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Characteristics of Respiratory Airflow during Exercise in Horses with Reduced Performance due to Pulmonary Emphysema or Bronchitis

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Summary

The diagnostic relevance of several respiratory parameters was studied in three groups of riding horses: (I) four healthy horses, (II) five horses with chronic bronchitis, (III) four horses with bronchitis and pulmonary emphysema. They were lunged without rider (5 min walk, 5 min trot) because it was expected that the pneumotachogram would show flow limitations more clearly during exercise than at rest. Electrocardiogram and respiratory airflow were transmitted telemetrically. At all gaits, group I had the lowest and group III the highest heart rates at a given velocity. Tidal volumes and inspiratory flow rates increased in group order. The respiratory time quotient (TE/TI) was negatively correlated with respiratory frequency; in bronchitic horses (group II) it was lower at all respiratory frequencies. The diseased horses had flow maxima later during inspiration and earlier during expiration than normal horses. The reduction in volume and flow reserves were readily observed on flow-volume loops. We conclude that the exercise pneumotachogram gives information of diagnostic relevance.

Index terms: Chronic obstructive pulmonary disease; pneumotachogram; tidal volumes; respiratory time quotient; flow volume loops.

Introduction

Chronic obstructive pulmonary diseases (COPD) are major causes of reduced performance in horses and present considerable diagnostic difficulties (McPherson *et al.*, 1978). Because of the legal consequences of trading such horses, it is highly desirable to have objective methods to document the presence or absence of COPD in horses. Well established methods exist to measure functional parameters such as lung compliance, flow resistances and respiratory work using stationary equipment in horses at rest or after excitement (Spörri and Leemann, 1964; Gillespie *et al.*, 1966; Sasse, 1971; Willoughby and McDonnell, 1979). It is conceivable, however, that minor grades of disease which do not impair resting pulmonary ventilation may become apparent only during exercise.

The Fleisch-type pneumotachograph system can only be used under laboratory conditions. In cooperation with the Physiology Department of the University of Nijmegen, Netherlands, we developed telemetric techniques to measure respiratory airflow in horses during riding (Hörnicke *et al.*, 1984). These techniques were found suitable to obtain pulmonary ventilation parameters under field conditions (Hörnicke *et al.*, 1983; Hörnicke *et al.*, 1987). We therefore began a study on the diagnostic relevance of respiratory parameters measured during exercise in COPD horses. Computer programs were developed which automatically derive characteristic properties of the pneumotachogram (PTG). It was found that the exercise PTG adds relevant information to the results of an examination in the resting state. The findings also illustrate how the respiratory system compensates for the impaired ventilatory capacity.

Material and Methods

Animals. Thirteen Standardbred horses were allotted to three different groups:

Group I: Four horses without pulmonary disease; age 5–13, mean 9 years; weight 540–652, mean 621 kg.

Group II: Five horses with chronic bronchitis; age 5–12, mean 9 years, weight 509–632, mean 577 kg.

Group III: Four horses with chronic bronchitis and pulmonary emphysema; age 7–18, mean 13 years; weight 450–640, mean 575 kg.

The diseased horses were selected from the patients of the large animal clinic, Tierhygienisches Institut Freiburg. They underwent clinical diagnosis including bronchoscopy.

Procedure. After recording respiration at rest for 5 min, the horses were lunged for 5 min each at a walk and trot. The length of the circle was carefully measured, the times measured by stopwatch and the velocities calculated. Environmental temperatures were 8–23°C, mean 17 ± 4°C; the relative humidity 37–83%. Most horses were studied twice, several weeks apart.

The techniques used have been described previously (Hörnicke *et al.* 1983, 1984). In brief, the horses were fitted with electrocardiogram (ECG) electrodes, mask-holder and a mask, to which a respiratory tube with flow transducer (Kimmich and Spaan 1980) was fixed. ECG and flow signal were transmitted by telemetry, received and stored on magnetic tape.

After data acquisition, the ECG and flow signal were demodulated, recorded, and analyzed to obtain steady state values for heart rate (HR) and respiratory frequency (f). Appropriate undisturbed parts of the experiment were then analyzed by computer, which sampled the flow signal every 10 msec, converted it to 1/sec and plotted PTG. PTGs and flow volume loops were averaged and displayed with the standard deviation of the instantaneous flow. For each single breath the following parameters were identified and tabulated (Fig. 1): duration of inspiration and expiration (TI and TE, msec); respiratory time quotient (TE/TI); volume of inspiration and expiration (V_I and V_E, 1 ATPS); inspiratory flow acceleration, represented by the flow rate 50 msec after the beginning of inspiration ($\dot{V}_{I50}$, 1/sec) (25 msec during trot); same for expiration ($\dot{V}_{E50}$ $\dot{V}_{E25}$, 1/sec); inspiratory and expiratory flow maxima ($\dot{V}_{Imax}$ and $\dot{V}_{Emax}$, 1/sec and their positions within the respiratory half-cycle. Mean values (± standard deviation) for the above parameters were calculated from 8 or more breaths. Twenty to 115 breaths were analyzed for each horse at each gait

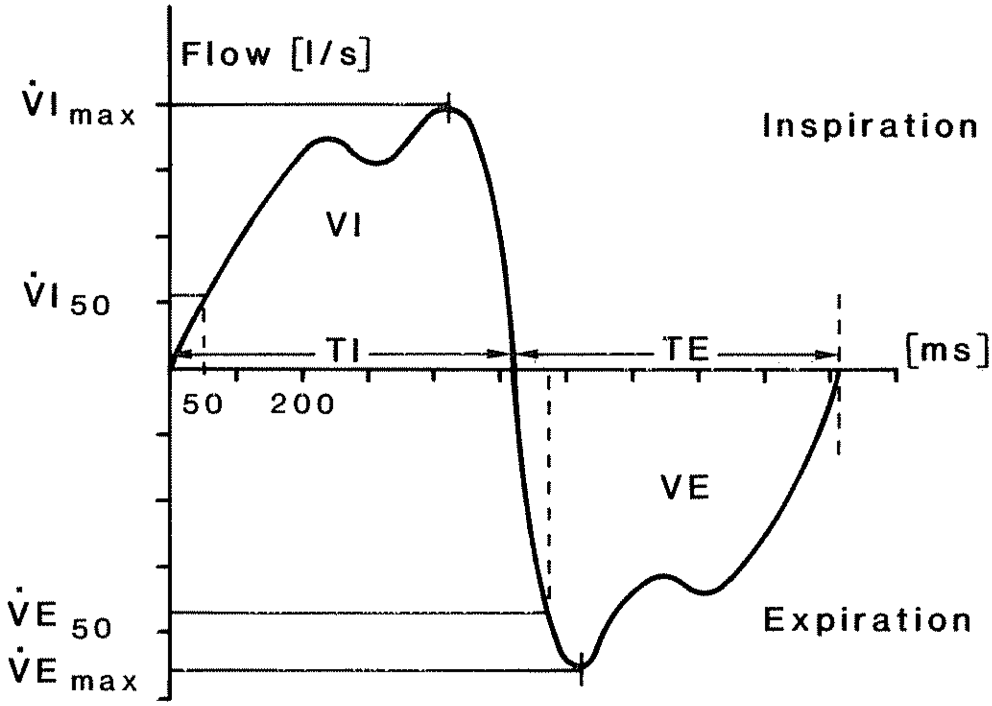

FIGURE 1. Schematic presentation of a pneumotachogram and the derived parameters.

Results

Results (mean ± SD) for the various parameters at rest and during exercise are presented in Table 1.

Velocity. The walking velocity during was 71–105 m/min. Group II horses walked significantly slower (by 10 m/min, $P < 0, 05$) when compared with group I. This difference was taken into account when the results were interpreted. Trotting velocity was 176–284 m/min with no significant difference between the groups.

Heart rate (HR). Resting heart rates (min^{-1}) of groups II (40 ± 4) and III (47 ± 6) were slightly higher than in the control horses (39 ± 11). Regression lines of HR on velocity for the three groups were parallel to each other. The calculated heart rates at a velocity of 200 m/min (HR_{200}) were: group I, 108 ± 9; group II, 111 ± 12; group III, 128 ± 30; the difference between groups I and III being significant ($P < 0.05$).

Respiratory frequency. The f at rest and during exercise was positively correlated with environmental temperature. The effect (f/°C) was 1.2 at rest, 2.5 during walk and 1.9 during trot. All respiratory frequencies were therefore corrected to 17.4°C which was the average environmental temperature during the control group experiments. On the basis of the corrected figures (Table 1), group III had the highest f at rest. At walk and trot, however, the diseased horses had equal or lower respiratory frequencies than the control horses. The coefficient of variation, representing the differences between experiments and horses, was large in the control group at rest (42%) but smaller in

TABLE 1. Respiratory parameters of the horses in the three experimental groups during rest and exercise.

Parameter	Unit		Group I S	Group I W	Group I T	Group II S	Group II W	Group II T	Group III S	Group III W	Group III T
f*	min^{-1}	$\bar{x}$	22	49	74	20	40	70	28[A]	46[a]	67*
		s	9	14	13	4	6	13	6	6	11
V_T	l	$\bar{x}$	4.9	6.7	9.2	6.2**	8.0	10.5*	7.0†[a]	8.9	11.2*
		s	1.0	1.1	1.9	.8	.5	.9	.8	1.5	1.5
TE/TI		$\bar{x}$	1.30	1.08	.94	1.09**	.97**	.87**	1.20	1.13[a]	1.07[a]
		s	.44	.19	.16	.11	.06	.05	.24	.17	.17
$\dot{V}_I$	l/s	$\bar{x}$	4.4	11.9	22.6	5.3	12.0	25.7	6.7	13.8*[a]	25.6
		s	1.9	4.3	6.4	2.4	2.1	3.4	2.2	1.8	4.2
$\dot{V}_E$	l/s	$\bar{x}$	4.0	11.9	25.5	4.9	12.4	29.6	5.9	12.7	24.6
		s	2.5	5.5	10.1	2.1	2.4	4.4	3.1	3.1	6.1
$\dot{V}_{Imax}$	l/s	$\bar{x}$	6.9	17.4	34.7	7.7	17.4	37.3	10.5*[a]	20.6*[a]	37.9
		s	3.1	6.3	9.0	3.4	3.0	4.3	2.8	3.0	5.8
$\dot{V}_{Emax}$	l/s	$\bar{x}$	7.2	19.7	40.6	8.6	20.4	42.7	11.7*	24.2	43.8
		s	3.9	8.2	12.0	3.7	3.9	6.4	3.7	5.0	3.9

f* = respiratory frequency corrected to the environmental temperature during the tests with group I by using an increment of 1.9 breaths/min/°C.
*,**,† = significantly different from group I with $P < 0.05$, 0.01 and 0.001, respectively.
a, A = significantly different from group II with $P < 0.05$ and 0.01, respectively. S, W, T = stand, walk, trot. $\bar{x}$, s = mean and standard deviation.

group II and III (18 and 21%, respectively). Less variation occurred during walk and trot.

Tidal volume (V_T) and pulmonary ventilation. Tidal volume was 4–8 l at rest; it increased to 5–11 l during walk and 6–14 l during trot. The diseased horses had significantly higher tidal volumes than the healthy horses (Table 1). The difference at rest (+1.3 l in group II and +2 l in group III) was maintained at both levels of exercise. Pulmonary ventilation was more variable. The only significant difference was a higher ventilation in group III at rest when compared to group I.

Respiratory times (TI, TE, TE/TI). In general the respiratory times reflected the trends in respiratory frequencies. During walk and trot, TE decreased more than TI. The respiratory time quotient (TE/TI) was thus lower at higher velocities. To analyze differences between the experimental groups, the dependence of TE/TI of f must be taken into account (Fig. 2). While there was little difference between groups I and III, the group II horses had a lower TE/TI at all respiratory frequencies.

When the steady state values for V_T were plotted against TI (Fig. 3a), V_I increased for a given TI in group order. These group differences, which indicate higher inspiratory flow rates, were particularly apparent during rest and walk.

Respiratory air flow rates ($\dot{V}_I$, $\dot{V}_E$, $\dot{V}_{Imax}$, $\dot{V}_{Emax}$). As a consequence of higher tidal volumes at low respiratory frequencies both mean and peak flow rates of the diseased horses were generally higher than the corresponding flows in the control group (Table 1). Most differences were not significant because of the variability within groups. Again, the differences were more apparent when differences in respiratory time were accounted for, for instance by plotting $\dot{V}_I$ against TI (Fig. 3b).

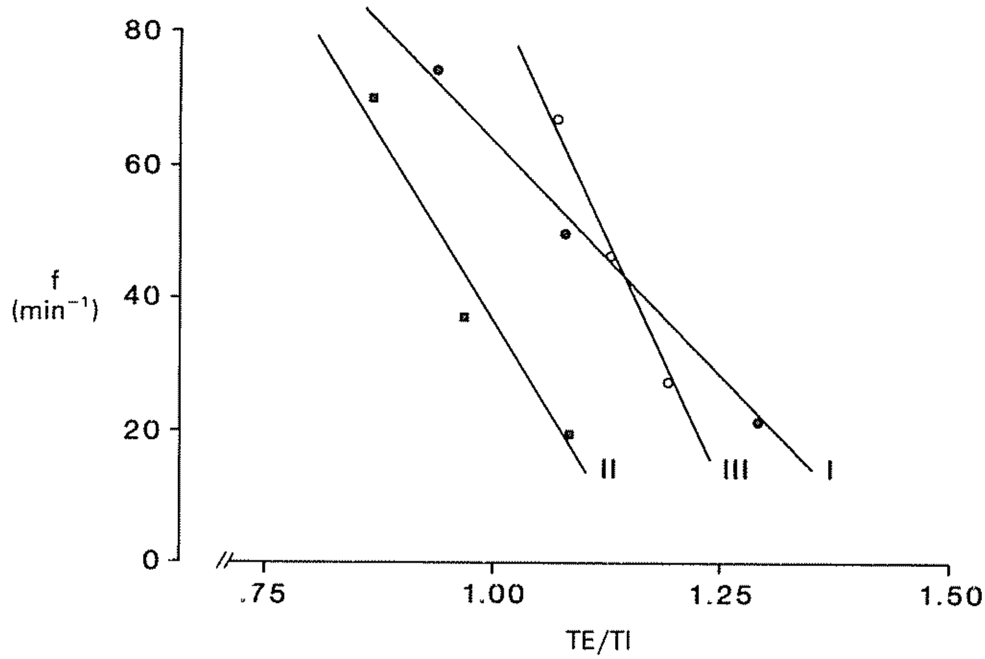

FIGURE 2. The respiratory time quotient (TE/TI) and its relation to respiratory frequency. I–III represent the 3 groups. The correlation coefficients were I = 996, II = .971, III = .997

Shape of the pneumotachogram. Irrespective of gait, the inspiratory flow maxima occurred at about mid-inspiration (at 40–60% of TI); as the exercise load increased the flow maximum occurred earlier (Fig. 4a). In group III horses, there was a tendency for flow maxima to occur later during rest as well as during exercise. The expiratory flow at rest had its maximum early (at 15–20% of TE) and shifted towards the second quarter during exercise. In group III the expiratory flow maxima occurred earlier at rest and this tendency was maintained during walk and trot (Fig. 4b). Group II was intermediate between I and III.

No significant differences were found between the groups with respect to air flow acceleration at the beginning of inspiration and expiration. Within 50 msec inspiratory flow attained 42% of its maximum value at rest and 68% during walk. The corresponding figures for expiratory flow were 64 and 73%. Examples of averaged pneumotachograms obtained during rest and during walk are shown in Fig. 5. In addition to the parameters already described, additional features are evident. The shape of the flow curves was individually different. The early flow maximum during expiration was apparent in the majority of the PTGs. Some of the group III horses had an expiratory flow pattern which has been previously described for horses with emphysema (Gillespie *et al.*, 1966; Spörri, 1971). When this shape was present it was maintained during the walk and trot. In one horse with emphysema and bronchitis this "emphysema-type" pattern was present at rest and exercise during the first investigation but not when the test was repeated 7 days later, in spite of the persistence of clinical signs.

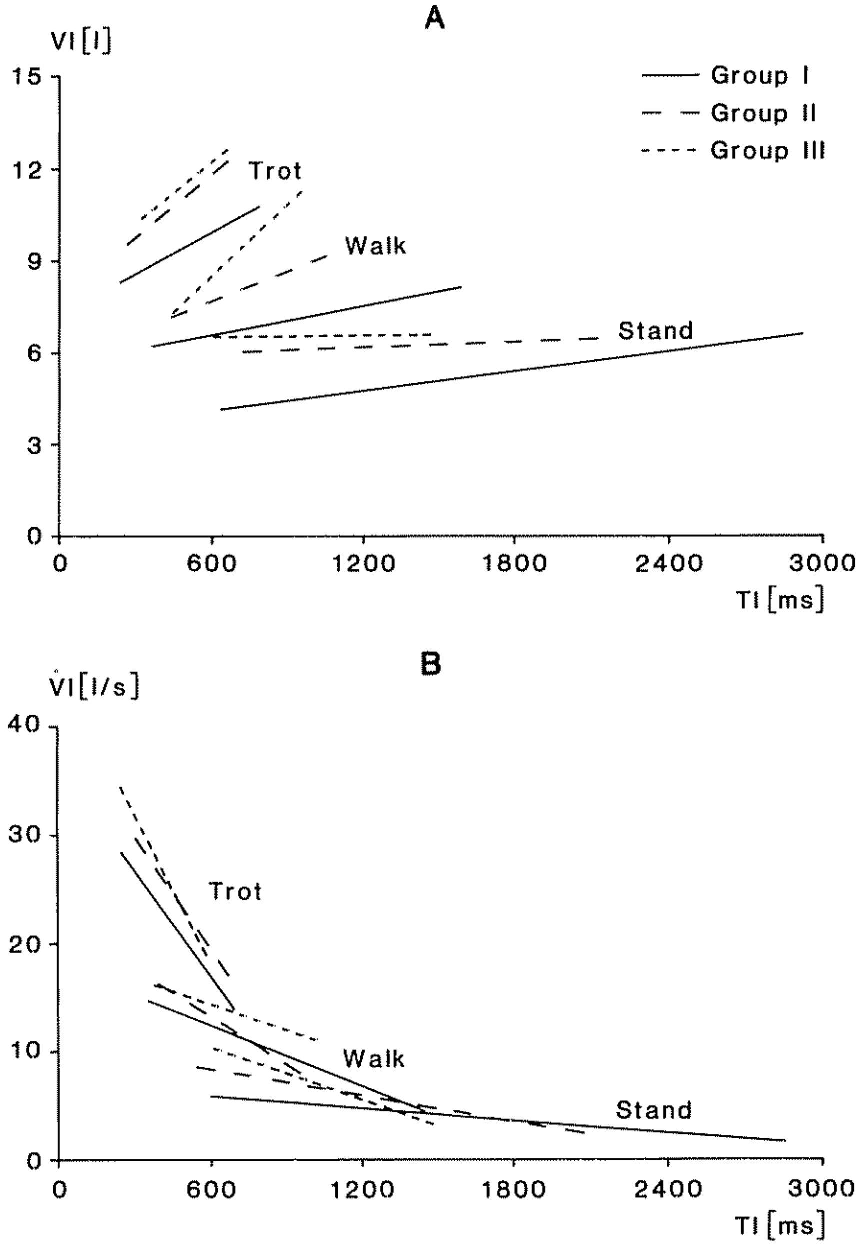

FIGURE 3. A: Inspiratory tidal volumes as related to inspiratory time (TI). B: Inspiratory flow rate (V̇I) as related to inspiratory time (TI).

Flow-volume loops. The combined flow-volume loops for resting, walking and trotting (Fig. 6) illustrate that all horses were able to maintain steady flow rates during most of the inspiratory cycle. Larger differences were apparent during expiration. While the control horses maintained high flow rates for about 2/3 of their expired volume,

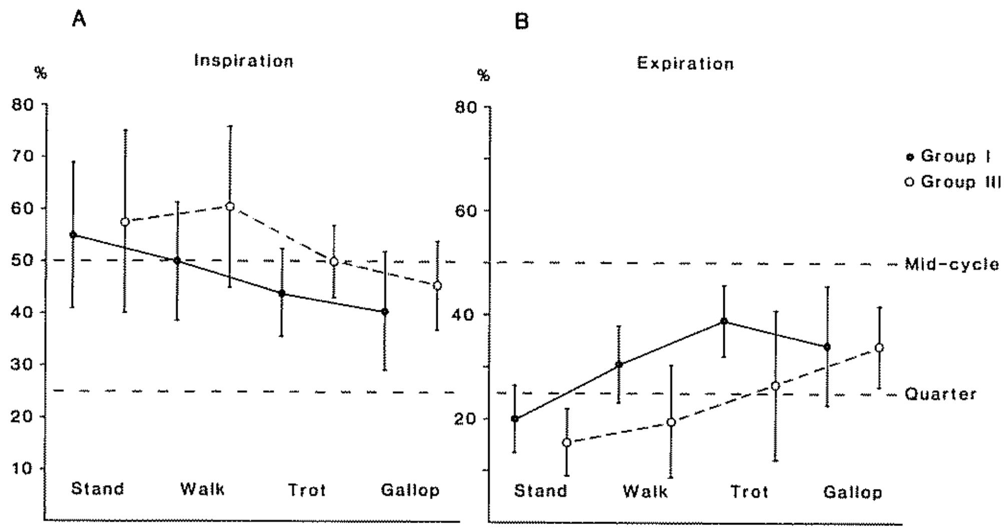

FIGURE 4 Position of the flow maxima during inspiration (A) and expiration (B).

group III horses reduced flow rates early in expiration. Fig. 6 also illustrates differences in respiratory reserve in the 3 groups. The bronchitic horses (group II) began with higher tidal volumes and thus increased flow more than volume, while the bronchitic horses with emphysema of group III had reduced reserves in both flow and volume. In the second half of expiration the flow curves during rest, walk and trot were very similar.

Discussion

Several reasons favor the measurement of respiratory parameters during exercise in the diagnosis of COPD: (1) Resting ventilation tends to be very irregular and is subject to emotional influences. It is therefore difficult to establish standard values and to set limits whose transgression indicates disease. During exercise, respiration becomes progressively more regular and emotional factors become negligible. This tendency to regularity was seen in this study. Sedation of the animals was not necessary to obtain useful data. (2) The conditions under which the test was performed correspond more closely to the conditions under which the reduced performance is observed. (3) Trends observed at rest can be confirmed under steady-state conditions at different levels of exercise. While about half of our horses could also be tested during gallop, the results were not presented here, because the data were incomplete. But in most instances the parameters measured during gallop extended and confirmed the results obtained at the other gaits (see for instance Fig. 4).

Our study was a pilot project. It established the feasibility of measuring respiratory flow during standardized exercise in diseased horses. It tested the usefulness of a number of variables derived from the PTG. It recognized certain trends, e.g. higher tidal volumes and flow rates and also shifts in the positions of the flow-maxima within the respiratory cycle. It is necessary that these findings are confirmed and extended in a larger sample of horses with COPD with well defined types of disease. It is thus con-

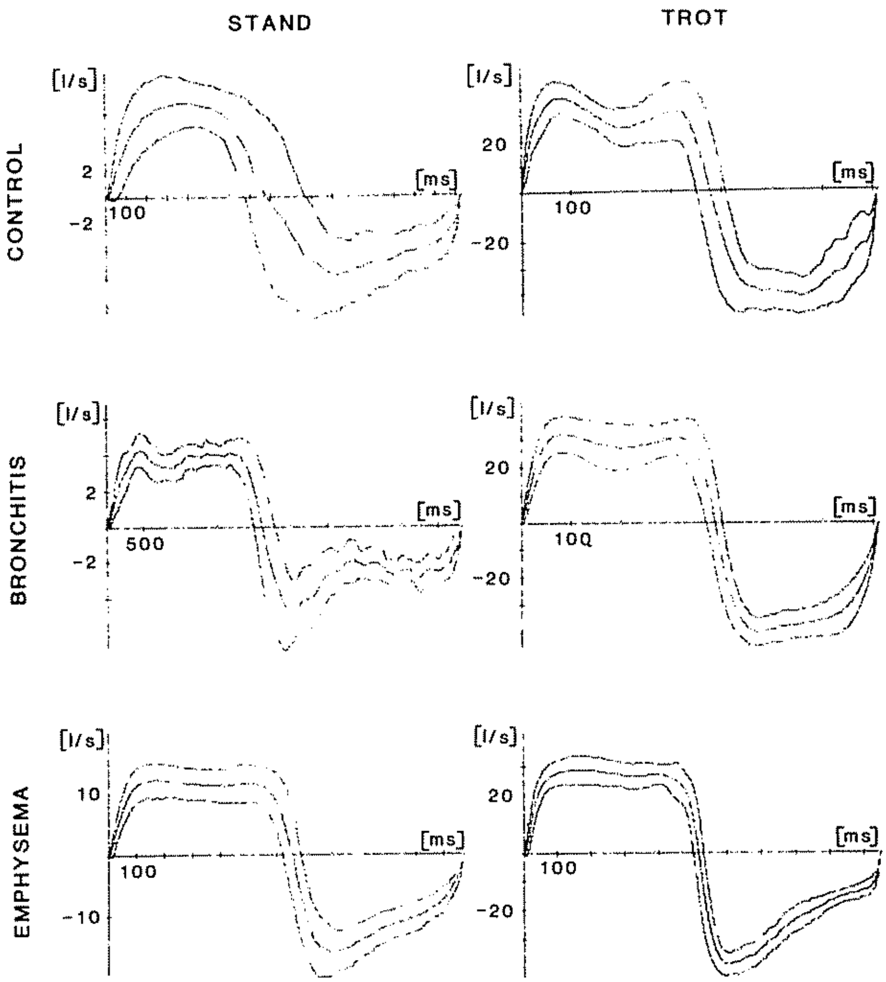

FIGURE 5 Shape of the pneumotachogram during rest and trot. Each experimental group is represented by one horse. The curves represent mean and standard deviation of the instantaneous flow for several breaths

ceivable to establish a set of variables, which by discriminant analysis would allow identification of pathological states with a high degree of confidence. A similiar approach using flow parameters has been succesfully applied in human patients (MacDonald and Cole, 1980). Additional parameters could be included in such a model and some of the present parameters could be more refined. Correction of respiratory frequency for environmental temperature (T_a) was found to be necessary and although T_a affected the other parameters in this study to a lesser degree, a correction for T_a may improve the accuracy of future comparisons.

The shift of the HR-velocity-regression towards higher heart rates (Maier-Bock and Ehrlein, 1978) documents that the performance of the horses is slightly reduced in group II and severely in group III. The greater impairment of the horses with bronchitis and

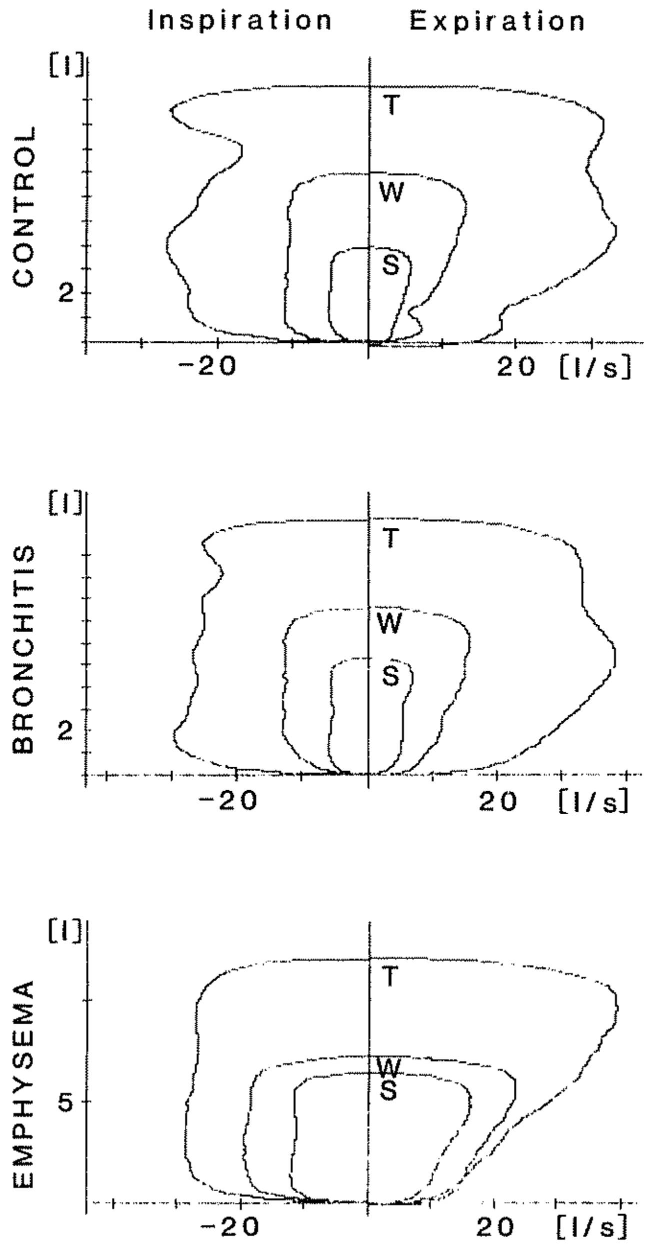

FIGURE 6 Flow volume loops from representative horses of the three groups for stand (S), walk (W) and trot (T)

emphysema (group III) is also evident by higher deviations in several parameters of pulmonary ventilation.

At rest and during the gaits with no or incomplete respiration-locomotion coupling (walk, trot) f was highly varible. This affected also the variability of other parameters like V_T, $\dot{V}$ etc. Group-effects were apparent when V_T, $\dot{V}$, etc. were plotted against f, TI or TE. Gretener (1975) has shown that in the resting horse TE/TI is highly dependent on f and to a lesser degree on V_T. At a given f and V_T horses with COPD had higher TE/TI. We found the same decline of TE/TI with f at rest and during exercise. But the bronchitic horses of group II had the lowest TE/TI in spite of a V_T which was intermediate between the tidal volumes of groups I and III. The TE/TI-f-plot may therefore be useful as a tool for the differential diagnosis of bronchitis with and without emphysema.

A triangular form of expiratory flow with an early maximum followed by a concave flow decline has been described as characteristic for horses with emphysema (Gillespie and Tyler, 1969). Spörri (1971) found this expiratory flow pattern in 3/4 horses with emphysema. In our group III this pattern occurred in three of the four horses.

A comparison of our results in horses with those of persons with obstructive pulmonary disease is difficult because of profound differences between horse and man with respect to respiratory mechanics and type of obstruction. However, structural similiarities between human and horse lungs may explain the frequent occurence of emphysema in both species (Gillespie and Tyler, 1969). The horse's inspiration at rest is biphasic and characterized by long periods of steady flow. The human resting PTG can be better represented by a sine wave (Bradley and Crawford, 1976). Expiration at rest is also biphasic in the horse and, in contrast to man, apparently active in its second part (Amoroso, *et al.*, 1962). Lower airway resistance comprises 70–90 of total respiratory resistance in horses but only 25–50% in human beings (Robinson and Sorensen, 1978). Equine chronic bronchitis tends to be a small airways disease with marked goblet cell proliferation and excessive mucus production, which may be accompanied by alveolar emphysema (Slauson and Hahn, 1980). The bronchitic and emphysematic forms of obstructive disease in human subjects produce quite different symptoms (Jones and Berman, 1984).

In spite of such species differences the expiratory flow pattern with an early peak and an exponential flow decline was considered as pathognomonic also in human medicine. Bradley and Crawford (1976) found this type in 60% of their restricted and obstructed patient but only in 16% of their control subjects. In most of these persons the shape of the PTG was not changed by moderate exercise. A shift of the flow maximum in the resting PTG toward the beginning of expiration was considered by Morris and Lane (1981) as characteristic for bronchitic patients. In our horses this shift occurred at rest and at all levels of exercise and was even more conspicous when bronchitis was accompanied by emphysema. In addition we observed that the inspiratory flow maximum occurred later during inspiration in these horses (Fig. 4).

In contrast to the forementioned apparent similiarities, there are several dissimilarities between horse and man in the effects of obstructive diseases on pulmonary mechanics. At rest and during exercise we found tidal volumes at a given inspiratory cycle length higher in the more severe obstructive disease (Fig. 3A). Using the same type of plot, Bradley and Crawford (1976) found the restricted and obstructed patients to have lower than normal tidal volumes.

A reduction in airflow is generally a prominent sign in persons with obstructive pulmonary diseases. McNeill *et al.*, (1959) found both the absolute values of $\dot{V}_I$ and $\dot{V}_E$ as well as the $\dot{V}_E/\dot{V}_I$ ratio to decrease with increasing severity of the disease. Our horses were able to increase mean and peak flow rates considerably during exercise. The quotients $\dot{V}_E/\dot{V}_I$ and $\dot{V}_{Emax}/\dot{V}_{Imax}$ both increased during exercise but there were no differences between the groups.

In conclusion, the characteristics of respiratory airflow of COPD horses differ in many aspects from the airflow described for human subjects with obstructive pulmonary diseases. Future studies are necessary to define the reasons for these differences. Respiratory airflow telemetry during standardized exercise tests is an excellent tool to study respiratory function over its whole range of adaptation.

Acknowledgments

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Exercise Tolerance in Standardbred Trotters with T-wave Abnormalities in the Electrocardiogram

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Summary

The T-wave configuration is very labile in the horse and varies with fluctuations in the vagal tone but the clinical significance of T-waves of abnormal polarity and amplitude is still obscure. In this study an attempt was made to differentiate pathological and physiological T-wave changes by inducing an increased vagal tone with a nose twitch and to elucidate the diagnostic significance of the prevailing abnormal T-waves by exercise tolerance testing on a high-speed treadmill.

In most horses, application of a nose twitch causes a decrease in the heart rate and an increased frequency of sinoatrial and 1st and 2nd degree atrioventricular (AV) blocks indicating a rise in the vagal tone. If this reflex vagotonia occurs, the majority of "abnormal" T-waves return to normal in parallel with the decrease in the heart rate. In 18 racehorses with a history of decreasing performance presented to the university clinic, abnormal T-waves were recorded even after applying a nose twitch. Heart rate, respiratory rate and blood lactate responses to a standard exercise test on a high-speed treadmill did not differ significantly from a reference population of apparently sound Standardbreds. The mean red cell volume (CV), however, was significantly larger in the horses with abnormal T-waves, and both the exercise and recovery heart rates were significantly higher than predicted from CV. The blood lactate accumulation during exercise was less in this group than predicted

It was concluded that abnormal T-waves per se are not associated with decreased exercise tolerance, but may indicate a vago-regulatory imbalance related to overtraining and red cell hypervolemia.

Index terms: Blood volume, heart rate, blood lactate, treadmill exercise, horse.

Introduction

The clinical significance of T-wave abnormalities in the equine electrocardiogram (ECG) is still not known. Anomalies of the repolarization phase of the ECG have been suggested to indicate myocardial disease (Steel, 1963; Bergsten and Persson, 1966; Persson, 1969; Fregin, 1975; Holmes and Rezakhani, 1975). The T-wave is very labile in the horse, however, making the evaluation of its diagnostic significance extremely difficult. A number of both physiological and pathological factors influence the polarity