Equine Exercise Physiology 3: 83–91, 1991

Effect of Treadmill Exercise on Intrapleural, Transdiaphragmatic and Intra-abdominal Pressures in Standardbred Horses

R. SLOCOMBE,[1] K. BROCK,[1] G. COVELLI[1] and W. BAYLY[2]

[1]*School of Veterinary Science, University of Melbourne, Parkville, Victoria, 3052, Australia and* [2]*College of Veterinary Medicine, Washington State University, Pullman, Washington, 99164, USA*

ABSTRACT. Transdiaphragmatic and intra-abdodminal pressures were measured in 6 healthy Standardbreds during graded treadmill exercise in order to better understand basic diaphragmatic function and to determine the influence of the abdominal viscera on the diaphragm at different gait and exercise intensities. Transdiaphragmatic pressures were measured using balloon catheters placed in the mid-thoracic oesophagus and stomach. Intragastric pressures were compared to intraperitoneal and intrarectal pressures to determine whether abdominal pressure changes were similar at all 3 sites. Transdiaphragmatic pressures were affected by exercise intensity and by gait, with maximal pressure swings occurring at the gallop. Greatest values for peak transdiaphragmatic pressure were recorded during inhalation, suggesting that maximal diaphragmatic work occurs then. During exhalation, transdiaphragmatic pressures were less than inhalation pressures at the same exercise level. Peak inspiratory intrapleural pressures during exercise may provide an estimate of diaphragmatic performance in the horse that is as useful as direct or derived measurement of transdiaphragmatic pressure. Three measures of intra-abdominal pressure differed significantly. Although all catheters were phase matched to 7 Hz, and pressure signals were in phase at rest, phase shifts occurred in abdominal pressure signals with exercise. These shifts became more marked with increasing exercise intensity. The data indicate that an abdominal "piston" effect may occur during galloping, which probably facilitates exhalation. Using simple balloon catheter systems, our data indicate that intragastric balloons may not be a reliable way of estimating intra-abdominal or transdiaphragmatic pressures in horses that have recently eaten.

Key words: Horses; intragastric pressure; diaphragmatic function; exercise; intrapleural pressure; transdiaphragmatic pressure

INTRODUCTION

This study was performed to develop information on diaphragmatic function in exercising horses and relate these measurements to pressure changes in the thorax and abdomen during exercise. An abdominal "piston" effect has been postulated to explain physiologic advantages that horses may gain if ventilation is facilitated by the tight linkage of stride and breathing frequencies.[9]

In horses, respiratory function is thought to be one of the factors limiting athletic performance at high exercise intensities.[2–4,6,13] For humans, diaphragmatic performance is an important influence on respiratory function. The capacity of the diaphragm to maintain performance despite increased work loads reflects its ability to resist or delay the development of fatigue.[14–17,20,21] As with other skeletal muscles, respiratory muscle performance can be evaluated for both strength and endurance.[21] Respiratory muscle strength can be assessed by determination of maximal intrapleural pressures, by measurement of transdiaphragmatic pressures, and by maximal sniff pressures.[14–16,21] Respiratory muscle endurance is assessed by measuring the ability to sustain peak respiratory pressures, some measurement systems utilizing the addition of resistive or elastic loads.[16 17 21]

Because many of the conventional tests for human respiratory muscle strength and endurance are effort dependent and require voluntary co-operation to produce maximal respiratory excursions, these measures are not generally adaptable for use in animals.[21] Other factors may make relationships between transdiaphragmatic pressure and diaphragmatic muscle work difficult to interpret in large animals. There may be postural differences attributable to the motion of the diaphragm in exercising upright bipeds vs the diaphragmatic motion of quadrupeds. Certainly, thoracic wall mechanical properties differ greatly between species, and there may be regional inhomogeneities in thoracic wall properties[10] that could cause the contribution of the diaphragm to ventilation to differ during exercise between species. Furthermore, in horses there is likely to be a considerable variation in local pressures across regions of the diaphragm because of stratification of intrapleural pressures due to gravity,[11] because of inhomogeneous distribution of inspired air to lung regions during each tidal volume manoeuvre[1 19] and because of local influences of cranial abdominal viscera upon the abdominal side of the diaphragm.

Despite these limitations, a better understanding of diaphragmatic function in horses may be useful for several reasons. First, the influence of gait upon respiratory function remains poorly documented in horses. Although the entraining of stride to breath cycle is well known, it is unclear whether there is an overall positive effect on respiratory function.[5 22 23] It seems logical that horses at full gallop should facilitate exhalation because of an abdominal piston effect, similar to that described for humans exercising on a trampoline, but the existence of this piston effect has not been proven for horses. Secondly, one hypothesis to account for exercise-induced pulmonary haemorrhage (EIPH) of horses suggests that haemorrhage occurs as a consequence of shear forces generated at the boundaries of lung regions that have inhomogeneous ventilation. It is possible that diaphragmatic activity could contribute to regional inhomogeneities in intrathoracic pressure in animals affected by EPIH and account for the usual distribution of lesions. Thirdly, the low compliance of the equine chest wall probably restricts lateral expansion of the thorax during inspiration, and caudal displacement of the diaphragm may be extremely important in producing ventilation at a relatively low energy cost. This role of the diaphragm may be accentuated for saddled horses where a tight girth strap might further restrict chest wall motion. Finally, in humans suffering from asthma, physiotherapy to improve diaphragmatic performance can limit the disability suffered by this airway obstructive disorder. If respiratory function is indeed a limiting factor for some forms of equine athletic performance, then training procedures to develop diaphragmatic strength and endurance may have a rational basis.

The objectives of this study were to: (1) describe the basic function of the diaphragm in horses, as assessed by transdiaphragmatic pressure measurement; (2) document the influence of gait and exercise intensity on transdiaphragmatic pressures; (3) determine the extent to which regional differences in intra-abdominal pressure occur at different gaits and exercise intensities.

METHODS

Animals. Six clinically normal untrained Standardbred horses weighing approximately 500 kg were studied. They were maintained at pasture and were acquainted with treadmill exercise, although the horses were not in work. They were brought in from pasture immediately prior to instrumentation.

Equipment. Four identical balloon catheters were constructed of polyethylene tubing that had a series of side holes in the distal

8 cm. A thin walled, 10 cm long latex balloon covered this end. Catheters remained in phase at frequencies up to 7 Hz by using an oscillating sinusoidal pressure signal generated by a speaker-in-box system. A guide wire passed down the length of the catheter prevented kinking and facilitated passage of two catheters, one placed into the mid-thoracic oesophagus and the second into the stomach. These catheters were passed via the external nares into the oesophagus subsequent to desensitization of the cranial aspects of the nose with a local anaesthetic spray. Position of the catheters was confirmed by radiography and by demonstration of typical pressure deflections upon inhalation at rest. An additional catheter placed in the palm of a hand was gently advanced into the rectum so that it lay approximately 75–90 cm cranial to the anus. This catheter was secured in place by taping it to the ventral aspect of the tail. The fourth catheter was placed free within the abdominal cavity via a midline stab incision midway between the xyphoid and the umbilicus. Placement was confirmed by the appearance of peritoneal fluid at the stab incision site and by the ease of passage of the catheter into the peritoneal cavity. Balloons contained 1.0 ml air and were connected to Validyne differential air pressure strain gauge transducers. The proximal ends of all catheters were connected to 3-way stopcocks so that balloon volume could be checked prior to each experiment and so that pressures could be recorded relative to atmospheric pressure. This arrangement also allowed catheter patency to be checked when pressure signals appeared attenuated. If unusual pressure tracings were recorded, balloon volume was checked and if air could not be injected with ease, the catheter was assumed to be kinked, the catheter relocated and the experiment repeated. Glass syringes were used to evaluate balloon patency because of their low barrel friction compared to plastic syringes. Transducer signals were demodulated and amplified using a Gould physiograph and pressures recorded on thermal paper using an electrostatic thermal array recorder (Gould TA2000). Transducers were calibrated using a water manometer.

Experimental design. Catheterized horses were placed on a treadmill at 0° inclination and a sequence of exercises performed. Because of insufficient transducer–amplifier systems to measure all combinations of catheter pressure differences simultaneously, 3 protocols were performed with the order randomized between horses. Transducer configurations in the first protocol were intrapleural pressure–atmospheric pressure (P_{pl}), intragastric pressure–atmospheric pressure (P_{ig}), intraperitoneal pressure–atmospheric pressure (P_{pt}), and intrarectal pressure–atmospheric pressure (P_{ir}). In the second protocol, transducer configurations compared P_{pl}, $P_{pl}-P_{ig}$, $P_{ir}-P_{ig}$ and $P_{pt}-P_{ig}$. In the third protocol, P_{pl}, $P_{pl}-P_{ig}$, P_{ig} and P_{ir} were compared. For each protocol, pressures were recorded at rest, at a 2.0 m s^{-1} walk , a 4.5 m s^{-1} slow trot, a 7.0 m s^{-1} fast trot and a 9.0 m s^{-1} gallop. Horses maintained each speed for approximately 1 min before accelerating to the next speed. This time was sufficient to allow a constant respiratory pattern to develop, as determined by the intrapleural pressure tracing. A minimum of 3 similar breaths per speed were analysed. Horses rested between protocols for 10 min, and by this time P_{pl} had returned to baseline.

Statistical analyses. Data were analysed by factorial analysis of variance; where significant differences existed ($a \leqslant 0.05$) Student–Newman–Keul multiple range tests were used to compare means.

RESULTS

Transdiaphragmatic pressures. Peak transdiaphragmatic pressures were influenced by the phase of respiration and the intensity of exercise. These values were similar to those recorded directly for $P_{ig}-P_{pl}$ (Fig. 1), except during inhalation at the gallop. Transdiaphragmatic pressures increased during inspiration (i.e. the abdominal cavity increased in pressure relative to the thorax) and de-

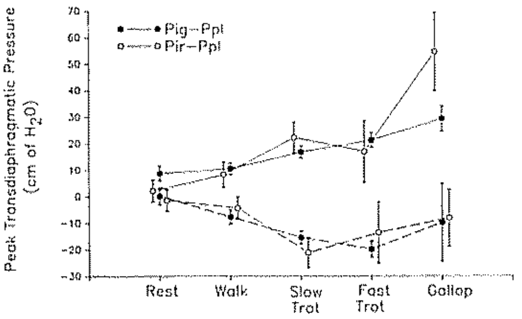


Fig 1 Relationship of peak transdiaphragmatic pressure to speed, illustrating the differences between intragastric pressure (P_{ig}) and intrapleural pressure (P_{pl}), or intrarectal pressure (P_{ir}) and P_{pl}. Inhalation is denoted by solid lines and exhalation by dashed lines.

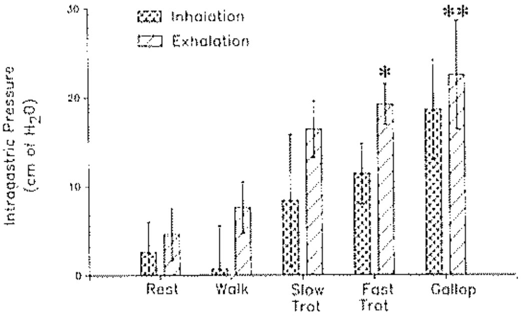


Fig 3 Relationship between peak intragastric pressures, phase of respiration, and speed. The baseline is zero with respect to atmospheric pressure. * denotes significantly different from rest. ** denotes significantly different from rest and walk

creased slightly during exhalation. These effects were greater with more intense exercise. Direct measurement of P_{di} differed from values derived by subtracting peak P_{pl} from peak P_{ig} by as much as 20 cmH$_2$0 during galloping.

Effect of exercise The onset of exercise increased both inspiratory and expiratory intrapleural pressures. With increasing speed, peak inspiratory pressures became progressively more negative with respect to atmospheric pressure and peak expiratory pressures became progressively more positive (Fig. 2).

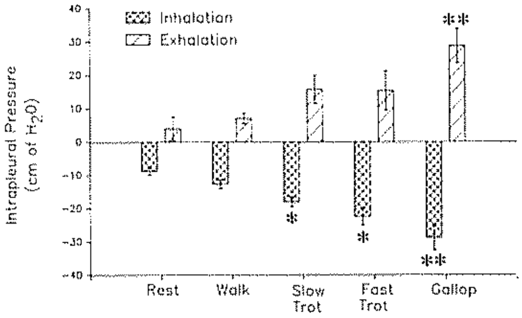


Fig 2 Relationship between peak intrapleural pressures, phase of respiration, and speed. The baseline is zero with respect to atmospheric pressure. * denotes significantly different from rest and walk. ** denotes significantly different from all other groups.

Gastric pressures were not significantly altered during inspiration by increased exercise intensity averaging at rest and all exercise levels 8.3±4.3 cm H_2O ($\bar{x}$ ± SEM). Gastric pressures during exhalation were significantly increased with increases in exercise intensity (Fig. 3).

Intraperitoneal pressures did not change with exercise intensity for either inhalation or exhalation (inhalation, 2.1±0.4 cm H_2O; exhalation, 3.7±1.3 cm H_2O). Rectal pressures were significantly affected by exercise for both inhalation and exhalation (Fig. 4), but peak pressures during exhalation were greatest at the fast trot, not the gallop.

Measures of pressures on the abdominal side of the diaphragm. Intrapleural pressures were highly reproducible and repeated measurements on the same horse always gave similar pressure tracings. However, the magnitude of differences between P_{pl} and the various intra-abdominal pressures was variable, due not only to the site of pressure measurement within the abdomen, but also because of great variation between results from repeated measurements in the same animal. There were significant interactions between phase of the respiratory cycle, exer-

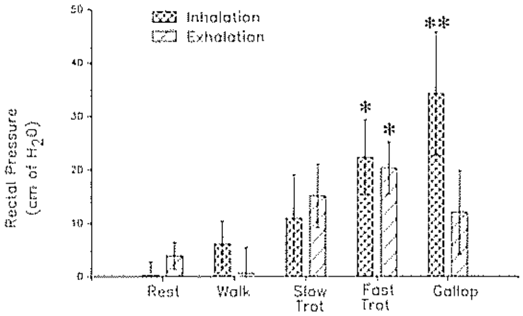


Fig 4 Relationship between peak intrarectal pressures, phase of respiration and speed. The baseline is zero with respect to atmospheric pressure * denotes significantly different from rest. ** denotes significantly different from rest, walk and slow trot

cise intensity and site of abdominal pressure measurement. P_{pl}, P_{ig} and P_{ir} were similar in horses at rest (Fig. 5), but differences became progressively more apparent with increasing intensity of exercise, all measures differing significantly in horses at the gallop during inhalation. In general, rectal pressures were greater than pressures recorded in either the peritoneal cavity or the stomach. However, the data in Fig. 5 do not adequately depict other considerations relating to abdominal pressure measurement. The pressure waveforms were complex (Figs. 6A–E) and the maximal value alone did not adequately describe the relationships between intrathoracic and intra-abdominal pressures for each speed. Fig. 6A illustrates pressure tracings with the horse standing quietly on the treadmill, and peak pressures at inhalation and exhalation are in phase. At a walk (Fig. 6B), only some pressure spikes were transmitted into the thorax, and pressure peaks did not occur simultaneously, especially during exhalation. Changes in respiratory frequency were common, especially at the slow trot (Fig. 6C). The differences between the 3 abdominal pressures were striking at speeds above the slow trot. At the fast trot, respiration was closely linked with gait, but pressure changes associated with the gait were only obvious on the rectal pressure tracing and did not appear consistently on the gastric pressure tracing (Fig. 6D). At the gallop there was 1 : 1 entraining of ventilation with stride. Rectal pressure and intrapleural pressure were similar (Fig. 6E) although they appeared 180° out of phase. Maximal recorded pressure swings during galloping were −40 to +45 cmH_2O (intrapleural pressures) and +66 to −100 cmH_2O (intrarectal pressures).

DISCUSSION

Determination of intra-abdominal pressures using the 3 balloon catheters demonstrated that considerable regional variations exist. The data clearly show differences in pressures obtained from each of the balloons placed in the abdomen. There were also inconsistent readings for each catheter, especially P_{ig}. There may be several causes for these results. There are probably real differences in regional pressures throughout the abdomen attributable to elastic, resistive and inertial effects of different regions of the visceral mass. Our data also suggest that some of the differences measured may be spurious. Accurate estimates of pressure using balloon-catheter systems rely on the bal-

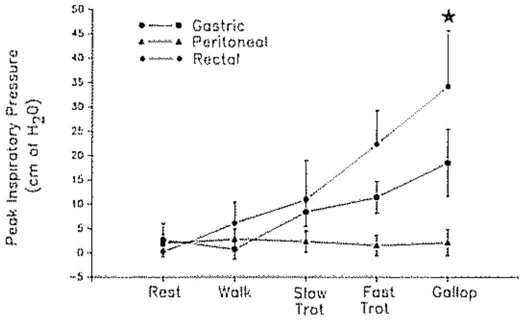
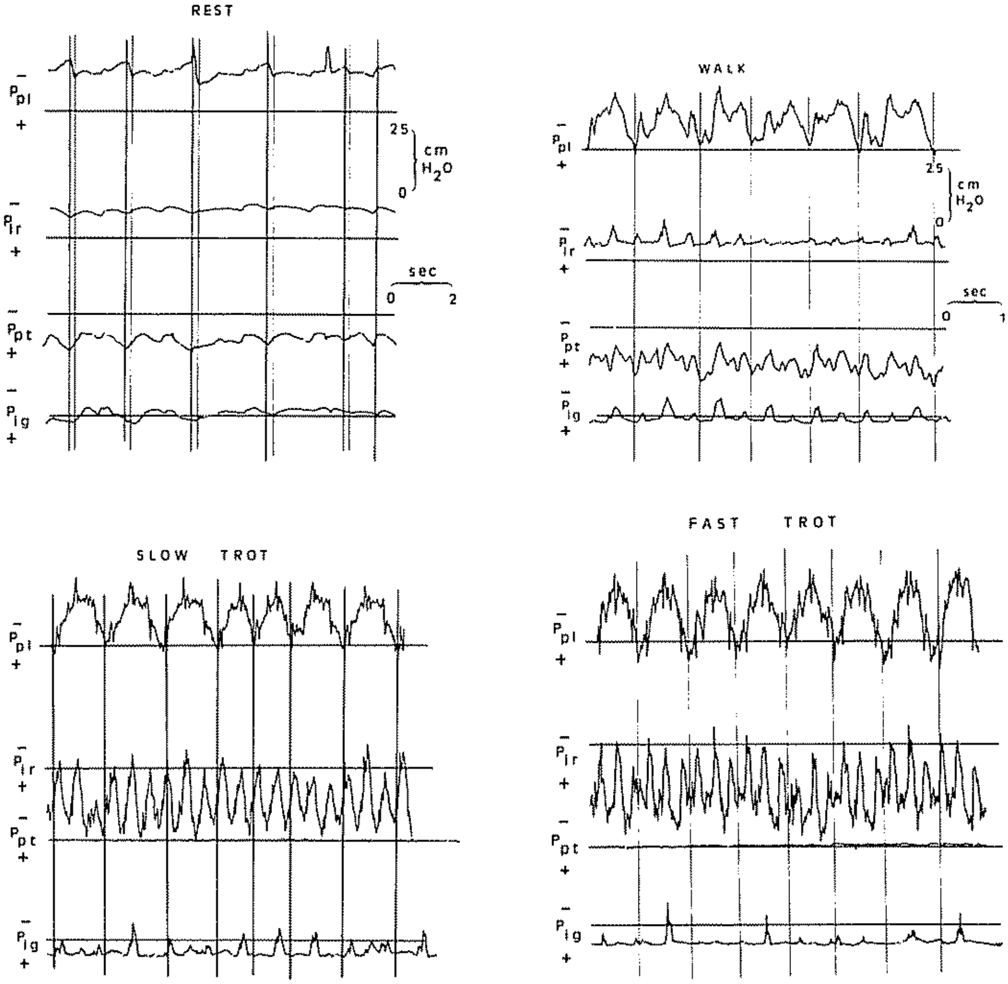


Fig 5 Comparison of peak pressures during inspiration for the 3 estimates of intra-abdominal pressure. The baseline is zero with respect to atmospheric pressure. All 3 measures were significantly different at the gallop, and only rectal and gastric pressures increased with greater intensity exercise. * denotes significant differences between groups at the gallop.



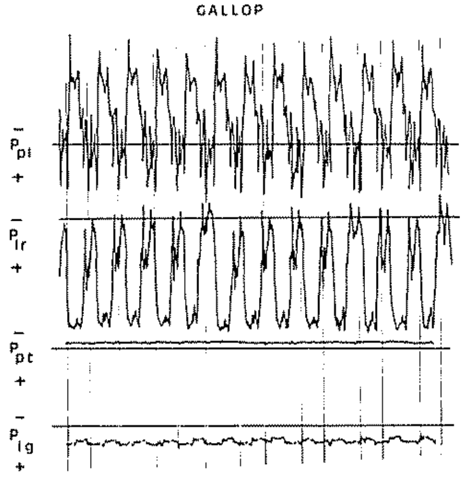


Fig 6 Pressure recordings from intrapleural (P_{pl}) intragastric (P_{ig}), intrarectal (P_{ir}) and intraperitoneal (P_{pt}) balloon catheters from horse 4 at rest (6 A), walk (6 B), slow trot (6 C), fast trot (6 D) and gallop (6 E). Thick lines on 6 A are at peak inspiratory pressure, thin lines at peak expiratory pressure Scales for time and pressure for 6 C, D and E are as for 6 B and vertical lines denote peak exhalation Pressures positive with respect to atmospheric pressure lie below the baseline, whereas negative pressures are plotted above the baseline. Baselines for each catheter are at zero atmospheric pressure.

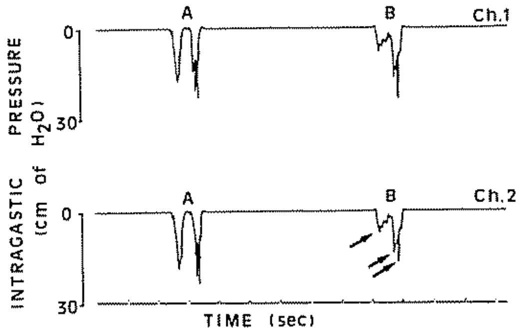


Fig. 7. Pressure recordings from 2 catheters placed in the stomach (channel 1 and channel 2). At A, both catheters lay close to the mucosa, and compression led to identical pressure spikes in both channels. At B, the balloon in the catheter in channel 2 was buried in ingesta. Note the attenuation of pressure signal in channel 2 compared to channel 1 (arrows).

loon being surrounded by a fluid medium for local changes in pressure to be transmitted accurately to the balloon. The attenuated signal that was always present from the peritoneal catheter is presumably because the viscera surround the catheter and buffer pressure changes in the abdomen. Similarly, if the gastric balloon were to become embedded in the ingesta found in the stomach, the pressure signal would be attenuated. In order to evaluate whether gastric ingesta could attenuate measurement of rising intragastric pressure, an experiment was conducted in which the stomach was removed intact from a recently killed horse (destroyed because of a limb fracture), the oesophageal and duodenal openings ligated, and 2 identical catheters placed in the stomach. One catheter was manipulated to lie against the mucosa, the other so that the balloon tip was buried within ingesta. Pressures measured by both catheters were compared during cycles of external compression and decompression of the stomach. Fig. 7 illustrates that there was significant attenuation of the pressure signal in the balloon catheter buried in the ingesta compared with the other catheter. We concluded that gastric contents could affect the reliability of intragastric pressure measurements in unfasted horses.

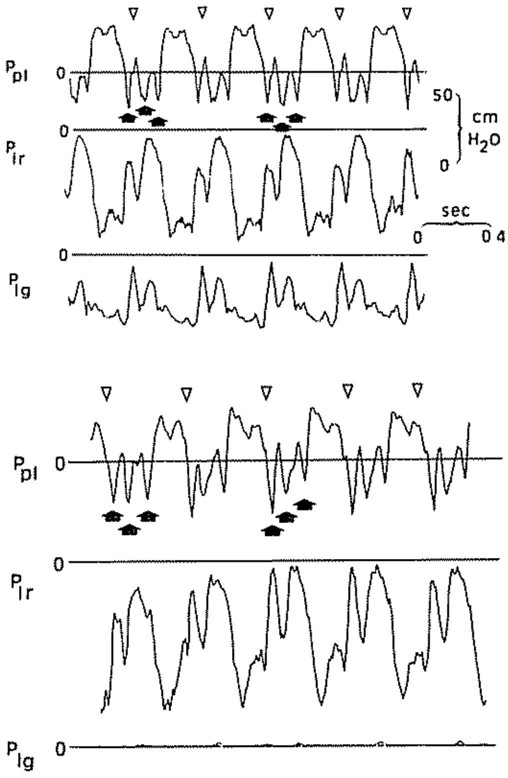


Fig. 8. Pressure recordings from intrapleural (P_{pl}), intragastric (P_{ig}) and intrarectal (P_{ir}) balloon catheters from horse 6 during two separate runs (8 A and 8 B) at the gallop. Open triangles denote planting of the lead foot, as recorded with an event marker on the physiograph. Solid arrows denote positive intrapleural pressure spikes that occurred during exhalation.

A second factor that also was likely to profoundly influence local pressure estimations was the motion of viscera around the catheter during exercise. This could have accounted for the pressure deflections of similar sign during inspiration for P_{pl} and P_{ig} (Figs. 6 A and 6 B). Although phase matched at rest, pressure peaks in the different balloon catheters demonstrated obvious phase lags during exercise that became larger with increasing speed. This phenomenon may be caused by the effects of inertia on different parts of the abdomen when the visceral mass is accelerated and decelerated rapidly during exercise. Measurement of abdominal inertance was not done in this study, but would be necessary to evaluate this hypothesis.

Despite the occasional inconsistencies in intragastric pressure recordings, it was obvious that transdiaphragmatic pressure increased progressively during inhalation with increasing exercise intensity. This suggests that in horses undergoing vigorous exercise, the diaphragm contributes significantly to inspiratory effort. Conversely, during exhalation, transdiaphragmatic pressure did not change significantly with increased exercise intensity, indicating that the role of the diaphragm remains relatively passive during this phase of respiration.

Intrarectal pressures were the most consistent of the 3 measures of intra-abdominal pressure. However, use of different catheters and either withholding feed or drenching the horse to liquefy stomach contents, might make intragastric balloon measurements more reliable. Other workers[5,13] with-held feed from their animals for 12 hours prior to study, thus their P_{ig} measurements may have been more reproducible than ours. However, it would be preferable not to with-hold feed in horses in work that are presented for performance testing.

The use of peak inspiratory pressures may be useful in performance testing, because it is a simple procedure unlikely to be influenced by the measurement system, as are more elaborate systems of pulmonary mechanics measurement.[8] Respiratory mechanics are useful in determining sites of abnormality within the respiratory system,[12,18] whereas peak inspiratory pressures assess the respiratory muscles' capacity for work.[16,17,21] Whether such measurements will prove useful as predictors of athletic ability or in refining training techniques that affect respiratory muscle function remains to be determined. It is possible that intragastric pressures are influenced by the degree of gastric filling with ingesta, by treadmill slope and by gait during exercise testing. These factors will need to be carefully standardised, even in maximal exercise tests, in order to provide useful data.

The influence of gait on respiratory function has been studied[2–5,23] and an abdominal piston effect has been identified in trotting ponies.[5] Our data support an abdominal piston effect during exhalation of galloping horses as indicated by the 3 positive pressure spikes seen in P_{pl} during exhalation (Fig. 8). Fig. 8 illustrates the relationship between pressures on an expanded scale for 2 series of gallops. Rectal and intrapleural pressures are very similar between the 2 exercise trials, but P_{ig} is markedly attenuated in Fig. 8 B. During exhalation, intrapleural pressure traces showed a consistent triple positive spiked pattern. At the time the first spike occurs, rectal pressure is decreasing. This could represent diaphragmatic relaxation at the initiation of exhalation, allowing passive cranial motion of abdominal contents and a decrease in abdominal pressure. The second spike in intrapleural pressure during exhalation is preceded by planting of the lead foot and a rise in intragastric and intrarectal pressures. It could be caused by abdominal compression and projection of abdominal contents cranially. The third pressure spike occurs despite decreasing abdominal pressures and might reflect continued forward motion of the abdominal contents cranially and decompression of the abdomen against a relaxed diaphragm. Inhalation was not associated with the development of pressure spikes in P_{pl} at the gallop and negative pressures in the thorax were associated with increased abdominal pressure, presumably because of diaphragmatic contraction and expansion of thoracic contents caudally. Based on the studies by Attenburrow,[7] the 3 pressure spikes noted upon exhalation cannot be accounted for solely because of foot placement, because only one foot is planted during exhalation at the gallop; 3 strike during inhalation and lift during exhalation.[7] However, Attenburrow suggested that exhalation is facilitated by weight bearing in the forelimbs; later in exhalation, flexion of the back and abdominal contraction were thought to contribute to expiratory effort.[7]

Our study is of limited value because we were not able to measure diaphragmatic contraction (via electromyography), abdominal inertance or exactly record the relationship of individual foot placement to respiratory events for each gait. These data would be necessary to support our suggestions regarding the abdominal piston.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the Australian Equine Research Foundation.

REFERENCES

1. Amis, T. C., Pascoe, J. R. and Hornof, W. (1984). Topographic distribution of pulmonary ventilation and perfusion in the horse. Am. J. Vet. Res. 45, 1597–1601
2. Anderson, L. S., Butler, P. J., Roberts, C. A., Snow, D. H. and Woakes, A. J. (1989). Changes in the pattern of breathing for the Thoroughbred horse at different work levels. Proc. 8th Vet. Resp. Symp., Comparative Respiratory Society, Liège, Belgium, p. 17.
3. Art, T., Anderson, L., Woakes, A. J., Roberts, C., Butler, P. J., Snow, D. H. and Lekeux, P. (1990). Mechanics of breathing during strenuous exercise in Thoroughbred horses. Resp. Physiol. 82, 279–294.
4. Art, T. and Lekeux, P. (1988). Respiratory airflow patterns in ponies at rest and during exercise. Can. J. Vet. Res. 52, 299–303.
5. Art, T. and Lekeux, P. (1988). Locomotion-respiration coupling in trotting ponies. Proc. 7th Vet. Resp. Symp., Comparative Respiratory Society, Chicago, USA.
6. Art, T., Serteyn, D. and Lekeux, P. (1988). Effect of exercise on the partitioning of equine respiratory resistance. Equine Vet. J. 20, 268–273.
7. Attenburrow, D. P. (1982). Time relationship between the respiratory cycle and limb cycle in the horse. Equine Vet. J. 14, 67–72
8. Bayly, W. M., Schulz, D. A., Hodgson, D. R. and Gollnick, P. D. (1987). Ventilatory responses of the horse to exercise: effect of gas collection systems. J. Appl. Physiol. 63, 1210–1217
9. Bramble, D. M. and Carrier, R. C. (1983). Running and breathing in mammals. Science 219, 251–256
10. Chihara, K., Macklem, P. T. and Ward, M. (1989). A comparison of rib cage distortability between dogs and humans. Proc. 8th Vet. Resp. Symp., Comparative Respiratory Society, Liège, Belgium, pp. 9–11
11. Derksen, F. J. and Robinson, N. E. (1980). Esophageal and intrapleural pressure in the healthy conscious pony. Am. J. Vet. Res. 41, 1756–1761
12. Derksen, F. J., Stick, J. A., Scott, E. A., Robinson, N. E. and Slocombe, R. F. (1986). Effect of laryngeal hemiplegia and laryngoplasty on airway flow mechanics in exercising horses. Am. J. Vet. Res. 47, 16–20
13. Desmecht, D., Art, T., Amory, H. and Lekeux, P. (1988). Assessment of respiratory muscle performance in non-co-operative subjects: a preliminary study. Proc. 7th Vet. Resp. Symp., Comparative Respiratory Society, Chicago, USA
14. Gross, D., Ladd, H. W., Riley, E. J., Macklem, P. T. and Grassma, A. (1980). The effect of training and endurance on the diaphragm in quadriplegia. Am. J. Med. 68, 27–35
15. Kolbeck, R. C. and Spier, W. A. (1989). Diltiazem, Verapamil and Nifedipine inhibit Theophylline-enhanced diaphragmatic contractility. Am. Rev. Resp. Dis. 139, 139–145
16. Koulouris, N., Mulvey, D. A., LaRoche, C. M., Sawicka, E. H., Green, M. and Moxham, J. (1989). The measurement of inspiratory muscle strength by sniff esophageal, nasopharyngeal and mouth pressures. Am. Rev. Respir. Dis. 139, 641–646.
17. Leith, D. E. and Bradely, M. (1976). Ventilatory muscle strength and endurance training. J. Appl. Physiol. 41, 508–516
18. Shappell, K. K., Derksen, F. J., Stick, J. A. and Robinson, N. E. (1988). Effects of ventriculectomy, prosthetic laryngoplasty and exercise on upper airway function in horses with induced left laryngeal hemiplegia. Am. J. Vet. Res. 49, 1760–1765
19. Slocombe, R. F., Robinson, N. E., Derksen, F. J. and Carrig, C. B. (1988). Thoracic radiographic appearance during lung inflation in neonatal calves. Vet. Res. Comm. 12, 259–272
20. Supinski, G., Dimarco, A., Ketai, L., Hussein, S. and Altose, M. (1988). Reversibility of diaphragm fatigue by mechanical hyperperfusion. Am. Rev. Resp. Dis. 138, 604–609.
21. Weiner, P., Suo, J., Fernandez, E. and Cherniack, R. M. (1989). Efficiency of the respiratory muscles in healthy individuals. Am. Rev. Resp. Dis. 140, 392–396
22. Wilson, B. A., McKay, S. P. and McDonell, W. (1989). Effects of Heliox breathing during forced ventilation at rest and during exhaustive exercise. Proc. 8th Vet. Resp. Symp., Comparative Respiratory Society, Liège, Belgium, p. 8
23. Woakes, A. J., Anderson, L. S., Butler, P. J. and Snow, D. H. (1989). The effect of gait on ventilation in the exercising Thoroughbred racehorse. Proc. 8th Vet. Resp. Symp., Comparative Respiratory Society, Liège, Belgium, p. 16.

Equine Exercise Physiology 3: 92–96, 1991

Draught Load and Speed Compared by Submaximal Tests on a Treadmill

M. GOTTLIEB-VEDI, B. ESSÉN-GUSTAVSSON and S. G. B. PERSSON

Swedish University of Agricultural Sciences, Faculty of Veterinary Medicine, Department of Medicine and Surgery, Box 7018, S-750 07 Uppsala, Sweden

ABSTRACT. Six Standardbred trotters exercised on a horizontal treadmill with consecutively increasing draught load (D-test) or speed (S-test). D-test was performed at a walk of 2 m s^{-1}. Oxygen uptake ($\dot{V}O_2$), heart rate (HR) and minute ventilation ($\dot{V}E$) increased linearly in both tests and reached a mean of 73 ± 9 ml kg^{-1} min^{-1}, 172 ± 12 bpm and 917 ± 93 l min^{-1} at the heaviest draught load (107.1 kp). The values for HR and $\dot{V}O_2$ were close to those measured at a speed of 8 m s^{-1} in the S-test. The relationships between $\dot{V}O_2$ and HR, $\dot{V}E$ and blood lactate concentration did not differ between the two tests. Stride frequency increased in both tests, whereas stride length increased in S-test and decreased in D-test. In conclusion, similar cardiopulmonary and lactate responses were obtained in the two tests. D-test may therefore be an alternative to S-test for horses which have difficulty trotting fast enough for exercise tolerance testing.

Key words Horses; draught load; training; oxygen uptake; heart rate.

INTRODUCTION

Pulmonary ventilation and oxygen uptake have previously been measured in several studies in horses performing exercise at different speeds on a treadmill.[2,3,8,11,13] Little is known however, about respiratory gas exchange during draught work. This is worthy of study, as draught-loaded exercise is used as a method of training Standardbred horses for racing.

When Standardbred trotters are trained conventionally, the work intensity is increased by increasing speed. During draught-loaded exercise the work intensity may be enhanced by increasing draught resistance, by which high work intensities can be reached at low velocities. This may affect the cardiorespiratory system, blood lactate response and locomotion pattern differently. The purpose of this study was to compare incremental draught load versus speed in exercise tolerance testing using oxygen uptake, heart rate and blood lactate responses as parameters.

MATERIALS AND METHODS

Six clinically healthy, lightly trained Standardbred trotters were used. They were 1 mare, 4 geldings and 1 stallion ranging in age between 4 and 13 years (mean = 7 ± 4).

Incremental draught work was performed on a horizontal treadmill (Sikob) at a walk of 2 m s^{-1}. Weights were suspended from a rope which was horizontally connected to the harness and passed over a pulley mounted on a support behind the treadmill. The draught resistance, beginning at 4.1 kilopond (kp), was increased by 20.6 kp every 2 min up to a final level of 107.1 kp. One kilopond = 1 kg m s^{-2} = 9.81 N.[6] The horses wore a mask for determination of oxygen uptake ($\dot{V}O_2$) during the test. The draught resistance was measured before the test by a force transducer (strain-gauge, Type KRG-4) fastened between the harness and the rope and coupled to a transducer indicator (Type BKI-1). From this the output signal was scaled, low-pass filtered and recorded by a stripchart recorder (modified Moseley Model 680 M).