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General Articles

Effects of unilateral laser-assisted ventriculocordectomy in horses with laryngeal hemiplegia

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Summary

Reasons for performing study: **Recent studies have evaluated surgical techniques aimed at reducing noise and improving airway function in horses with recurrent laryngeal neuropathy (RLN). These techniques require general anaesthesia and are invasive. A minimally invasive transnasal surgical technique for treatment of RLN that may be employed in the standing, sedated horse would be advantageous.**

Objective: **To determine whether unilateral laser-assisted ventriculocordectomy (LVC) improves upper airway function and reduces noise during inhalation in exercising horses with laryngeal hemiplegia (LH).**

Methods: **Six Standardbred horses were used; respiratory sound and inspiratory transupper airway pressure (Pui) measured before and after induction of LH, and 60, 90 and 120 days after LVC. Inspiratory sound level (SL) and the sound intensities of formants 1, 2 and 3 (F1, F2 and F3, respectively), were measured using computer-based sound analysis programmes. In addition, upper airway endoscopy was performed at each time interval, at rest and during treadmill exercise.**

Results: **In LH-affected horses, Pui, SL and the sound intensity of F2 and F3 were increased significantly from baseline values. At 60 days after LVC, Pui and SL had returned to baseline, and F2 and F3 values had improved partially compared to LH values. At 90 and 120 days, however, SL increased again to LH levels.**

Conclusions: **LVC decreases LH-associated airway obstruction by 60 days after surgery, and reduces inspiratory noise but not as effectively as bilateral ventriculocordectomy.**

Potential relevance: **LVC may be recommended as a treatment of LH, where reduction of upper airway obstruction and respiratory noise is desired and the owner wishes to avoid risks associated with a laryngotomy incision or general anaesthesia.**

Introduction

Recurrent laryngeal neuropathy (RLN) in horses leads to dynamic collapse of the airway during strenuous exercise, resulting in upper airway obstruction (Morris and Seeherman 1990; Martin *et al.* 2000; Dixon *et al.* 2001). In addition, a characteristic inspiratory whistling noise is associated with the condition (Williams 1874; Derksen *et al.* 2001; Dixon *et al.* 2001). In show horses, respiratory noise during exercise may lead to penalties during competition.

The use of bilateral ventriculocordectomy has been recommended as the surgical treatment of choice in RLN-affected show horses, because in experimentally induced laryngeal hemiplegia (LH), the technique effectively reduces respiratory noise, improves upper airway function and has few serious post operative complications (Brown *et al.* 2003). However, bilateral ventriculocordectomy requires general anaesthesia and a laryngotomy (Brown *et al.* 2003).

Laser-assisted surgery performed through a fibreoptic endoscope is less invasive, and does not require general anaesthesia (Hawkins and Andrews-Jones 2001). We recently demonstrated, however, that laser-assisted vocal cordectomy is ineffective in reducing LH-associated respiratory noise (Brown *et al.* 2005). Because the laryngeal ventricle is the probable primary source of noise (Attenburrow 1982), these results may be explained by failure of the surgical technique to remove this structure. Therefore, in the current study, the efficacy of a new surgical technique that results in the transnasal removal of both left laryngeal ventricle and vocal fold, without requiring the use of a laryngotomy incision or general anaesthesia, was evaluated.

Materials and methods

Animals

Six Standardbred horses (median age 9.5 years; range 5–15 years) 3 geldings and 3 mares, were used. All horses were administered an anthelmintic and vaccinated against eastern and western encephalitis, tetanus, equine influenza and rhinopneumonitis before the start of the study. Physical examination of the horses and endoscopic evaluation of the upper airway was performed, at rest and during high-speed treadmill exercise, and did not reveal abnormalities in any of the horses. Maximum heart rate (HR_{max})

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Fig 1: Transnasal burr. The burr's tip is shown in the insert.

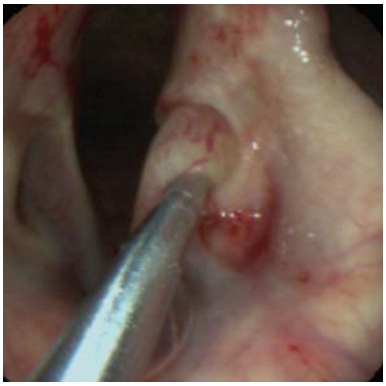

Fig 2: The burr has engaged and is everting the saccule.

was determined by use of a telemetry system, and an incremental exercise test (Lumsden *et al.* 1993; Tetens *et al.* 1996). Horses were maintained on pasture between measurement periods and surgical procedures. The All-University Committee on Animal Use and Care at Michigan State University approved the study.

Experimental protocol

Each horse served as its own control. Respiratory sounds and inspiratory transupper airway pressure were measured before (baseline), and 14 days after induction of LH by left recurrent laryngeal neurectomy, and again 60, 90 and 120 days following unilateral, laser-assisted ventriculocordectomy (LVC). All data were collected with the horses exercising on a treadmill at speeds corresponding to maximum heart rate (HR_{max}). Following a 4 min warm-up period at 4 m/sec, horses were exercised at a speed corresponding to HR_{max} for 2 min. Respiratory sound recordings and transupper airway pressure measurements were performed during separate exercise periods. The sequence of respiratory sound and transupper airway pressure recordings was randomised.

Upper airway endoscopy was performed in the resting horse, before and immediately after surgical procedures, and again at 14, 30, 60, 90 and 120 days following LVC to confirm induction of LH, or to document any complications as a result of LVC. High-speed treadmill videoendoscopy was also performed in all horses at 60, 90 and 120 days after LVC.

Measurement techniques

Maximum heart rate: Horses were trained to work on a treadmill and underwent an incremental exercise test to determine the relationship between treadmill speed and heart rate (Lumsden *et al.* 1993; Tetens *et al.* 1996). For the exercise test, each horse warmed-up for 3 min at a treadmill speed of 4 m/sec and then the speed was increased to

TABLE 1: Inspiratory transupper airway pressure (Pui), inspiratory sound level (SL) and sound intensity of formants 1, 2, and 3 (F1, F2, F3, respectively) in horses exercising at maximum heart rate before (baseline) and after induction of laryngeal hemiplegia (LH) and 60, 90, and 120 days following laser-assisted ventriculocordectomy (LVC)

	Baseline	LH	60	90	120
Pui (cmH_2O)	-24.9 ± 3.7	-41.9 ± 2.6*	-28.2 ± 3.6^	-30.3 ± 8.6^	-28.6 ± 11^
SL (dB)	-22.9 ± 0.7	-17 ± 0.7*	-23 ± 0.5^	-17.5 ± 1.0*	-19.6 ± 0.4*
F1 (dB)	-48.3 ± 1.4	-48 ± 0.6	-50.9 ± 0.5	-45.2 ± 0.2*	-47.9 ± 0.7
F2 (dB)	-59.9 ± 0.9	-42.6 ± 1.8*	-53.8 ± 1.7*^	-49.1 ± 2.6*^	-52.9 ± 2.3*^
F3 (dB)	-63.1 ± 1.9	-55.7 ± 1.2*	-60.4 ± 1.1	-58.5 ± 2.2	-60.4 ± 1.7

*Indicates significant difference from baseline. ^Indicates significant difference from LH values.

6 m/sec for 90 sec. Subsequently, the treadmill speed was increased every 60 sec to 8, 10, 11, 12 and 13 m/sec. The test ended when the horses could no longer hold their position on the treadmill. Heart rate was measured with a radiotelemetry unit (Digital VHF Telemetry System, M1403A)[1], and recorded during the last 15 sec of each exercise period. The treadmill speed that produced HR_{max} was identified.

Respiratory sound recordings: Respiratory sounds were recorded using a dynamic unidirectional, microphone (F-V9)[2] mounted on a cavison and positioned equidistant between the horse's nostrils, approximately 4 cm from the horse's nose. The microphone was connected to a cassette recorder (RQ-210Z)[3]. The respiratory

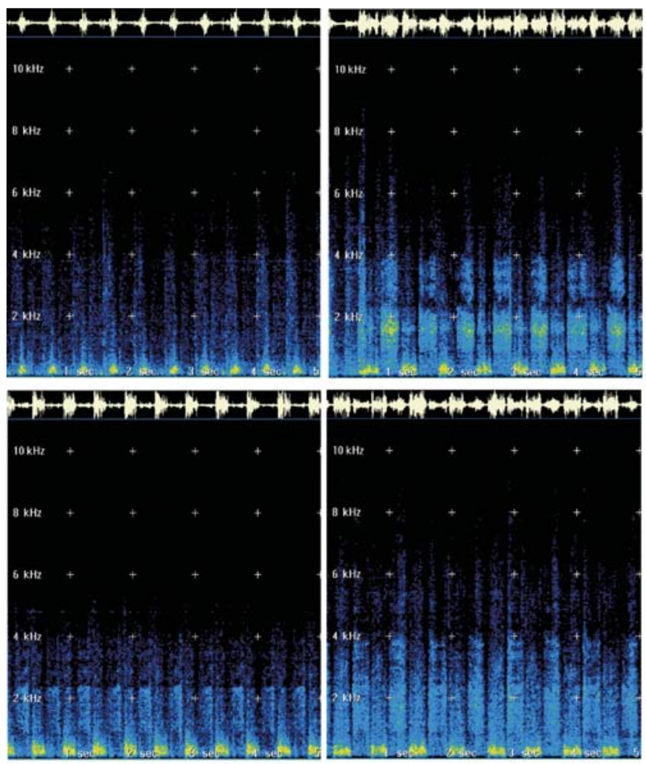

Fig 3: Respiratory sound spectrograms of a horse exercising on a treadmill at speeds corresponding to maximum heart rate (HR_{max}) at baseline (top left), after induction of LH (top right), and 60 (bottom left) and 90 (bottom right) days after LVC. Time (sec) is on the x axis and frequency (KHz) is on the y axis. Sound intensity increases with brightness of the colour (black indicates that no sound was recorded). The top tracing is the recorded sound waveform in the time domain.

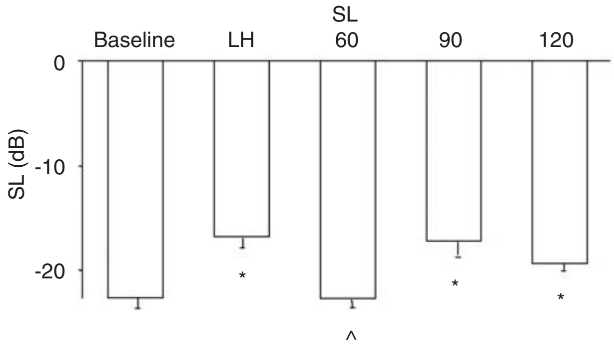

*Fig 4: Inspiratory sound level (SL) in horses exercising at maximum heart rate before (before) and after induction of laryngeal hemiplegia (LH), and 60, 90 and 120 days after unilateral laser-assisted ventriculocordectomy (LVC). *Indicates a significant difference from baseline levels. ^Indicates a significant difference from LH.*

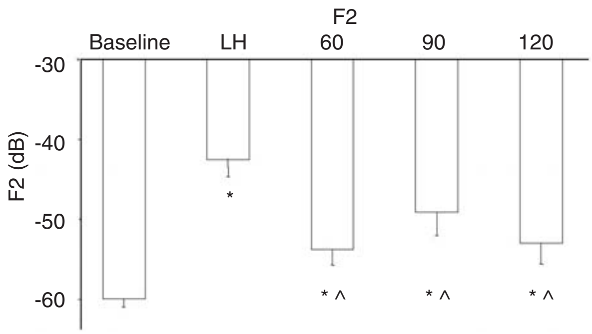

*Fig 5: Peak sound intensity of formant 2 (F2) in horses exercising at maximum heart rate before (before) and after induction of laryngeal hemiplegia (LH), and 60, 90 and 120 days after unilateral laser-assisted ventriculocordectomy (LVC). *Indicates a significant difference from baseline levels. ^Indicates a significant difference from LH.*

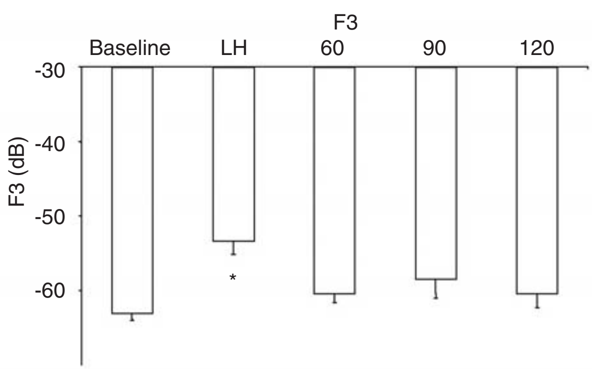

*Fig 6: Peak sound intensity of formant 3 (F3) in horses exercising at maximum heart rate before (before) and after induction of laryngeal hemiplegia (LH), and 60, 90 and 120 days after unilateral laser-assisted ventriculocordectomy (LVC). *Indicates a significant difference from baseline levels.*

sound recordings were subsequently digitised for analysis using a sampling rate of 22 KHz. The audiocassette recorder was calibrated as described previously (Derksen *et al.* 2001).

Respiratory sounds were analysed by use of computer-based spectrum[4] and sound analysis (Sound Forge 6.0)[5] programmes. This analysis allows simultaneous listening to the respiratory sounds and viewing of the spectrogram, thus enhancing ease of interpretation. All data reported are the average of 10 consecutive breaths recorded during the last 30 sec of the protocols. Sound

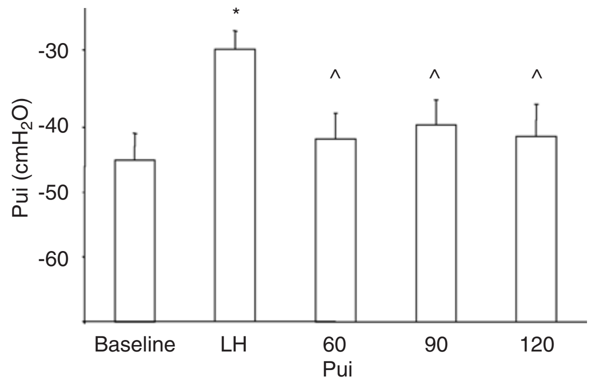

*Fig 7: Inspiratory transupper airway pressure (Pui) in horses exercising at maximum heart rate before (before) and after induction of laryngeal hemiplegia (LH), and 60, 90 and 120 days after unilateral laser-assisted ventriculocordectomy (LVC). *Indicates a significant difference from baseline levels. ^ Indicates a significant difference from LH.*

intensity was expressed in decibel (dB), with 0 dB an arbitrary value. The root mean square of the inspiratory sound level (SL) was calculated. The frequency range of the 3 inspiratory formants (F1, F2 and F3) characteristic of horses with LH (Derksen *et al.* 2001) was identified by visual inspection of the sound spectrum. Subsequently, the central frequency and the frequency range of one-third octave bands either side of the central frequency was derived. Peak sound intensity in this frequency range was calculated (Derksen *et al.* 2001; Brown *et al.* 2004).

Transupper airway pressure

The inspiratory transupper airway pressure (Pui) was defined as the difference between tracheal pressures and barometric pressure at the beginning and end of inhalation. This pressure was measured by means of a side-hole catheter passed through the nasal passage to the mid-cervical region of the trachea. The catheter was attached to a differential pressure transducer (DP-45-22)[6] and a physiograph (Dash 12)[7]. Before each experiment, the differential pressure transducer was calibrated by use of a water manometer (Derksen *et al.* 2001).

Surgical procedures

For all surgical procedures, all horses were administered perioperative antibiotics (ampicillin trihydrate 15 mg/kg bwt i.v.

Fig 8: Endoscopic view of the surgical site at 90 days. Note that the left saccule and vocal cord have been removed, and that the mucosa has healed.

t.i.d., gentamicin sulphate 6.6 mg/kg bwt i.v. s.i.d.) and an anti-inflammatory agent (flunixin meglumine 1.1 mg/kg bwt i.v. b.i.d.).

Left recurrent laryngeal neurectomy: Each horse was placed under general anaesthesia in right lateral recumbency and the left, mid-cervical region clipped and prepared for aseptic surgery. An incision was made immediately ventral to the jugular vein and the left recurrent laryngeal nerve was identified and isolated. Identification of the correct nerve was confirmed by endoscopic visualisation of abduction of the left corniculate process during nerve stimulation by use of a hemostatic forceps. After isolation, a 2.5 cm segment of the nerve was transected and removed.

Unilateral laser-assisted ventriculocordectomy: Horses were restrained in stocks and sedated by use of a continuous infusion of detomidine HCl. Topical mepivicaine was applied to the left vocal cord and ventricle by use of a catheter passed through the biopsy channel of the endoscope. A 980 nm diode laser (980-25 laser)[8], with a 600 µm bare quartz fibre, and 20 W was used in contact fashion to excise the vocal fold and the ventricle. An average of 8500 J was used. With the endoscope passed up the right nostril, the dorsal, ventral and caudal margins of the vocal fold were released while traction was applied to the vocal fold using bronchoesophageal forceps. Encased in a 1.9 cm stomach tube, a specially constructed transnasal burr[9] was then inserted through the left nostril into the left laryngeal ventricle (Fig 1). The ventricle was everted (Fig 2), and the vocal fold and everted ventricle were excised with the endoscopically guided diode laser.

Post operative care

All horses were administered phenylbutazone (2.2 mg/kg bwt *per os* b.i.d.), sulphamethoxazole and trimethoprim (30 mg/kg bwt *per os* b.i.d.) and topical pharyngeal spray containing DMSO, dexamethasone, nitrofurazone and glycerine twice daily for 7 days following surgery. Horses were stall rested for 14 days. Upper airway endoscopy was performed on the horses at rest, 14 days after surgery, and revealed no abnormalities associated with LVC. The horses were turned onto pasture at that time.

Statistical analysis

Data were analysed with a repeated measure analysis of variance[10]. When treatment effects were significant ($P<0.05$), means were compared with the Student-Newman-Keuls test.

Results

In horses exercising at HR_{max}, induction of LH resulted in a high-pitched, inspiratory noise characterised by 3 formants (F1, F2 and F3) centred around 247 ± 12, 1375 ± 9 and 3252 ± 82 Hz (mean ± s.e.), respectively (Fig 3). Compared to baseline, Pui, SL and the sound intensities of F2 and F3 were increased significantly, while F1 was unaffected (Table 1).

Laser-assisted ventriculocordectomy decreased the sound intensity of F2 and F3. At all measurement periods following surgery, F2 was significantly improved from LH values, but remained significantly different from baseline. Following LVC, F3 was not significantly different from LH or baseline values (Figs 4, 5, 6).

Sixty days after LVC, SL decreased significantly compared to LH values, and was no longer significantly different from baseline. By 90 and 120 days following LVC, however, SL increased again such that SL was significantly different from baseline and not significantly different from LH values (Figs 4, 5, 6).

The Pui returned to baseline values at all measurement periods following LVC (Fig 7).

Endoscopic examination immediately after left recurrent laryngeal neurectomy confirmed induction of laryngeal hemiplegia in all horses. No complications associated with LVC were detected during resting or treadmill endoscopy in any of the horses (Fig 8).

Discussion

Laser-assisted ventriculocordectomy (LVC) was performed transnasally in the standing, sedated horse, thereby eliminating complications associated with a laryngotomy incision and general anaesthesia. The procedure was made possible by a novel transnasal burr inserted through the nostril on the same side as the paralysed arytenoid cartilage. The transnasal burr was used to engage and evert the ventricle on the affected side, allowing it to be excised using a diode laser (Sullins 2005). This procedure was relatively simple to perform and there were no complications associated with the surgery in any of the horses.

The LVC returned inspiratory transupper airway pressure (Pui) in LH-affected horses to baseline levels at all measurement periods. The only other technique that fully reverses upper airway obstruction, as measured by Pui, in LH-affected horses is prosthetic laryngoplasty (Derksen *et al.* 1986; Shappell *et al.* 1988; Tetens *et al.* 1996). For example, in a recent study, in horses that underwent laryngoplasty for treatment of LH, Pui was reduced from a mean of 47.3 to 33.5 cmH_2O by 60 days following surgery (Brown *et al.* 2004). In the current study, Pui was reduced from a mean of 41.9 to 28.2 cmH_2O by 60 days following LVC. Other techniques for treatment of LH-affected horses involving removal of the vocal cord, ventricle or combinations thereof have only been able to reduce upper airway obstruction partially (Brown *et al.* 2003, 2005) or not at all (Shappell *et al.* 1988). The reason why LVC completely returned Pui to baseline values is unclear. We speculate that by removing the left vocal fold and ventricle using laser energy, collateral tissue damage resulted in more scarring than occurs following conventional removal of these structures with a scalpel and, therefore, better stabilisation of the affected arytenoid. These results further support the contention that stabilisation of the affected arytenoid, but not full abduction, is required for upper airway function to return to baseline values in LH-affected horses (Brown *et al.* 2004). It must be noted that, in this study, only Pui and not inspiratory impedance or arterial blood gases were measured. It is possible that these latter measures of upper airway function may not have returned to baseline following LVC. Furthermore, caution is indicated when interpreting these data relative to racehorses with RLN. The horses in the current study exercised at maximum heart rate rather than maximum speed. Racing animals exercise at greater speed, and hence are likely to have greater transupper airway pressures than horses used in this study. It is possible, therefore, that under racing conditions, LVC and/or laryngoplasty may be insufficient to fully reverse airway obstruction in RLN-affected horses.

In horses with LH, the greatest increase in sound intensity is found in the F2 frequency band (Derksen *et al.* 2001). Indeed, the characteristic high-pitched noise heard during inhalation in LH-affected horses is primarily the result of increased sound intensity in this region (Attenburrow 1982). LVC partially improved the sound intensity of F2 and F3. This result is superior to results reported following unilateral vocal cordectomy for the treatment of LH (Brown *et al.* 2005). One of the differences between unilateral vocal cordectomy and LVC is that in the latter technique the ventricle is removed. Because the ventricle is thought to be the primary source of the noise associated with F2 (Attenburrow 1982), this difference between these surgical techniques probably explains the greater efficacy of LVC.

The reduction in sound intensity of F2 and F3 following LVC was not as complete as reported following bilateral ventriculocordectomy (Brown *et al.* 2003). In the latter technique, both left and right ventricles and vocal cords are removed. After LVC, in some LH-affected horses exercising at maximum heart rate, billowing of the right ventricle and vocal cord was observed endoscopically. It is possible, therefore, that under these conditions the contralateral ventricle may become a source of inspiratory noise. Therefore, in LH-affected horses, removal of both ventricles and vocal cords may be required for optimal noise reduction. By 60 days following LVC, SL returned to baseline values. However, 90 and 120 days after LVC, SL increased again and was significantly different from baseline and not significantly different from LH values. The return of SL to LH values at 90 and 120 days after LVC was unexpected. Because Pui had returned to baseline values at these time periods, these observations support previous findings that residual airway obstruction and noise following surgery are not correlated (Brown *et al.* 2004). Following laser surgery, tissues undergo denaturation and shrinkage, followed by a repair response characterised by fibroplasia, neovascularisation and fibrovascular scar formation (Arnoczky and Aksan 2000). The timing of these responses in the equine airway is unknown but, in other species, it may take as long as 12 weeks for thermally modified tissues to regain normal strength (Chen *et al.* 1998). During that same period, tissues are susceptible to deformation (Schaefer *et al.* 1997). Horses were exercised at maximum heart rate 60 days after LVC, subjecting tissues to physiological stresses. At 90 and 120 days following surgery these processes may have resulted in changes in laryngeal conformation, airflow turbulence and noise generation during exercise.

Various surgical techniques have been recommended for the treatment of LH-affected horses (Marks *et al.* 1970; Ducharme and Hackett 1991; Lumsden *et al.* 1994; Russell and Slone 1994; Brown *et al.* 2003; Fulton *et al.* 2003). When choosing which technique to employ, the surgeon must weigh the ability of the procedure to reduce noise and improve airway function against the potential side effects associated with each procedure. It follows, therefore, that the selection of one technique over another is dictated by the intended use of the horse, cost of the procedure, expectations of the owner regarding noise production following surgery, the owner's tolerance for risk of intra- or post operative complications and those associated with general anaesthesia. This investigation was designed to evaluate the improvement in upper airway function and the reduction of noise in LH-affected horses after LVC when exercising on a treadmill at speeds corresponding to HR_{max}. The findings suggest that LVC results in reduction of airway obstruction from 60 days onwards following surgery, while noise production during inhalation is partially improved. Performing LVC in the standing horse eliminates the need for general anaesthesia and may be an effective alternative to prosthetic laryngoplasty in cases where the primary aim of surgery is to eliminate upper airway obstruction and where there is low risk tolerance for complications associated with laryngoplasty and general anaesthesia. In addition, in show horses where reduction of upper airway noise is the primary desired outcome, LVC may provide an alternative to procedures involving removal of the vocal fold, ventricle or combinations thereof, where complications associated with a laryngotomy incision, general anaesthesia and/or cost are a concern.

Acknowledgements

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Manufacturers' addresses

[1]Hewlett Packard, Andover, Massachusetts, USA.
[2]Sony Corporation, New York, USA.
[3]Panasonic Inc, Secaucus, New Jersey, USA.
[4]www.visualizationsoftware.com
[5]Sonic Foundry, Madison, Wisconsin, USA.
[6]Validyne Engineering Sales, Northridge, California, USA.
[7]Astro-Med, West Warwick, Rhode Island, USA.
[8]DiodeVet, Newark, Delaware, USA.
[9]Sontec Instruments Inc, Englewood, Colorado, USA.
[10]Sigmastat 2, Chicago, Illinois, USA.

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