Upper Airway Pressure-Flow Relationships in Horses with Laryngeal Hemiplegia

F. J. Derksen, J. A. Stick and N. E. Robinson

Pulmonary Laboratory College of Veterinary Medicine
Michigan State University, East Lansing

Introduction

Left laryngeal hemiplegia is a common disease of horses that has been recognized since the 1800s.[1] The condition results from decreased motor activity of the intrinsic muscles of the larynx, including the cricoarytenoideus dorsalis muscle.[2] This latter muscle is the primary dilator of the rima glottidis.[2] Pathophysiologically, the disease is characterized by the loss of innervation by the recurrent laryngeal nerve.[3] The left recurrent laryngeal nerve is affected in the majority of cases and right-sided or bilateral laryngeal paresis is rare.[4] Traveling from its proximal end distally, the affected nerve shows a progressive loss of myelinated fibers.[3] Left laryngeal hemiplegia is uncommon in horses less than 15 hands high and it is an unusual diagnosis in ponies.[5] The condition is acquired and most affected horses are between 3 and 7 years of age.[6]

The degenerative neuropathy of the recurrent laryngeal nerve and neurogenic atrophy of the intrinsic muscles of the larynx are irreversible.[7] Therefore, several surgical techniques have been devised to reconstruct the rima glottidis to its maximum diameter. Surgical techniques used in cases of left laryngeal hemiplegia include ventriculectomy,[7] prosthetic laryngoplasty,[8] and subtotal left arytenoidectomy.[9] One of the techniques most commonly used in the treatment of left laryngeal hemiplegia is prosthetic laryngoplasty as described by *Marks* et *al.* in 1970.[8] In this technique a prosthetic device replaces the cricoarytenoideus dorsalis muscle, fixing the left arytenoid in a permanently abducted position.[10]

In spite of the common occurrence of left laryngeal hemiplegia and the frequency of surgical intervention in the disease, the effects of left laryngeal hemiplegia on upper airway flow mechanics during exercise or efficacy of surgical intervention have not been documented. Published surgical success rates are based on subjective criteria.[11] In this paper, we describe the effects of left laryngeal hemiplegia on upper airway flow mechanics in exercising horses and evaluate the efficacy of surgical repair by prosthetic laryngoplasty.

Materials and Methods

Five horses [11.4 ± 3.1 years of age weighing 457 ± 14 kg (X ± SEM)] were used in the experiments. Horses had been on pasture for at least 30 days prior to the experiments and had been immunized with equine influenza and rhinopneumonitis virus vaccines. On endoscopic examination, the upper airways of horses were normal prior to the experiments. Horses were trained to wear a face mask and work on a treadmill at a walk, trot, and canter. Training took approximately 2 weeks.

Measurement Techniques

For the measurement of inspiratory and expiratory flow rates at the nostrils, a tight fitting face mask was fitted over the nose and sealed with a rubber shroud. The mask was designed to allow unimpeded dilation of the nostrils. Two Fleisch #4 pneumotachographs were mounted on the mask. The combined resistance of the mask-pneumotachograph assembly was 0.04 cm H_2O/L/sec at a flow rate of 50 L/sec. Pressure changes across the pneumotachographs were measured using a differential pressure transducer and photorecording physiograph located adjacent to the treadmill. After each experiment the pneumotachograph transducer system was calibrated using a rotameter flow meter capable of measuring flow rates up to 90 L/sec. Pressure changes across the upper airway were measured using a differential pressure transducer. Upper airway pressure (Pu) was defined as the pressure difference between a side-hole catheter in the trachea and the mask pressure. To measure lateral tracheal pressure the catheter was placed in the trachea as follows: One meter of 350 polyethylene tubing (ID, 3.17 mm; OD, 3.99 mm) was introduced through a metal cannula inserted percutaneously into the ventral aspect of the rostral one third of the cervical trachea. This catheter was advanced rostrally and exited through a nostril. A plastic washer (1.5 cm diameter) was placed over the cranial end of the catheter, the catheter tip was flaired and drawn back through the nostril into the trachea until the washer was firmly seated against the tracheal wall. The catheter was secured in place using a spring assembly.[12] To avoid phase differences between measuring devices, the flow and pressure signals were matched to 10 HZ as previously described.[13] Because of the interaction of airway deformation and inertia at high respiratory rates, pressure and flow signals generated under exercise conditions were not in phase. Therefore, upper airway resistance was defined as the ratio of peak Pu and peak air flow rates for a given breath. Both inspiratory and expiratory resistance were calculated (R_I and R_E respectively). Each data point calculated was the average of the least 10 breaths. To measure the heart rate, an electrocardiogram was recorded on the physiograph using a base-apex lead system. Heart rate data points were the average of at least ten R—R intervals.

Experimental Design

Upper airway flow mechanics measurements were made with horses on a treadmill (incline 6.38°): standing (period A), walking at 1.3 M/S (period B), trotting at 2.6 M/S (period C), trotting at 4.3 M/S (period D), and standing after exercise (period E). At periods B,C, and D animals were exercised for 2 minutes and data were collected during the last minute of each period. Horses were allowed a 1-minute rest between measurement periods B and C and periods C

Table 1:

	A	B	C	D	E
HR min^{-1}	50+9	100±7*	154±4*	185±3*	148±7*
f min^{-1}	33±3	62±11*	76±11	90±11*	55±6*
$\dot{V}_{Imax}$ L/S	5.0±1.1	14.5±1.7*	30.0±2.3*	40.1±4.2*	22.6±4.2*
$\dot{V}_{Emax}$ L/S	5.2±0.9	15.8±2.3*	32.9±3.6*	43.2±4.9*	23.5±2.6*
R_I cm H_2O/L/S	0.41±0.09	0.36±0.05	0.44±0.05	0.37±0.06	0.31±0.04
R_E cm H_2O/L/S	0.27±0.03	0.26±0.04	0.27±0.07	0.23±0.07	0.25±0.06

Heart rate (HR), respiratory frequency (f), peak inspiratory flow ($\dot{V}_{Imax}$), peak expiratory flow ($\dot{V}_{Emax}$), inspiratory resistance (R_I) and expiratory resistance (R_E) (X±SEM) of 5 normal horses. A = standing; B = walking (1.3 M/S); C = slow trotting (2.6 M/S); D = fast trotting (4.6 M/S); E = standing post exercise. * Indicates significant difference from preceding value.

and D. At period E, measurements were taken immediately after exercise. Experiments were performed under control conditions, 10 days following left recurrent laryngeal neurectomy and at least 14 days following prosthetic laryngoplasty.[8]

Statistical Analysis

Effects of exercise, left recurrent laryngeal neurectomy and prosthetic laryngoplasty on upper airway flow mechanics were analyzed using a two-way analysis of variance.[14] When the f value was significant at alpha <0.05, treatment means were compared using Tukey's *w*-procedure.

Results

Effects of exercise on upper airway flow mechanics values in the 5 normal horses are reported in Table 1. Increasing treadmill speed from period A (standing) to period D (trot, 4.4 M/S, 6.38° incline) progressively increased heart rate (HR), respiratory frequency (f), peak inspiratory flow ($\dot{V}_{Imax}$), and peak expiratory flow ($\dot{V}_{Emax}$), while inspiratory resistance (R_I) and expiratory resistance (R_E) remained unchanged.

The effects of left recurrent laryngeal neurectomy and prosthetic laryngoplasty on R_I in 5 horses are shown in Fig. 1. At periods D and E, left laryngeal neurectomy resulted in a significant increase in R_I, a decrease in $\dot{V}_{Imax}$ and flow limitation (Fig. 2). Flow limitation, decreased $\dot{V}_{Imax}$ and increased R_I were reversed by prosthetic laryngoplasty. Neither left recurrent laryngeal neurectomy nor prosthetic laryngoplasty had an effect on HR, f, $\dot{V}_{Emax}$ or R_E when compared to control values at any of the measurement periods.

Discussion

Left recurrent laryngeal neurectomy did not have a significant effect on flow mechanics of the upper airway when horses were standing or walking. This is not surprising since the larynx contributes little to respiratory resistance in the resting horse and since laryngeal movements are minimal at rest.[15] A similar inability to detect increased laryngeal resistance in resting horses with laryngeal hemiplegia has been reported previously.[16] To demonstrate the effect of laryngeal hemiplegia on upper airway flow mechanics, air flow rates were increased by exercising the horses.

Under control conditions, $\dot{V}_{Imax}$ and $\dot{V}_{Emax}$ increased 8fold from period A to period D. Following left recurrent laryngeal neurectomy, flow limitation occurred on inhalation at approximately 25 L/S, i.e. no further increase in flow was measured with increasing driving pressure (Fig. 2). Flow limitation during inhalation and increased R_I probably resulted from collapse of the unsupported left arytenoid cartilage.[16] Once narrowed, inspiratory intraairway pressure is likely to become more subatmospheric (Bernoullis prin-

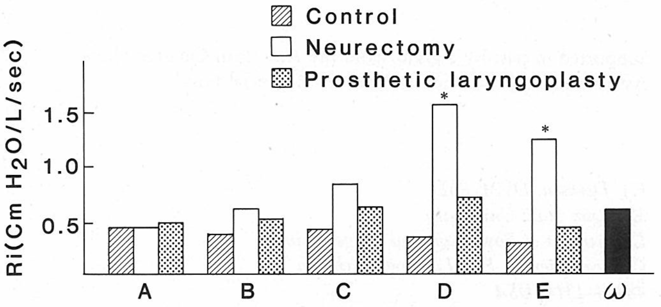

Fig. 1: Mean-peak inspiratory resistance at measurement periods A (standing), B (walking, 1.3 M/S), C (trotting, 2.6 M/S), D (trotting, 4.6 M/S) and E (standing, post-exercise).
Hatched bar = control.
Open bar = following left recurrent laryngeal neurectomy.
Stippled hatched bar = following prosthetic laryngoplasty.
w = Tukey's *w* value.
* indicates significant difference between treatment groups.

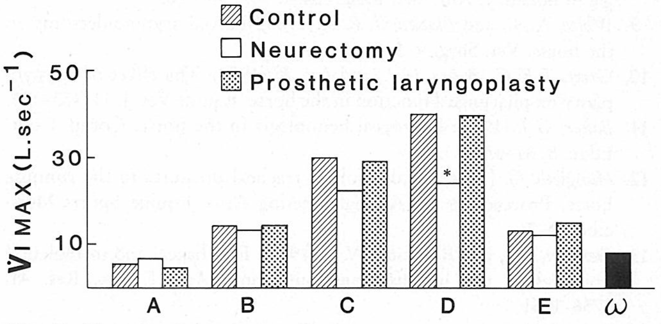

Fig. 2: Mean-peak inspiratory flow at measurement periods A (standing), B (walking, 1.3 M/S); C (trotting, 2.6 M/S); D (trotting, 4.6 M/S, and E (standing, post-exercise).
Hatched bar = control.
Open bar = following left recurrent laryngeal neurectomy.
Stippled hatched bar = following prosthetic laryngoplasty.
w = Tukey's *w* value.
* indicates significant difference between treatment groups.

ciple) producing a vicious cycle of further collapse of the upper airway and flow limitation (dynamic collapse). Since f was not significantly different before and after left recurrent laryngeal neurectomy in any measurement period, inspiratory flow limitation at period D may have resulted in hypoxemia and hypercapnia. Blood gas measurements in one horse with left laryngeal hemiplegia, galloping 1 mile in 1 minute 56 seconds, supports this conclusion.[17]

Prosthetic laryngoplasty prevented the increase in R_I and flow limitation seen following left recurrent laryngeal neurectomy in period D (Figs. 1 and 2). The mechanism whereby prosthetic laryngoplasty prevents increased R_I and flow limitation is probably by supporting the left arytenoid cartilage, thereby limiting dynamic collapse on inspiration. Endoscopic examination of 2 of the 5 subjects 14 days following prosthetic laryngoplasty showed that the corniculate process of the arytenoid cartilage was in a fully abducted position, while in 3 of the subjects, the corniculate process was in the resting position as defined by *Johnson.*[18] Despite the lack of full abduction in all subjects following prosthetic laryngoplasty, flow limitation and increased R_I at period D, as seen following left recurrent laryngeal neurectomy, was corrected by the surgical procedure. This suggests that the major factor determining the ability of prosthetic laryngoplasty to reduce R_I and to prevent flow limitation is not the degree of artenoid abduction, but the stability of the arytenoid cartilage.

The tendency for dynamic collapse of unsupported structures increases with inspiratory flow rates (Bernoullis principle). Air flow rates generated by horses during maximal exercise are unknown. *Leith* et *al.*[19] reported maximal expiratory flow in 4 normal anesthetized horses at 65–90 L/S. However, it is unlikely that horses generate maximal flow rates even under extreme exercise conditions. The highest reported peak flow rate of exercising horses is approximately 125 ml/s/kg at a fast gallop (550 m/min)[20] compared to 87 ml/s/kg in the present study. Since in this study air flow rates generated at the highest exercise level were probably not as high as those encountered while racing, the conclusion that prosthetic laryngoplasty reduced R_I to base-line levels must be interpreted with caution. With air flow rates encountered during racing, increased R_I may have been detected following prosthetic laryngoplasty.

References

1. *Fleming, G.* (1882): Laryngismus paralytica ("Roaring"). Vet. J. Ann. Comp. Pathol. 14, 1–12.
2. *Cole, C. R.* (1946): Changes in the equine larynx associated with laryngeal hemiplegia. Am. J. Vet. Res. 7, 69–77.
3. *Duncan, I. D., Griffiths, I. R., McQueen, A.,* et *al.* (1974): The pathology of equine laryngeal hemiplegia. Acta Neuropathol. 27, 337–348.
4. *Cook, W. R.* (1965): Diagnosis of respiratory unsoundness in the horse. Vet. Rec. 77, 516–528.
5. *Cook, W. R.* (1976): Laryngeal paralysis in the horse. Ph. D. Thesis, Cambridge University.
6. *Marks, D., Mackay-Smith, M. P., Cushing, L. S.,* and *Leslie, J. A.* (1970): Etiology and diagnosis of laryngeal hemiplegia in horses. J. Am. Vet. Med. Assoc. 157, 429–436.
7. *Hobday, F.* (1936): The surgical treatment of roaring in horses. North Am. Vet. 17, 17–21.
8. *Marks, D., Mackay-Smith, M. P., Cushing, L. S.,* and *Leslie, K. A.* (1970): Use of a prosthetic device for surgical correction of laryngeal hemiplegia in horses. J. Am. Vet. Med. Assoc. 157, 157–163.
9. *White, N. A.,* and *Blackwell, R. B.* (1980): Partial arytenoidectomy in the horse. Vet. Surg. 9, 5–12.
10. *Greet, T. R. C., Baker, G. J.,* and *Lee, R.* (1979): The effect of laryngoplasty on pharyngeal function in the horse. Equine Vet. J. 11, 153–158.
11. *Baker, G. J.* (1983): Laryngeal hemiplegia in the horse. Comp. Cont. Educ. 5, 61–67.
12. *Mangseth, G.* (1984): Evaluation of tracheal pressures in the running horse. Proceedings 1st Annual Meeting Asso. Equine Sports Medicine, 74–76.
13. *Derksen, F. J.,* and *Robinson, N. E.* (1980): Esophageal and intrapleural pressures in the healthy conscious pony. Am. J. Vet. Res. 41, 1756–1761.
14. *Steel, R. G. D.,* and *Torrie, J. H.* (1960): Principles and procedures of statistics. New York, McGraw-Hill Book Co.
15. *Robinson, N. E., Sorenson, R. P.,* and *Goble, D. O.* (1975): Proceedings Am. Assoc. Equine Practitioners, 11–21.
16. *Robinson, N. E.,* and *Sorenson, P. R.* (1978): Pathophysiology of airway obstruction in horses: A review. J. Am. Vet. Med. Assoc. 172, 299–303.
17. *Bayly, W. M., Grant, B. D.,* and *Modransky, P. D.* (1984): Arterial blood gas tensions during exercise in a horse with laryngeal hemiplegia, before and after corrective surgery. Res. Vet. Sci. 36, 256–258.
18. *Johnson, J. H., Moore, J. W., Garner, H. E.,* et *al.* (1977): Clinical characterization of the larynx in laryngeal hemiplegia. Proceedings Am. Assoc. Equine Practitioners, 259–264.
19. *Leith, D. E.,* and *Gillespie, J. R.* 1971): Respiratory mechanics of normal horses and one with chronic obstructive lung disease. Fed. Proc. 30, 556.
20. *Hornicke, H., Meixner, R.,* and *Pollman, U.* (1982): Respiration in exercising horses. Proceedings Conference on Equine Exercise Physiology, 7–16.

Supported in part by a grant from the American Quarter Horse Association and the Michele Volkoff Memorial Fund.

F. J. Derksen, DVM, PhD
Michigan State University
Department of Physiology and Large Animal
Clinical Sciences, East Lansing, Michigan
48824–1314, USA