demand. That, coupled with the higher, post-ex pO<sub>2</sub> in mules after acclimatization, provides some objective support to the claim that mules are “better” at altitude than horses.



## Evaluation of a portable equine metabolic measurement system

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### Introduction

The validity of a portable metabolic measurements system for horses, the Cosmed K4B2 gas analysis system, was investigated. K4B2 consists of an airtight face mask (Equimask®) mounted with two turbines to measure airflow and a catheter that continuously collects expired air. A portable analyser measures gas concentration on a breath-by-breath basis.

### Material and methods

The reproducibility of the metabolic and ventilatory measurements given by K4B2 was tested using a submaximal treadmill exercise with 5 untrained saddle horses (5 min walk, 5 min trot, 1 min gallop at 7 m/sec and 8 m/sec). The horses underwent this test twice at a 3 day interval. Secondly, VO<sub>2</sub>max from 5 horses was measured on a treadmill (10 min warm up, then gallop at increasing intensity up to fatigue with an 8% slope) with the K4B2 system and a reference method (Rmet) (ultra-sonic pneumotachographs to measure airflow and mass spectrometer to measure breath by breath expired gas concentrations). The measurements obtained at maximum effort were compared.

### Results

There was no significant difference between the measurements obtained at a 3 day interval using the K4B2 (ANOVA for repeated measures,  $P > 0.05$ ). VO<sub>2</sub>max, tidal volume (VT) and respiratory frequency (FR) obtained with K4B2 and Rmet were similar (VO<sub>2</sub>:112 ± 26mL/kg/min, VT:14 ± 3L and FR:122 ± 19/min with K4B2; VO<sub>2</sub>:114 ± 18mL/kg/min, VT:113 ± 2L and FR:119 ± 11/min with Rmet), while VEmax measured with the K4B2 was significantly higher (1693 ± 188 L/min with K4B2 vs 1553 ± 189 L/min with Rmet). However, the percentage difference between both methods was less than 10%.

### Conclusion

According to its satisfactory reproducibility, and the similarity of its VO<sub>2</sub>max values with those obtained by Rmet, K4B2 is acceptable for routine VO<sub>2</sub> measurement in track conditions.



## **Locomotor and respiratory coupling: factors of variation in Standardbred Trotters in the field**

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### **Introduction**

The coordination between locomotor and breathing rhythms has been described in many animal species. In particular, a tight relation between limb and respiratory rhythms in galloping horses due to mechanical constraints in the thoracic region has been shown. This synchronisation leads to a 1/1 ratio between stride frequency (SF) and respiratory frequency (RF) during galloping. The purpose of this study was to describe stride frequency and respiratory frequency during a standardised exercise test on the track in Standardbred Trotters. The relationships between those variables, their ratio, and supposed factors of variation (speed of exercise, age-training status, and physiological parameters V4 and V200) were studied.

### **Material and methods**

Sixty French Trotters performed a standardised exercise test on the track consisting of three 3-min steps at constant speed. The speeds (V) of exercise varied between 8.5 and 12.5 m/s. Some variables were measured during exercise: SF using an accelerometric device (Equimetrix®), heart rate using a heart rate monitor (Polar), RF using a microphone in front of the nostrils, and blood lactate concentration after each step. Physiological variables V4 and V200 were calculated, and race performance indices were recorded.

### **Results**

Study results indicated two strategies of locomotor-respiratory coupling: some trotters showed a 1/1 ratio while some others showed a 3/2 ratio between SF and RF, independently of the speed of exercise. No relationship between the SF/RF ratio and physiological parameters or race performance indices was found.

### **Conclusion**

The results showed two individual strategies of locomotor-respiratory coupling at high speed in Standardbred Trotters. There was no evident link between one of these strategies and physiological or race performance parameters.



## Breath types during and after intense treadmill exercise to fatigue in thoroughbred racehorses

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### Introduction

Coupling of locomotion to breathing is a feature of galloping exercise in horses. However, differences in types of breath have been demonstrated, with reference to “big respiratory cycles” and “flow hesitations”. The aim of this study was to investigate the occurrence of different breath types during and after intense treadmill exercise, and test the hypothesis that large breaths were a function of respiratory frequency.

### Material and methods

Six trained and clinically normal Thoroughbred horses were used in this study. The exercise test consisted of 3.5 minutes trotting at 3.5 m.s<sup>-1</sup>, then a 30 second period of acceleration to 9 m.s<sup>-1</sup>. Horses then completed 75 s exercise at 9 and 10 m.s<sup>-1</sup> and variable periods of exercise at 11 m.s<sup>-1</sup>. Treadmill slope was 10%. The exercise test was terminated when the horse could no longer maintain the same speed as the treadmill. Breath-by-breath pulmonary ventilation was measured continuously during exercise and continued after exercise.

### Results

Five different breath types were identified. They were classified as normal monophasic, normal biphasic, deglutition, effort pause, or large breaths. Breath types during exercise varied between horses. Respiratory frequencies (Rf) at 9 and 10 m.s<sup>-1</sup> were 117.4 ± 2.6 (SD) and 120.1 ± 2.5. There were 2.2 ± 5 and 2.8 ± 2.5 large breaths during 75s exercise at 9 and 10 m.s<sup>-1</sup>. During exercise at 10 m.s<sup>-1</sup> the number of large breaths was significantly related to Rf ( $r = -0.86$ ,  $P = 0.03$ ). During 120 seconds after exercise there were two distinct populations of breaths, large and normal monophasic.

### Conclusion

Large breaths are a normal feature of pulmonary ventilation during and after intense exercise. These breaths should be studied during evaluation of pulmonary function in exercise tests.



## Oxygen consumption (VO<sub>2</sub>) during trotting on a 10% decline

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### Introduction

Although there are energetic measurements of horses running on the level and incline, there are no measurements during decline locomotion. This may be due, in part, to the potential for muscle damage produced by eccentric contractions. In humans running on a 10% decline, VO<sub>2</sub> decreased by 35% and stride frequency (SF) decreased by 3% when compared to level locomotion (Minetti et al. 1994). We hypothesized that metabolism and SF would be decreased in horses on a 10% decline when compared to the level.

### Material and methods

Six horses ( $437 \pm 47$  SD kg) were acclimated to trotting on the level and decline prior to data collection. VO<sub>2</sub> was measured (using an open flow system) during trotting between 2.0 and 4.0 m/s (at 0.25 m/s increments) on a treadmill on the level and declined 10%. Stride frequencies were based on a minimum of 30 strides for each speed. Data were analyzed using a repeated measures ANOVA.

### Results

VO<sub>2</sub> decreased ( $P < 0.001$ ) on the decline by an average of 46%, but there was an interaction of speed and condition ( $P = 0.0067$ ) indicating a greater relative effect at the higher speeds. Mean stride frequencies increased by 1.6% ( $P = 0.0026$ ).

### Conclusion

The lower energetic costs on a 10% decline were consistent with data on humans, but, unlike horses, humans decrease their stride frequencies. No adverse effects of downhill training were observed.

