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Clinical Method for Evaluation of Upper Airway Function

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ABSTRACT. A technique was described for diagnosis of upper airway obstruction and evaluation of the effects of corrective surgery. During standardized exercise the intratracheal pressure was recorded in 20 normal horses and in 10 horses with suspected laryngeal hemiplegia. The recordings were performed with a tape recorder receiving signals from a transducer connected to an intratracheal catheter, introduced percutaneously. The pressure graphs of the horses with laryngeal hemiplegia differed significantly from those of the normal horses with respect to respiratory rate (decreased), negative inspiratory pressure (increased) and duration of inspiration (increased). A "comparison factor" was calculated from these data for the inspiratory resistance of the upper airways. This factor was significantly increased in horses with laryngeal hemiplegia. Post-operative pressure graphs of horses subjected to laryngoplasty showed an obvious "normalization" in cases with clinical improvement.

Key words. Airway obstruction; horses; intratracheal pressure; laryngeal hemiplegia; laryngoplasty; standardized exercise.

INTRODUCTION

Upper airway obstruction in the horse and its clinical significance has been extensively discussed for many years. However, the evaluation of the various conditions involved is still controversial and contradictory.[1,2,5,6,14] Speirs pointed out the difficulties in evaluating these conditions and the lack of available data defining the pressure and flow characteristics of the upper respiratory tract during exercise. There is a need for a simple and objective method for recording relevant respiratory parameters during exercise which is applicable to clinical use.[16,18–20] Derksen et al. have described a technique for measuring the resistance in the upper airways in the exercising horse.[8,13] The intratracheal pressure and the inspiratory airflow were recorded simultaneously. The intratracheal pressure was recorded via an intratracheal catheter inserted percutaneously and the air flow with a pneumotachograph on a face-mask. The inspiratory resistance was defined as the ratio of the peak negative inspiratory pressure and the peak inspiratory airflow. These investigations gave interesting results in horses with experimentally induced laryngeal hemiplegia and the technique was also used to evaluate the effect of ventriculectomy and laryngoplasty.[8,17] The technique seems too complicated to be used as a clinical tool in practice.

Evaluation of the respiratory resistance by measuring the intrathoracic pressure via an esophageal balloon is described by several authors.[4,7] This method has the advantage of being noninvasive and easy to use. However, calculation of the resistance in the upper airways cannot be made from these pressure recordings since they reflect the total resistance of the airways. Funkquist et al.[9] suggested a method for recording the respiratory pressure variations in the trachea in the exercising horse. They also proposed a method to calculate the upper airway resistance based on these pressure recordings. This

Table 1. *Distribution on age, sex and breed of the horses examined*

	Normal horses	Suspected lar. hemi-plegia	Re-exam-ined after surgery
Total number	20	10	5
Age in years ($\bar{x} \pm SD$)	5.1 ± 2.0	7.8 ± 4.1	9.2 ± 3.6
Sex			
Stallion	2	1	–
Gelding	7	9	5
Mare	11	–	–
Breed			
Standardbred	18	1	1
Warmblood	2	7	4
Thoroughbred	–	2	–

method gave promising results when used on a small group of normal horses and on horses with induced laryngeal hemiplegia. The method has now been applied on a greater number of normal horses and on a group of horses with idiopathic laryngeal hemiplegia, some of which were re-examined after corrective surgery. The purpose of the present study is to assess the feasibility of using the method for diagnosing upper airway obstructions and evaluating corrective surgery.

MATERIAL AND METHODS

Horses

The recordings of the intratracheal pressure during exercise were performed on 20 normal horses used for research investigations and on 10 horses with suspected laryngeal hemiplegia. Five of the latter group were re-examined after corrective surgery. The criteria for being "normal" were the absence of abnormal respiratory noise during exercise, lack of abnormalities on endoscopic examination of the larynx and pharynx and absence of any previous history of respiratory disease. The 10 horses with suspected laryngeal hemiplegia all had a history of reduced exercise performance and abnormal respiratory noise. On endoscopic examination 9 of them showed obvious asymmetry of the arytenoid cartilages with the left dropping towards the midline. The other horse did not show any obvious asymmetry of the larynx. The horses were examined by different clinicians in two clinics. Five of the horses, all of which had shown obvious laryngeal asymmetry and abnormal pressure graphs at the first examination, were re-examined 3.5 to 7 months after corrective surgery, when prosthetic laryngoplasty was performed with a concurrent ventriculectomy.[14,15] Age, sex and breed of all horses examined are shown in Table 1.

Standardized exercise test

The horses were subjected to a standardized exercise test on a treadmill with an inclination of 6.25°. The intratracheal pressure and heart rate (HR) were recorded at rest before exercise, at speeds of 2, 3, 4, 5, 6, 7 (in some cases 8) m s^{-1} and finally at rest 2 min after finishing the exercise test. The horses were exercised 2 min at each speed and recordings made during the last 30 seconds of each period. At a speed of 2 m s^{-1} all horses walked and at speeds of 3, 4 and 5 m s^{-1} all horses trotted. At speeds of 6, 7 and 8 m s^{-1} some horses trotted and some cantered.

Recording techniques

For recording the intratracheal pressure a teflon catheter was percutaneously inserted into the trachea using a guide technique.[9] The catheter was fixed to the horse with tape and towel clamps and connected to a pressure transducer, fixed on the ventral aspect of the horse's neck with Velcroband. In the early examinations, the signals from the pressure transducer were recorded on tape and displayed as graphs on a recorder. The evaluation of the various parameters described were based on these graphs. In the later examinations the signals stored on tape were digitalized with an A/D-converter and the calculations were performed with a computerized method.

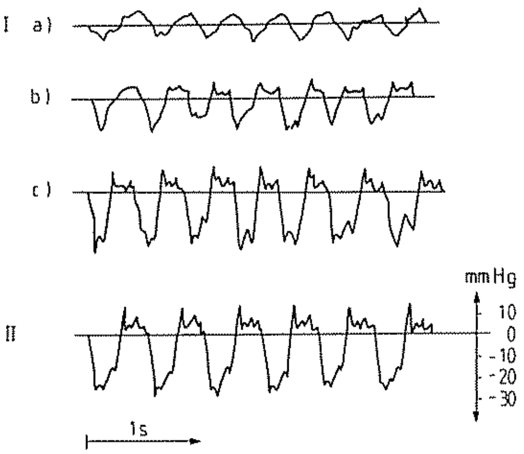


Fig 1 Intratracheal pressure in normal, exercising horses. I. Warmblood, mare, 8 years: (*a*) walk 2 m s^{-1}; (*b*) trot 5 m s^{-1}; (*c*) canter 7 m s^{-1}. II. Standardbred, mare, 3 years, trot 7 m s^{-1}.

Evaluation of the pressure graphs

The last 10 breaths of each recording period were analyzed with respect to the following parameters: respiratory rate (RR), peak inspiratory and expiratory pressure (IP, EP) and inspiratory and expiratory duration (ID, ED). To achieve a parameter reflecting changes in both pressure and duration, the area delineated by the zero line and the pressure graph was calculated (i.e. standard speed of the recording device 25 mm s^{-1} and the deviations corrected to a calibration of 1 mm = 1 mmHg). The area defined above was calculated for inspiration (IA) as well as for expiration (EA). An approximate "comparison factor" for the inspiratory resistance of the upper airways (CF) was calculated according to the equation:[9]

$$\mathrm{CF} = \frac{1}{T}\left(\int_0^T \sqrt{\Delta p}\, dt\right)^2$$

where T is the duration of the inspiration, Δp the intratracheal inspiratory pressure with reversed sign and $\int_0^T$ the integrated area delimited by the inspiratory pressure graph and the zero line.

Statistical analysis

For the group of normal horses and the group of horses with laryngeal hemiplegia, mean values and standard deviations were calculated for all parameters studied at each speed. Student's *t*-test was used to evaluate the significance of a difference between normal horses and horses with laryngeal hemiplegia.

RESULTS

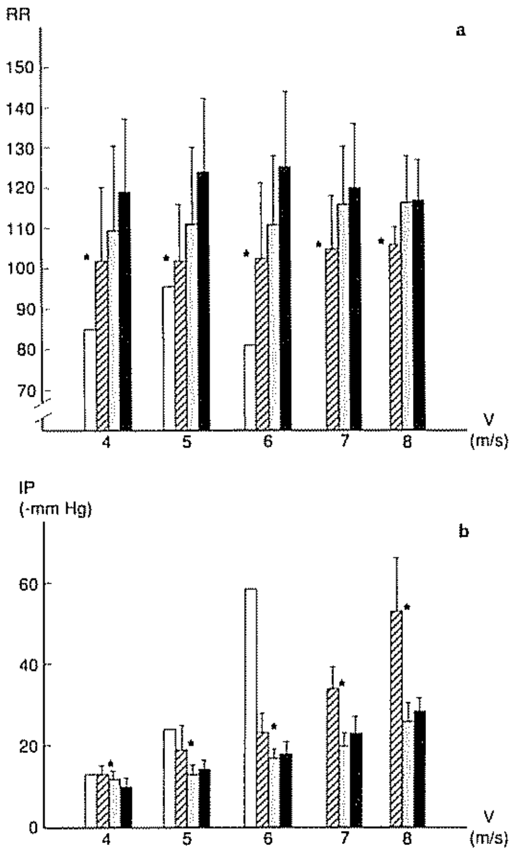
Normal horses

Typical examples of pressure graphs from normal horses at different speeds and gaits are shown in Fig. 1. The pressure graphs at rest, during walking at 2 m s^{-1} and trotting at 3 m s^{-1} showed such large variations from one breath to another that a detailed numerical analysis was not meaningful. At 4 and 5 m s^{-1} all 20 horses trotted; at 6 m s^{-1} one horse and at 7 m s^{-1} 2 horses cantered while the remaining horses trotted. From the 9 horses that managed 8 m s^{-1}, 2 cantered and 7 trotted at this speed. The difference between the intratracheal pressure graphs for trot and canter at the same speed was essentially a "smoother" inspiratory graph at canter without obvious effect on the numerical values of the parameters studied (Fig. 1).

The effect of exercise on RR and on the calculated inspiratory parameters; IP, ID, IA and CF, is shown in Fig. 2*a–e* (mean ± SD). With increasing treadmill speed from 4 to 8 m s^{-1}, the following parameters all progressively increased: HR ($\bar{x} = 191 \pm 10$ at 7 m s^{-1}), IP, EP, ID, IA, EA and CF. The increase in EP and EA was not as pronounced as the increase in the corresponding inspiratory parameters. The RR increased up to 6 m s^{-1} but then decreased at speeds of 7 and 8 m s^{-1}. The ED was approximately unchanged at speeds of 4 to 8 m s^{-1}.

Horses with suspected laryngeal hemiplegia

One of the horses in this group did not manage to complete the exercise test (i.e. it was interrupted at 6 m s^{-1} because of respiratory



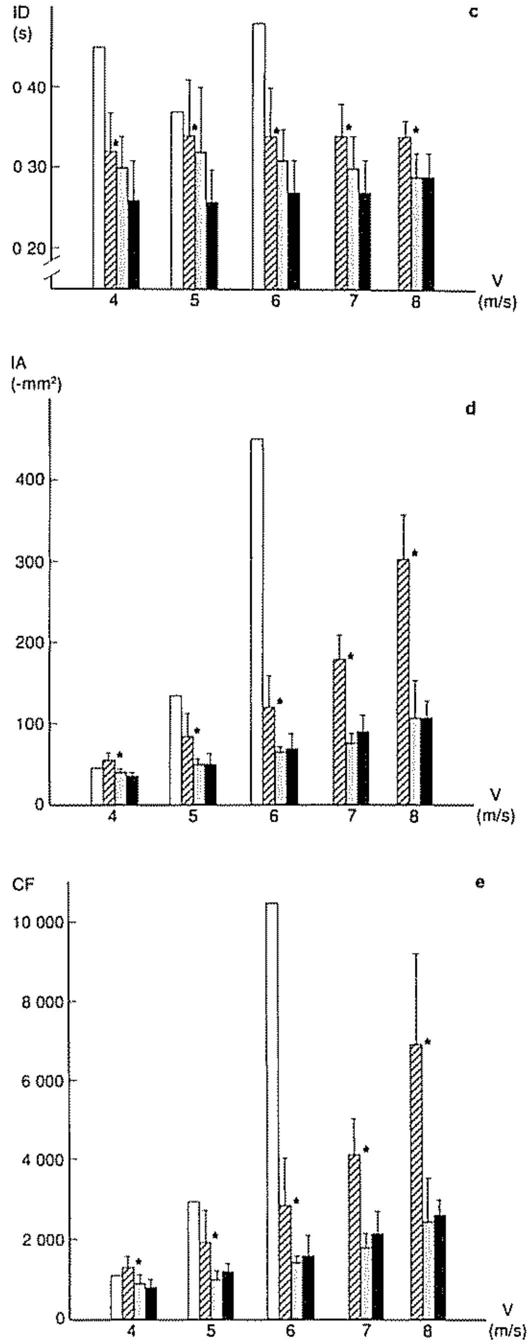


Fig 2 Respiratory rate and inspiratory parameters studied during exercise at 4 to 8 m s^{-1}. Mean ± SD for the group of normal horses, the group of horses with laryngeal hemiplegia and the group of horses re-examined after corrective surgery. □, horse that did not fulfill the exercise test; ▨, horses with laryngeal hemiplegia, $n=8$ at 4–7 mm s^{-1}, $n=5$ at 8 m s^{-1}; ▩, horses re-examined after corrective surgery, $n=4$ at 4–7 m s^{-1}, $n=3$ at 8 mm s^{-1}; ■, normal horses, $n=20$ at 4–7 m s^{-1}, $n=9$ at 8 m s^{-1}. Significant difference between the group of normal horses and the group of horses with laryngeal hemiplegia is shown (*$p \leqslant 0.05$): (*a*) respiratory rate (RR); (*b*) peak inspiratory pressure (IP); (*c*) inspiratory duration (ID); (*d*) "inspiratory area" (IA); (*e*) "comparison factor" for the inspiratory resistance (CF).

distress). Another horse did not show obvious laryngeal asymmetry on endoscopic examination. These 2 horses will be accounted for separately. The remaining 8 horses all trotted at 4 and 5 m s^{-1}. At 6 m s^{-1}, 2 horses and at 7 m s^{-1} 3 horses cantered while the rest of the horses trotted. Of the 5 horses that managed 8 m s^{-1}, 2 cantered and 3 trotted.

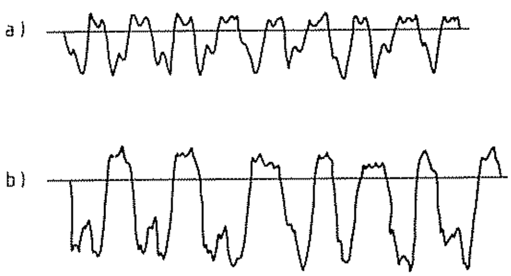


Fig. 3. Intratracheal pressure in 2 horses trotting at 7 m s^{-1}: (*a*) normal (Standardbred, mare, 3 years); (*b*) horse with laryngeal hemiplegia (Warmblood gelding, 6 years).

The inspiratory pressure graph displayed an obvious difference in shape from that of the normal horses (Fig. 3). The inspiratory phase was prolonged and the negative inspiratory pressure was increased. At high trotting speeds there was an inspiratory plateau on the pressure graph. In canter the inspiratory plateau of the pressure graph was not so obvious, but the numerical values of the parameters calculated did not differ significantly from those calculated at trot at the same speed. Increasing treadmill speed increased HR ($\bar{x} = 174 \pm 11$ at 7 m s^{-1}), RR, IP, EP, IA, EA and CF. The inspiratory duration was unchanged from 4 to 8 m s^{-1} and the expiratory duration decreased from 4 to 8 m s^{-1}. The effect of exercise on RR and on the inspiratory parameters ($x \pm$ SD), calculated from the pressure graphs, is shown in Fig. 2*a–e*. Compared with the normal horses, the horses with laryngeal hemiplegia show a significantly decreased RR and a significant increase in all inspiratory parameters. The expiratory parameters examined differed in a corresponding, but not so obvious, way. The inspiratory parameters of the horse that did not manage to complete the exercise test are shown in Fig. 2. As can be seen, this horse showed obvious differences from both groups of horses already at 5 m s^{-1}.

The horse, with no obvious laryngeal asymmetry on endoscopic examination, had a significantly increased negative inspiratory pressure at 7 and 8 m s^{-1} compared to the normal horses. No differences were observed in any of the other parameters studied.

Horses re-examined after surgery

Four of the 5 horses that were re-examined 3.5 to 4.5 months after prosthetic laryngoplasty showed improvement with respect to performance, respiratory sounds and at endoscopic examination (i.e. left arytenoid cartilage in a more abducted position than before surgery).

The pressure graphs of the 4 improved horses all changed in a normal direction (Fig. 4). After surgery, none of them showed any significant difference from the normal horses concerning the calculated values for IP, IA and CF. Two horses still had a significantly prolonged ID and one of these also a significantly lowered RR compared with the normal group. The effect of exercise on RR

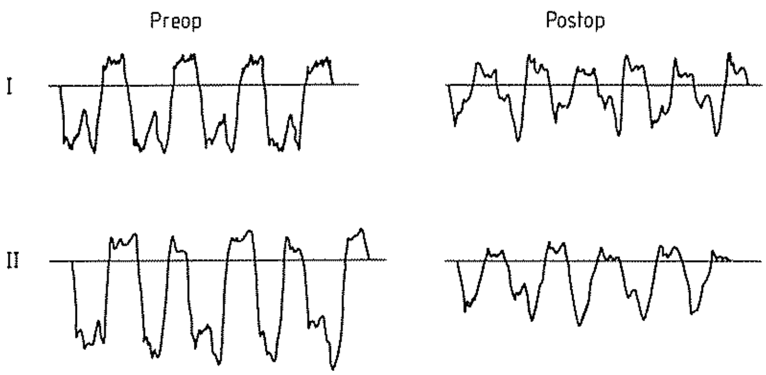


Fig 4. Intratracheal pressure in 2 horses with laryngeal hemiplegia before and after laryngoplasty. I. Warmblood, gelding, 14 years trot 8 m s^{-1}. II. Warmblood, gelding, 6 years trot 7 m s^{-1}

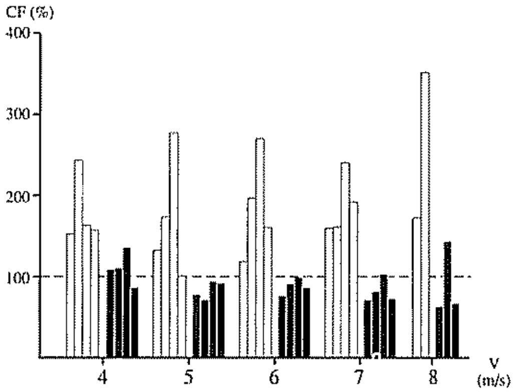


Fig 5 Comparison factor for the inspiratory resistance in the upper airways (CF) in 4 horses with laryngeal hemiplegia, during exercise before and after corrective surgery. The CF is expressed as a percentage of the mean of 20 normal horses at corresponding speeds. □, CF before; ■, CF after laryngoplasty. At 8 m s^{-1} the horses are, in order from left to right, 1 and 3 before surgery and 1, 3 and 4 after surgery.

and the inspiratory parameters after surgery is shown in Fig. 2*a–e*.

In the fifth horse that was re-examined after surgery, the prosthesis had to be removed because of infection. In this horse the reduced performance, the respiratory noise and the asymmetry of the left arytenoid cartilage persisted. The pressure graph had the same appearance as before surgery.

DISCUSSION

Intratracheal pressure data in horses with laryngeal hemiplegia have so far been made mainly in experimental animals. The present paper is the first account of investigation of the intratracheal pressure in horses with spontaneous laryngeal hemiplegia. These pressure studies assist in quantifying the disturbances of upper airway function and allowing objective evaluation of the effects of therapeutic measures. In the present study the IP as well as the ID increased at high exercise speeds in 9 horses with laryngeal hemiplegia. The two parameters that were calculated on the basis of both inspiratory pressure and duration (IA and CF, Fig. 2) showed a still greater deviation from the normal. The values of these two parameters for the 9 horses with laryngeal hemiplegia all deviated significantly from the values of the normal horses at high exercise speeds. One or both of the latter parameters may, consequently, be valuable tools when diagnosing increased upper airway resistance in conditions with obscure clinical signs.

One horse in the laryngeal hemiplegia group differed from the other horses in this group. Of the parameters studied, it only deviated significantly from the normal by having abnormal inspiratory noise and increased negative inspiratory pressure at 7 and 8 m s^{-1}. Laryngoscopy of this horse did not reveal any obvious asymmetry. The recordings from this horse show that also a single parameter sometimes may give valuable diagnostic information. The comparison factor (CF) may be used to compare the resistance of the upper airways in different horses[9] (or in the same horse at different occasions), only with the assumption that the horses to be compared have the same tidal volume. Expressed in practical terms this means that the comparison should be made at the same speed. Consequently, we found it interesting to express the CF at different speeds in some of our patients as a percentage of the mean of the same factor in the normal horses at the corresponding speed. We chose, for these analyses, the 4 horses that were operated upon with clinical success. In Fig. 5 the CF of these 4 horses before and after corrective surgery is given as a percentage of the mean value in normal horses. The calculations based on the pre-operative recordings showed an obvious increase in resistance, with considerable individual variations, at speeds from 4 to 7 m s^{-1}. In all 4 horses there was an obvious change of CF in the normal direction after corrective surgery.

The calculated pre-operative values for upper airway resistance accounted for in Fig. 5 should be compared with the results of Derksen et al.,[8,17] who studied the effect of neurectomy of the left recurrent nerve on flow mechanics in the horse. They calculated the upper airway resistance on the basis of direct measurements of the respiratory parameters concerned. In the neurectomized experimental horse, the inspiratory resistance of the upper airways increased from 160 to 280% of the pre-operative value when the speed increased from 2.6 to 4.3 m s^{-1}. The resistance to air flow through a passage of constant caliber, expressed as ratio of pressure difference and air flow, is independent of flow rate if the effect of turbulence is neglected. This means that a change in resistance to airflow through a certain passage may indicate a change in the dimension of the passage. Derksen et al. showed that in the normal horse the upper airway resistance decreases with increasing flow rates, which they explained as a result of the activity of the dilating muscles at the larynx and the external nares. The increase in upper airway resistance in the neurectomized horse of Derksen et al. is explained as a result of a "collapse of the unsupported left arytenoid cartilage". Our studies on the upper airway resistance in horses with spontaneous laryngeal hemiplegia are in agreement with these experimental findings. The quantitative difference in upper airway resistance between their experimental horses and our horses may be due to a different degree of paralysis of the dilator muscles in experimental and idiopathic cases of laryngeal hemiplegia.

Evaluation of the therapeutic result of upper airway surgery is often based on such indirect methods as endoscopy of the larynx or questionnaire to the owner or trainer concerning disappearing or persistence of respiratory noise, participation and success in races.[3,10–12,19] Our technique to estimate the respiratory resistance on the basis of intratracheal pressure recordings may open new ways to evaluate, more directly, the results of surgical intervention upon the upper airways. Fig. 5 may be seen as an illustration of this use of the technique.

The investigations reported here were performed using a high speed treadmill, mainly due to the lack of access to a suitable race track. However, the simplicity of the method makes it possible to use it for outdoor examinations under field conditions. The signals from the transducer can then be stored using a tape recorder placed on the saddle or in the sulky. Modified in this way the method may be used for studies of respiratory disturbances that appear mainly under racing conditions.

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