Pulmonary vascular pressures of exercising Thoroughbred horses with and without endoscopic evidence of EIPH

MURLI MANOHAR AND THOMAS E. GOETZ
Departments of Veterinary Biosciences and Veterinary Clinical Medicine,
College of Veterinary Medicine, University of Illinois, Urbana, Illinois 61801

Manohar, Murli, and Thomas E. Goetz. Pulmonary vascular pressures of exercising Thoroughbred horses with and without endoscopic evidence of EIPH. J. Appl. Physiol. 81(4): 1589–1593, 1996.—Exercise-induced pulmonary hemorrhage (EIPH) is a common occurrence in racehorses. The objective of this study was to compare pulmonary vascular pressures of healthy Thoroughbred horses with and without postexercise endoscopically detectable fresh blood in the trachea. The nasopharynx, larynx, and trachea (down to the carina) of horses were examined weekly with an endoscope 55–60 min postexercise, and the diagnosis of EIPH was confirmed by the presence of fresh blood in the trachea. Measurements of heart rate and right atrial, pulmonary arterial, and pulmonary arterial wedge pressures were made during quiet rest and during treadmill exercise performed at 14.5 m/s on a 5% uphill grade. This workload elicited maximal heart rate of the horses. Mean pulmonary capillary pressure was estimated to be halfway between the mean pulmonary arterial pressure and the mean pulmonary arterial wedge pressure. These data from 7 healthy sound exercise-trained horses that were positive on 12 consecutive occasions (at 1-wk intervals) for the postexercise presence of fresh blood in the trachea were compared with those in 8 healthy horses that were consistently negative for the evidence of fresh blood in the trachea on postexercise endoscopic examination over 12–16 wk. The heart rate and the right heart and/or pulmonary vascular pressures in the two groups of horses were similar at rest. Exercise was attended by a large significant (P < 0.05) increase in these pressures and heart rate in both groups. However, statistically significant differences between endoscopically EIPH-positive and endoscopically EIPH-negative horses for heart rate and right atrial and pulmonary vascular pressures were not found during exercise. Thus these data revealed that the magnitude of exercise-induced right atrial as well as pulmonary arterial, capillary, and venous hypertension in endoscopically EIPH-positive horses that are otherwise healthy is quite similar to that in endoscopically EIPH-negative horses during comparable exertion.

exercise-induced pulmonary hemorrhage; pulmonary circulation; pulmonary hemodynamics

EXERCISE-INDUCED PULMONARY HEMORRHAGE (EIPH) is frequently observed in racehorses. On the basis of postexercise endoscopic detection of fresh blood in the trachea, it has been reported that the incidence of EIPH in racehorses of Thoroughbreds (9) and Standardbreds (2) horses probably exceeds 75%. It is commonly held in “racing circles” that EIPH contributes to exercise intolerance, i.e., loss of stamina and/or performance, even though definite proof is lacking (2, 9). Although it has been demonstrated that hemosiderin-laden macrophages could be recovered in the tracheobronchial washings from all Thoroughbreds in training (11), the fact remains that unless overt epistaxis occurs, the diagnosis of EIPH in racehorses is made on endoscopic examination of the airway performed ~60 min postexercise (9). Furthermore, the decision in competitive racing as to whether a racehorse is prescribed prerace furosemide administration for prevention and/or management of EIPH is also based on the endoscopic observation of fresh blood in the trachea after a race (Dr. R. Jensen, Illinois Racing Board, personal communication).

Recent work has demonstrated that exercising horses develop marked pulmonary arterial, capillary, and venous hypertension (3–6), and it is believed that the high transmural (intravascular minus perivascular alveolar) pulmonary capillary pressure exerted on the blood-gas barrier, which has to be quite thin (0.3–0.6 µm) to provide for diffusion of respiratory gases, probably contributes to stress failure of pulmonary capillaries (10), resulting in EIPH. Despite this recognition, to our knowledge there have been no reports comparing pulmonary vascular pressures of horses that exhibit EIPH with those that do not. Thus the primary objective in this study was to compare the rest and exercise values of pulmonary vascular pressures of Thoroughbred horses in which fresh blood is detected on postexercise endoscopic examination of the trachea with those in which fresh blood is not detected on the postexercise endoscopic examination of the airway. In our experiments, horses performed high-intensity short-term exercise at maximal heart rate.

MATERIALS AND METHODS

Horses. Experiments were carried out on 15 Thoroughbred horses (7 fillies and 8 geldings) aged 2.5–5 yr and weighing between 375 and 523 kg. The horses were divided into two groups (see EIPH-positive and EIPH-negative groups), designated as endoscopically EIPH-positive (n = 7) and endoscopically EIPH-negative (n = 8) horses. The horses were housed in an air-conditioned building and were accustomed to being handled by people. They were fed a diet of alfalfa hay and oats, and free access to water was provided. The horses were healthy, sound, and received routine treatments meeting veterinary medical standards for the equine species. Our protocols and procedures were approved by the Institutional Laboratory Animal Care and Use Committees.

Exercise training. Initially, the horses exercised on the high-speed treadmill set at 0% grade (on the flat). Starting with a walk at 2 m/s for 60 s, belt speed was raised in increments of 1 m/s every 60 s until the horses had trotted at 6 m/s for 60 s. Belt speed was then raised to 8 m/s for 60 s, to 10 m/s for 60 s, and finally to 14.2–14.5 m/s for 120 s. Thereafter, belt speed was reduced to 5 m/s for 60 s and then to 2 m/s for 5–7 min before the treadmill was stopped. Exercise was performed in this manner 3 days/wk for a period of 4–5 wk. For the next 3 wk, this incremental exercise
Experimental procedure. Our hemodynamic procedures have been described in detail previously (3-6); therefore, only a brief description is given here. On the day of the study, cardiac catheters (7F) equipped with tip manometers and fluid-filled lumens (Millar Instruments, Houston, TX) were advanced via the left jugular vein so as to simultaneously record phasic right atrial, right ventricular, pulmonary arterial, and pulmonary arterial wedge pressures. The in vivo catheter-manometer signals were matched with corresponding fluid-filled pressure signals obtained by using conventional transducers (Statham/Gould, Oxnard, CA) zeroed at the level of the point of the shoulder. The data were displayed on an oscillographic recorder (E for M, Lanexa, KS), and mean pressures were obtained by electronic integration of the phasic pressure signals.

Experimental protocol. The same experimental protocol was used for the two groups of horses. Hemodynamic measurements were first made in standing horses when heart rate and right heart and pulmonary vascular pressures had been stable for ~10-15 min. Thereafter, exercise was performed on a high-speed treadmill set at 5% uphill grade. Exercise began with a walk at 2 m/s for 60 s. Belt speed was increased in increments of 1 m/s every 60 s until the speed was 6 m/s. After the horses trotted for 60 s at 6 m/s, belt speed was raised to 8 m/s for 60 s and then to 14.5 m/s. Horses performed exercise at 14.5 m/s at 5% uphill grade for 90 s. Thereafter, belt speed was decreased to 5 m/s for 60 s and then to 2 m/s for 5 min before the treadmill was stopped.

Fig. 1. Heart rate of exercise-induced pulmonary hemorrhage (EIPH)-positive horses was similar to that of EIPH-negative horses both at rest and during exertion. *Significantly different from 8 m/s as well as 14.5 m/s for same group of horses, P < 0.05. **Significantly different from 14.5 m/s for same group of horses, P < 0.05.

RESULTS

Significant differences in heart rate, mean right atrial pressure, or pulmonary vascular pressures were not found between the two groups of horses either at rest or during exercise (Figs. 1-6). In both groups, exercise resulted in significant tachycardia and in right atrial as well as pulmonary arterial, capillary, and venous hypertension. During exercise at 14.5 m/s on a 5% uphill incline, mean right atrial, mean pulmonary arterial, mean pulmonary arterial wedge, and mean pulmonary capillary blood pressures of endoscopically EIPH-positive horses approached 61 ± 4, 96.5 ± 4.0, respectively, compared with 45.4 ± 3.7 and 14.9 ± 2.5, respectively, during exercise at 14.5 m/s on a 5% uphill grade.
Exercise also caused a significant increment in the pulmonary arterial pulse pressure (Fig. 3), and the pulmonary perfusion pressure gradient increased significantly from 561 mmHg at rest to 2761 mmHg.

Postexercise endoscopic examination of the airway revealed fresh blood in the trachea of each of the seven horses belonging to the EIPH-positive group. However, blood was not detected in the airways on the postexercise endoscopic examination in any of the horses belonging to the EIPH-negative group.

**DISCUSSION**

Our data have demonstrated that right atrial, pulmonary arterial, pulmonary capillary, and pulmonary venous pressures of Thoroughbred horses that exhibit fresh blood in the trachea during postexercise endoscopic examination are not different from those that do not exhibit fresh blood in the trachea postexercise; this was true at rest as well as during strenuous exertion. These data also confirmed earlier observations (3–6) that galloping horses develop significant pulmonary arterial, capillary, and venous hypertension.

It has been suggested that the incidence of EIPH may increase with age, but conclusive evidence is lacking.
the same hemodynamic procedures were employed to studied horses that were consistently negative (Because our experiments sought to clarify this issue, we pressures of EIPH-positive and EIPH-negative horses. of these reports (1, 10) compared the pulmonary vascular and 70 mmHg, respectively. It is worth noting that neither pulmonary arterial and mean left atrial pressures of 115 than in the present and previous (3–6) studies [had mean EIPH status) exercised at 10 m/s [a much lower workload from EIPH-negative horses exercised at similar or higher workloads (14.5 m/s on a 5% uphill grade), were less than the values reported from a filly exercised at 13.5 m/s]. Nonetheless, our data may not relate to the latter situation.

While stress failure of pulmonary capillaries (10) may occur at high transmural (intravascular minus perivascular/alveolar) pulmonary capillary pressures, the question arises as to why some horses consistently exhibit fresh blood in the trachea postexercise, whereas others may not, despite similarity of intravascular pulmonary capillary pressures during strenuous exertion (Fig. 6). Several possibilities may be considered. First, it needs to be emphasized that in the context of stress failure of pulmonary capillaries, the key variable (6, 10) is the transmural (intravascular minus perivascular) pulmonary capillary pressure. Given the similarity of pulmonary capillary blood pressure values during exertion in the endoscopically EIPH-positive and EIPH-negative horses (Fig. 6), it may be suggested that there may be differences in the perivascular alveolar pressure of EIPH-positive and EIPH-negative horses during exertion. To our knowledge, measurements of alveolar pressure in galloping EIPH-positive and EIPH-negative Thoroughbreds have not been made to date. Second, it is possible that there may be differences between EIPH-positive and EIPH-negative horses in terms of the strength of the blood-gas barrier. The strength of the blood-gas barrier is primarily in its connective and elastic tissue components (10). Studies examining this aspect of the blood-gas barrier in EIPH-negative vs. EIPH-positive horses have also not been reported, to our knowledge. Third, the endoscopic diagnosis of EIPH in this study was based on the postexercise macroscopic detection of fresh blood in the trachea. Although it has been demonstrated that all Thoroughbreds in training had hemosiderin-laden macrophages in the tracheobronchial washings several days postexercise (11), the fact remains that, at present, postexercise endoscopic examination of the airway is accepted as the most practical method of detecting EIPH in competitive horse racing (2, 9) and that only those racehorses that exhibit fresh blood in the trachea become eligible for prerace furosemide administration for prevention/management of EIPH. Chronologically, because racehorses are exercised frequently, tracheobronchial washings cannot determine with certainty which particular episode of high-intensity exercise caused EIPH. Finally, it remains to be definitively determined whether EIPH originates from the pulmonary circulation; the bronchial circulation may be the culprit instead (7, 9).

It is difficult to explain why our values of various pulmonary vascular pressures from both groups of horses (Figs. 2–6), which exercised at a much higher workload (14.5 m/s on a 5% uphill grade), were less than the values reported from a filly exercised at 13.5 m/s in the study by West et al. (10) and in the three...
horses exercised at 10 m/s in a preliminary report (1). One likely possibility is that the differences in these studies may be related to the different reference sites for pressure signals. In the present and previous (3–6) studies, pressure signals were referenced at the level of the point of the shoulder. Whereas Jones et al. (1) did not note the referencing of their pressure signals, West et al. (10) referenced the mean pulmonary arterial pressure at the level of the right atrium (it was, however, not described how the latter was established). In large animals, the hydrostatic pressure effect (due to gravitational force acting on a column of fluid) can be substantial and may account for these disparities.

In conclusion, our data have demonstrated that right heart and/or pulmonary vascular pressures of horses that exhibit fresh blood in the trachea on postexercise endoscopic examination are similar to those of endoscopically EIPH-negative horses both at rest and during high-intensity short-term exercise.

The authors gratefully acknowledge the excellent technical assistance of Beth Saupe, Donald Lantz, Eileen Sullivan, Richard Griffin, and Jay E. Kobel in carrying out these experiments.

This work was supported in part by a grant-in-aid from the Illinois Department of Agriculture Equine Research Funds. The high-speed treadmill at the University of Illinois College of Veterinary Medicine was procured with financial support from the Illinois Thoroughbred and Standardbred Breeders Fund.

Address for reprint requests: M. Manohar, Dept. of Veterinary Biosciences, College of Veterinary Medicine, Univ. of Illinois, 212 LargeAnimal Clinic, 1102 W. Hazelwood Dr., Urbana, IL 61801.

Received 21 February 1996; accepted in final form 23 May 1996.

REFERENCES