Intrathoracic Pressure in the Horse. Correlation between Intrapleural and Esophageal Pressures

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Introduction

One of the most important parameters in lung function tests in horses is the maximal change of intrathoracic pressure (*Sasse* 1971). Intrapleural pressure (P_{pl}), i. e. intrathoracic pressure measured directly in the pleural cavity, is considered to be the most reliable method for measuring intrathoracic pressure (*McPherson* and *Lawson,* 1974). This method, however, ist not very suitable for use outside a veterinary clinic. For this reason several authors have recorded esophageal pressure (P_{es}), but did not make statistical comparisons of pleural and esophageal pressures in horses (*Gillespie* and *Tyler* 1969, *Sasse* 1971, *McPherson* and *Lawson* 1974). The correlation between P_{es} and P_{pl} is not known. This correlation has been reported for calves (*Lekeux* 1984), whereas *Derksen* and *Robinson* (1980) compared intrapleural and esophageal pressure changes, measured at different sites in the thorax and the thoracic part of the esophagus, in ponies.
In many species the influence of body position and site of measurement were investigated both for intrapleural and esophageal pressure (*Banchero* et *al.* 1967). Recording P_{es} is necessary when lung function tests are done outside the clinic. It is questionable whether this method is reliable. That is, it is necessary to know if a correlation exists between P_{es} and P_{pl} in horses and the value of this correlation. What should be the measuring procedure and what instruments have the least possible influence on the values found are questions that need to be answered.

Materials and Methods

I Horses

In 15 unselected horses admitted to the Department of Large Animal Medicine for lung function testing, maxΔP_{pl} and maxΔP_{es} were recorded simultaneously.
MaxΔP_{pl} was used as a reference. Lung function tests were performed the first day after arrival at the clinic. The horses had not fasted and were unsedated. During the measurements the animals were restrained in stocks.

II Measurement of intrapleural pressure (P_{pl})

Measurement of intrapleural pressure was done as described by *von Neegard* and *Wirz* (1927), *Spörri* and *Denac* (1967) and *Sasse* (1971). On an imaginary line running from the tuber coxae to the shoulder a small spot in the 10th intercostal space was shaved and desinfected. After local anesthesia with 2 % xylocaine, a small skin incision was made and the pleural space was punctured with a sterilized Acufirm tissue cannula No. 1498, length 100 mm, diameter 3 mm, with two side holes near the tip. Unlike the description in earlier publications (*Sasse,* 1971) the procedure was done on the right side of the thorax. With a Braun Perfusor continuous infusion type 871, a sterile 0.9 % NaCL solution was pumped through the pressure transducer (Hewlett Packard type 1290A) and the cannula with a flow of 0.01 ml/min.
A Hewlett Packard 8805 E was used as a pressure amplifier and a Gould ES 1000 Electrostatic Recorder for recording.

III Measurement of esophageal pressure (P_{es})

Esophageal pressure was measured using an esophageal balloon made from a fingerstall. This balloon was sealed over the end of a polyethylene catheter connected to a pressure transducer. In this closed system, volume changes of the balloon caused pressure changes. The relation between volume changes and pressure changes depended on the volume-pressure coefficient of the system.

Conditions for a sensitive, accurate system

1) The balloon must follow volume changes with minimal resistance
ΔV balloon $\div$ ΔP balloon = C balloon = ∞
2) For catheter and pressure transducer the condition is however:
ΔV cath $\div$ ΔP cath = C cath = 0
When both conditions are fulfilled the volume-pressure coefficient of the whole system depends only on the volume of the system and the compressibility of air (*v. d. Woestijne,* 1964).

Experiment (1): Compliance of the balloon (C_{ball}).
A fingerstall, length 5.5 cm, diameter 1 cm was used as a balloon. The volume-pressure diagram of this balloon, determined according to *v. d. Woestijne* (1964) is shown in figure 1.

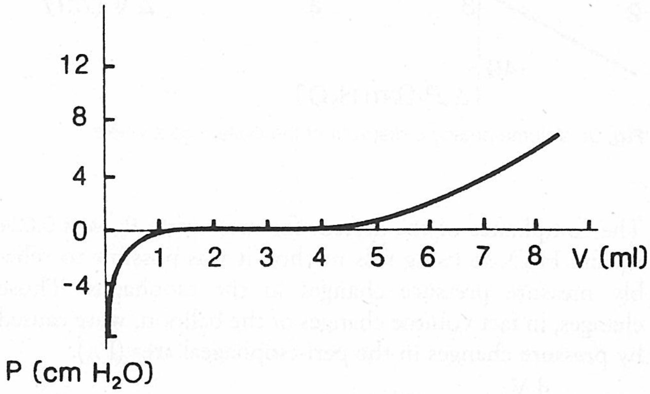

Fig. 1: Volume-pressure diagram of a fingerstall, length 5.5 cm, diameter 1 cm.

If the volume is between 1–4.5 ml the fingerstall fulfills the conditions of having infinite compliance.

Experiment (2): Compliance of the catheter and pressure transducer ($C_{cath.}$)
When the catheter and pressure transducer are rigid, the compliance depends on the compressibility of air only, 0.001 ml/cm H_2O (*v. d. Woestijne*, 1964).
For P_{es} measurement a polyethylene catheter was used, length 3 m, inside diameter 2.8 mm, volume 19 ml. The volume of the transducer was 1.4 ml.
Between the transducer and catheter a three way stopcock was connected with a syringe, making it possible to adjust the volume of the balloon before measuring P_{es}.
The volume-pressure diagram of catheter, stopcock, and pressure transducer determined as described by *van de Woestijne* (1964) is shown in figure 2.

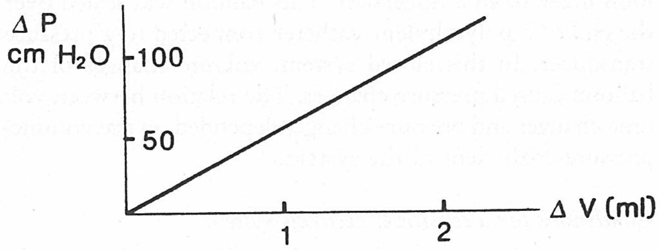

Fig. 2: Volume-pressure diagram of catheter, stopcock and pressure transducer.

Putting the balloon, sealed over the end of the catheter, in a completely waterfilled, hermetically closed bottle, the compliance of the system as a whole was measured. By changing the pressure in the bottle with help of a syringe, the volume of the balloon was changed.
The volume-pressure diagram of the system described is shown in figure 3. The starting volume of the balloon was 3 ml.

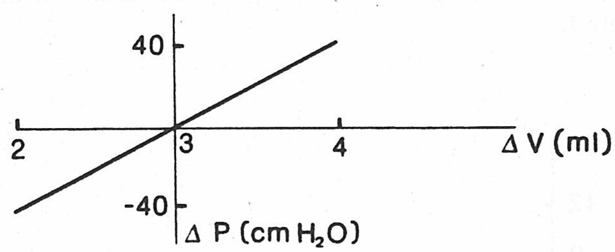

Fig. 3: Volume-pressure diagram of the system as a whole.

The compliance of the system for measuring P_{es} was 0.024 ml/cm H_2O, so using this method it was possible to reliably measure pressure changes in the esophagus. Those changes, in fact volume changes of the balloon, were caused by pressure changes in the peri-esophageal area (P_{th}).

$$\Delta V = \frac{d\,V_{syst}}{d\,P_{syst}} \times \Delta P_{th} \quad (1)$$

Esophageal pressure (P_{es}) and intrathoracic pressure (P_{th}) are not the same. The difference is caused by the elastance of the esophageal wall and peri-esophageal tissues $\left(\frac{d\,P_{es}}{d\,V_{es}}\right)$, so

$$\Delta P_{th} - \Delta P_{es} = \Delta V_{es} \times E_{es} \quad (2)$$

$$\Delta P_{th} - \Delta P_{es} = \frac{d\,V_{syst}}{d\,P_{syst}} \times E_{es} \times \Delta P_{th} \quad (3)$$

$$\frac{\Delta P_{th} - \Delta P_{es}}{\Delta P_{th}} = C_{syst} \times E_{es} \quad (4)$$

C_{syst} is constant, so the difference is constant if the elastance of the esophagus does not vary. This has been demonstrated for the dog (*Milic-Emili* and *Petit*, 1959), for man (*v. d. Woestijne*, 1964) and for human infants (*Senterre* and *Geubelle*, 1970).
Using the method described by *Senterre* and *Geubelle* (1970) elastance was measured in two horses. The elastance in the midthoracic part of the esophagus was 2.8 cm H_2O/ml.

$$E_{es} = \frac{d\,P_{es}}{d\,V_{es}} = 2.8 \text{ cm } H_2O/\text{ml} \quad (5)$$

For measurement of the esophageal pressure the same electronic equipment was used as was described for the intrapleural measurement. Esophageal pressure was determined in the midthoracic part of the esophagus (*Derksen*, 1980). This position was estimated as described by *Derksen* (1980). The horse was restrained with help of a twitch.
The catheter with the sealed balloon was pushed into the esophagus through a nasogastric tube and placed into the midthoracic part. After removing the nasogastric tube, the catheter was connected via the stopcock with the pressure transducer. With a syringe the volume of the balloon was adjusted to contain 2 ml of air.

IV Simultaneous measurement of P_{pl} and P_{es}

P_{pl} and P_{es} were recorded simultaneously, together with tidal volume and flow, so it was possible to read both pressures at the same time. Maximal pressure change of both P_{pl} and P_{es} and their correlation were calculated for a number of respirations in 15 horses.

Results

MaxΔP_{pl} and the corresponding maxΔP_{es} are shown in figure 4.
The corresponding maxΔP_{pl} and maxΔP_{es} of each respiration, 130 in total, were statistically analysed. The relation appeared to be linear, the corresponding regression formula being maxΔP_{pl} = 1.2 maxΔP_{es} + 2.3 (± 0.7) cm H_2O.
The correlation coefficient was 0.97.
r maxΔP_{pl} to maxΔP_{es} = 0.97 (6)

Discussion

The results of this study indicate that intraesophageal pressure change is in general smaller than pleural pressure

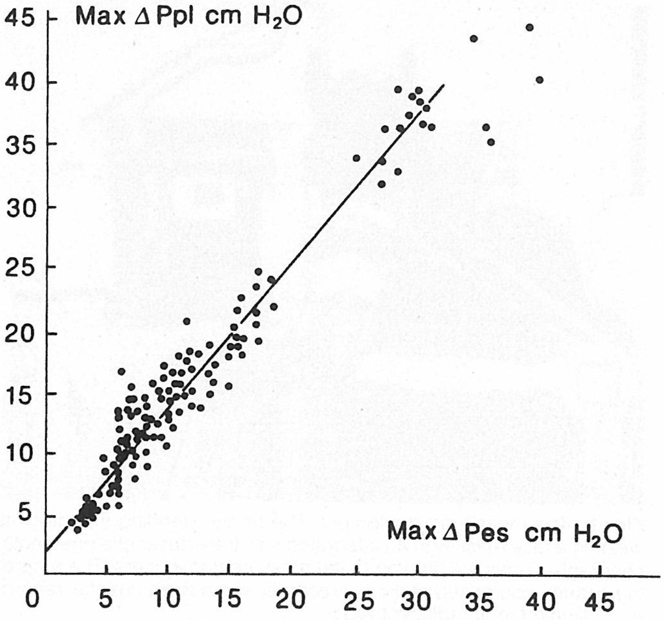

Fig. 4: The relation between the maxΔP_{pl} and the maxΔP_{es}, recorded simultaneously in 15 horses n = 130, r = 0.97 ($p<0.001$).

change. Several authors have reported a regional change in pleural pressure (*Derksen*, 1980; *Banchero*, 1967; *Gillespie*, 1969). Therefore it is important to standardize the place of measurement, however when measuring esophageal pressure this is not always easy.

Pressure changes during breathing are mainly caused by lung elastance and pulmonary resistance. Intraesophageal pressure is also influenced by the elastance of the esophageal wall and the peri-esophageal tissue.

Pressure change may vary during measurement of Ppl. This may be caused by irregular breathing, coughing, slight excursions of the needle in the pleural cavity and partial obstruction of the needle by blood or tissue.

Esophageal pressure may be influenced by cardiogenic activity, swallowing, coughing and the position of the balloon. Distinct influences of swallowing, coughing and the presence of air in the esophagus were discarded from calculations.

In horses, measurement of esophageal pressure is a reliable substitute for the pleural pressure when a number of conditions are fulfilled. However, there is a distinct risk of making errors.

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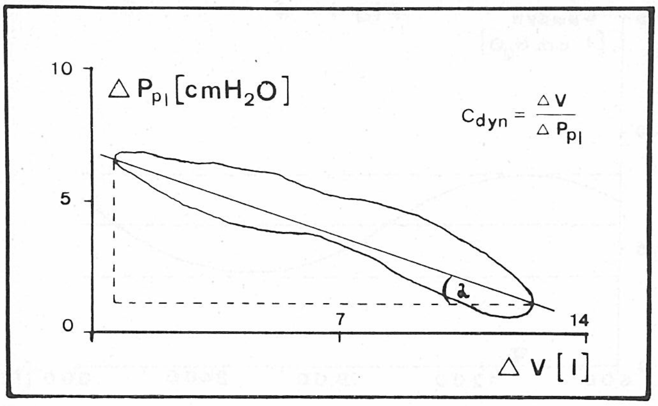


Fig. 4: Determination of dynamic compliance (C_{dyn}) of the airways, which is defined as volume change per unit pressure change. The loop diagonal and the abscissa form the angle α. Cot α gives the ratio $\frac{\Delta V}{\Delta Ppl}$

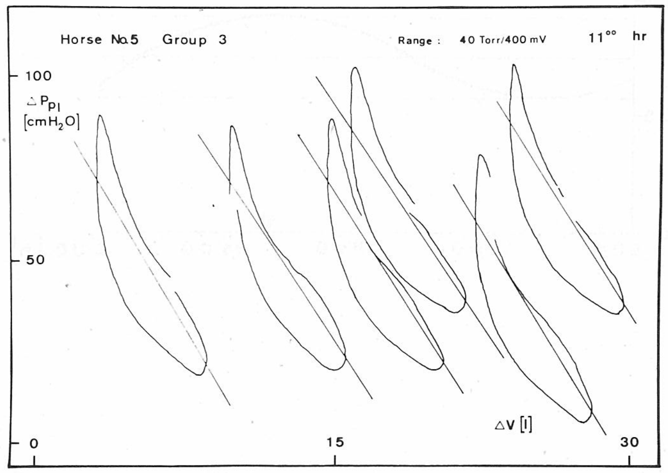
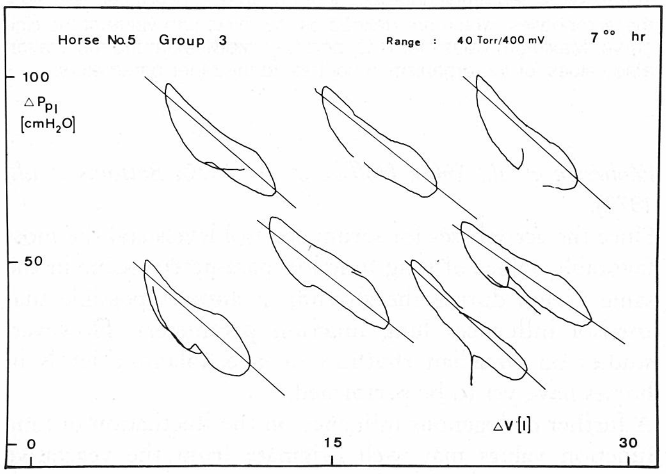


Fig. 5 and 6: Pressure-volume loops from the same horse monitored at different times. Pressure-volume loops assessed in one measuring period show homogeniety but are obviously different at an interval of 4 hours.



Test Procedure

Measurements were taken on three successive days at 6-hour intervals. A period of 24 hours was assumed for the rhythm and the course of the parameters monitored for a total of 72 hours. Measurements were taken at 2 a. m., 8 a. m., 2 p. m. and 8 p. m. Besides attention being paid to lung function parameters, blood was also taken from the carotid artery for determination of partial pressure of oxygen and carbon dioxide.

Biometric evaluation was carried out according to a variance analytical model in which a periodic regression of 24 hours was taken into consideration. *Stadler* et *al.* (1985) gave a detailed description of this method.

Results

C_{dyn}, W_{rs}, R_{tp}, ΔP_{es} and PaO_2 showed sine-shaped fluctuations which depended on the time of day and had reproducible minimum and maximum values. A statistically significant sine-shaped course with a 24-hour rhythm was determined for these parameters (see Figures 8 and 9). Figure 8 also shows that the daily fluctuations had a particularly wide amplitude in ΔP_{es} and C_{dyn} values. The difference between day and night values was sometimes clearly above 50 % of the mean.

Lung function values beneficial for the horses were attained during the first half of the day, i. e. between 6 a. m. and 1 p. m. while the least beneficial values appeared between 6 p. m. and 1 a. m. (see Figure 9).

Also noteworthy, in a comparison of C_{dyn} and PaO_2 acrophases, the highest oxygen values occurred 1–2 hours later than the optimum compliance values.

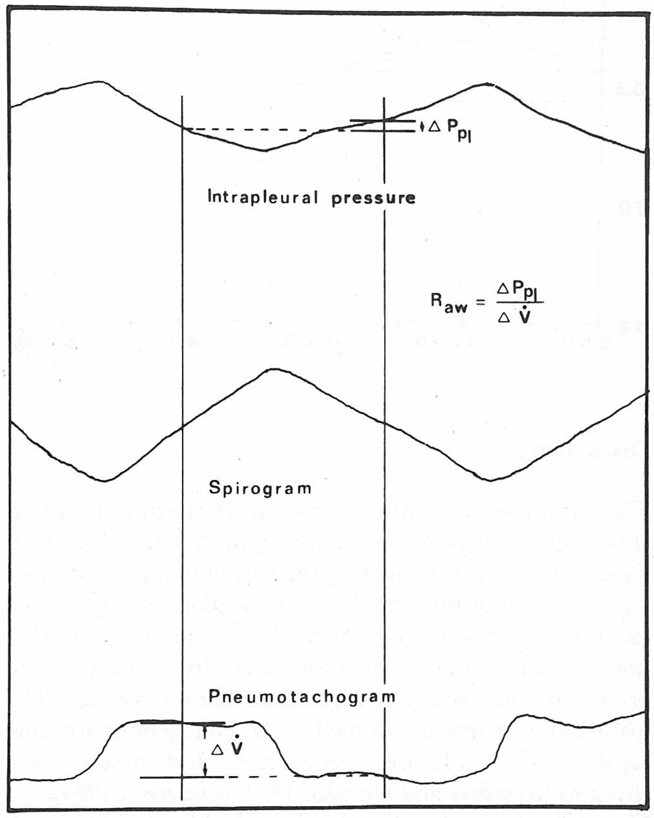
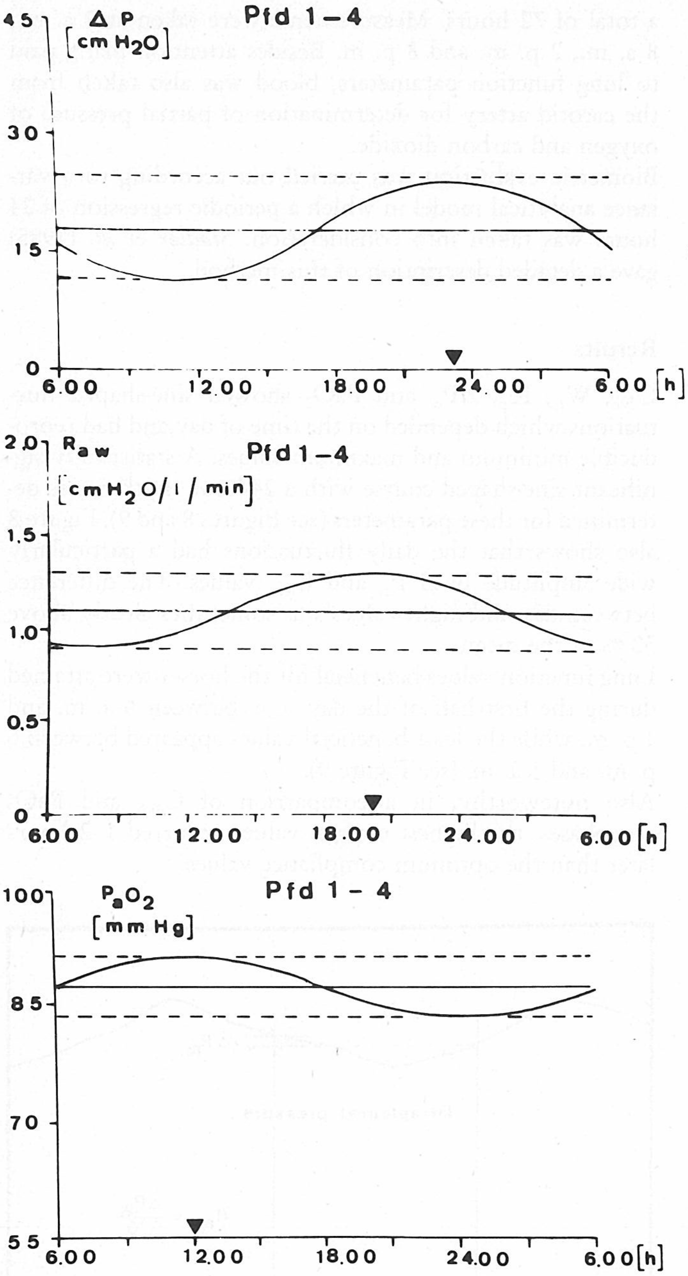


Fig. 7: Calculation of total pulmonary resistance (R_{tp}) according to the method of *Frank* et *al.* (1957). R_{tp} is defined as the ratio of pressure change to unit flow change. Total pulmonary resistance (R_{tp}) was calculated at times of maximum flow rates, respectively in the middle of inspiration and expiration phases.



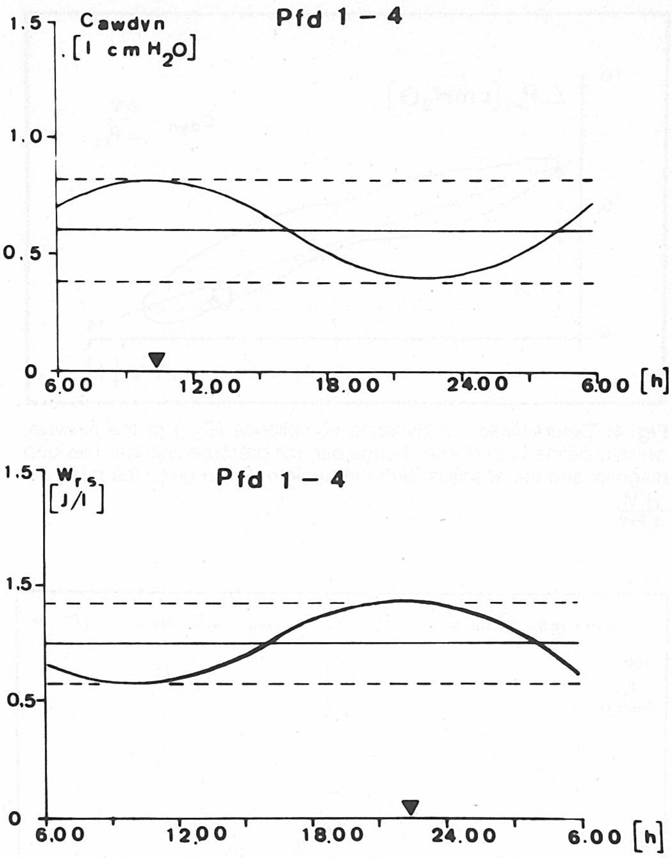


Fig. 8 a and b: Mean sine curves (horse 1–4) of lung function parameters. The distance between the continuous line and the dashed line is defined as the amplitude (Ao) of the rhythm. Closed triangles mark the acrophases, which are defined as the maximum value of the sine curve. Maximum values for P_aO_2 and C_{dyn} likewise are the most favorable values for the organism in contrast to the other parameters.

Discussion

The acrophases determined within daily rhythms occurred at the same time of day as values established for human patients with asthma. Here, too, the best lung function values were detected during the day and the worst at night. The fact that the present study made this finding indicates that horses with chronic bronchitis suffer from more severe bronchial constriction at night than during the day. The main cause of this is assumed to be endogenous irritants capable of amplifying genetically determined basic rhythms (*Reinberg* and *Gervais*, 1972; *Schweiger*, 1984).
Catecholamine and cortisol levels in the blood and urine also seem to be subject to circadian rhythms. For horses, a circadian, sine-shaped rhythm for serum cortisol was ascertained with maximum values between 6 a. m. and 10 a. m. (*Zolovick* et *al.*, 1966; *Hoffsis*, et *al.*, 1970; *Bottoms* et *al.*, 1972).
Since the acrophases for serum cortisol levels and the most favorable values of lung function parameters occur in the same period during the rhythm, it appears possible that cortisol influences lung function parameters. However, studies on circadian rhythms of catecholamine levels in horses have yet to be performed.
A further endogenous influence on the fluctuation of lung function values may well originate from the vegetative nervous system itself. The tonus of the sympathetic nervous system predominates during the day while vagal tone predominates at night (*Woolcock* et *al.*, 1969). Bronchial expansion is to be expected from sympathoadrenergic stimulation while parasympathetic stimulation (release of acetylcholine) causes constriction of the bronchial lumina. Such

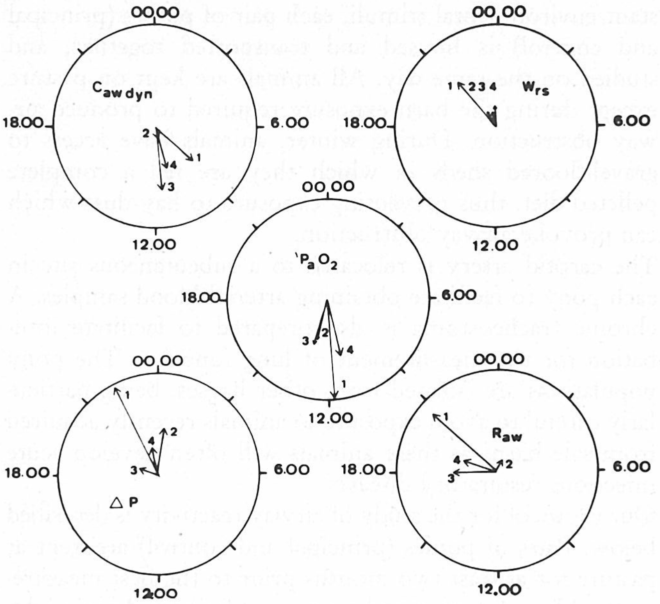


Fig. 9: Acrophases and amplitudes of lung function parameters. The arrows point toward the time of acrophases and length of the arrows represents the relative amplitudes of the parameter rhythms.

effects also have to be assumed for the horse. In healthy humans circadian rhythms in lung function parameters are very minor and hence scarcely detectable while, in patients with obstructive lung diseases, these rhythms are very prominent (*Nolte*, 1982). This phenomenon may be detectable in horses as well. These more pronounced daily rhythms in patients with bronchial diseases are probably the result of increased bronchial reactivity of their airways. This was confirmed by demonstrating nonspecific airway hyperreactivity in the four horses tested.

It can be assumed that in hyperreactive situations, endogenous and exogenous irritants causing cholinergic stimulation, have much stronger effects on the lung than normally is the case and therefore amplitude of daily rhythms is greatly increased in comparison to healthy horses. Thus circadian rhythms provide an explanation for dramatic increases in dyspnea observed at night in individual horses with bronchitis.

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