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Can an external device prevent dorsal displacement of the soft palate during strenuous exercise?

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Summary

Reasons for performing study: **Dorsal displacement of the soft palate (DDSP) is a common condition in racehorses for which various surgical treatments are often performed. In light of recent findings that suggested the position of the larynx may influence the occurrence of DDSP, we investigated whether a noninvasive mean of affecting the position of the larynx could be effective in the management of DDSP.**

Hypothesis: **An external device (laryngohyoid support; LHS) positioning the larynx in a more rostral and dorsal location and preventing caudal displacement of the basihyoid bone would be effective in preventing DDSP during strenuous exercise.**

Methods: **Ten horses were exercised on a high-speed treadmill under 4 different treatment conditions: control (n = 10); control with external device (n = 10); after bilateral resection of thyrohyoid (TH) muscles (n = 7); and after bilateral resection of TH muscles with external device (n = 7). Two trials were performed randomly for each of the 4 conditions. In *Trial 1*, videoendoscopic images of the upper airway, pharyngeal and tracheal static pressures, and arterial blood gases were collected. In *Trial 2*, airflow measurement combined with mask and tracheal static pressure was obtained, and upper airway impedance calculated. The trials allowed calculation of airway impedance and respiratory frequency, and assessment of ventilation using arterial PO_2 and PCO_2.**

Results: **Under control conditions, none of the 10 horses developed DDSP. There was no statistically significant effect from the LHS on airway impedance or respiratory frequency, nor on arterial PO_2 and PCO_2. Seven of the 10 horses developed DDSP during exercise after resection of the TH muscles. None of these 7 horses continued to experience DDSP during exercise with the external device. In the latter group and condition, the LHS significantly improved inspiratory and expiratory flow and impedance.**

Conclusions: **The LHS helped prevent experimentally induced DDSP at exercise, probably by statically positioning the larynx in a more rostral and dorsal position.**

Potential relevance: **Field studies are required to investigate whether the LHS can successfully prevent DDSP in horses with naturally occurring disease.**

Introduction

Intermittent dorsal displacement of the soft palate (DDSP) typically leads to markedly impaired performance and abnormal respiratory noise. Upon initial diagnosis, nonsurgical means such as a course of anti-inflammatory agents, tongue-tie use, increased fitness, various bits and rest are usually recommended (Freeman 1990; Ducharme and Hackett 1997; Parente *et al.* 2002; Barakzai and Dixon 2004). The proposed mechanism of action for these nonsurgical recommendations varies. Holcombe *et al.* (1998) indicated that anaesthesia of the pharyngeal branch of the vagus nerve led to DDSP, which was the basis for the hypothesis that upper airway inflammatory disease could result in neuritis that led to DDSP. Therefore, the use of anti-inflammatory agents as an aid in the management of DDSP in horses with upper airway inflammation became a recommendation (Holcombe and Ducharme 1999).

The role of the tongue-tie in preventing soft palate displacement has been the subject of much speculation. Cook (1981) hypothesised that caudal retraction of the tongue led to dorsal pressure on the ventral aspect of the soft palate and, therefore, displacement. Robinson and Holcombe (1996) proposed that the stability of the nasopharynx is enhanced by ventral movement of the hyoid apparatus, resulting in increased distance between the basihyoid and roof of the nasopharynx. The position of the hyoid apparatus appears to be influenced by traction of the tongue. Attempts were made to test this hypothesis in a follow-up study using computed tomography in anaesthetised horses (Cornelisse *et al.* 2001). However, effects from traction of the tongue on the position of the hyoid apparatus or the nasopharyngeal diameter could not be documented.

The use of a dropped or figure-eight noseband has been proposed to prevent ingress of air into the oropharynx (Ducharme and Hackett 1997), based on the hypothesis that this allows the oropharynx to maintain subatmospheric pressure, which applies ventral pressure on the soft palate. To our knowledge, no data are available that test this hypothesis. Various designs of bits have been reported anecdotally to prevent DDSP, but none have been statistically validated.

Cook (1981) was the first to propose that factors causing the larynx to be in a more caudal position lead to DDSP. Supportive evidence for this extrinsic cause of DDSP was provided by 2 experimental studies where surgical alteration extrinsic to the

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larynx and nasopharynx resulted in upper airway obstruction or DDSP during exercise (Holcombe *et al.* 1994; Ducharme *et al.* 2003). Holcombe *et al.* (1994) first reported that dysfunction of the sternothyrohyoid muscles by bilateral partial tenomyectomy led to an increase in upper airway pressure in horses during exercise, proving that structures other than the intrinsic nasopharyngeal musculature are important for maintaining nasopharyngeal stability. More recently, DDSP could be induced in 7 of 10 horses at exercise by bilateral resection of the thyrohyoid (TH) muscles (Ducharme *et al.* 2003). Furthermore, the DDSP created could be resolved surgically in 6 of 7 horses by suturing the thyroid cartilage to the basihyoid bone (presumably restoring the function of the resected TH muscles). These experimental studies support the concept that the position of the larynx and hyoid apparatus influence nasopharyngeal stability at exercise and the occurrence of DDSP.

Searching for a noninvasive treatment of DDSP, we investigated whether the action of the TH muscles could be restored by external pressure. Specifically, we hypothesised that the larynx could be positioned rostrally and dorsally by using an external device in the intermandibular space. The larynx would be moved dorsally by upward pressure on the ventral aspect of the thyroid cartilage and rostrally by applying forward pressure on the caudal aspect of the basihyoid bone. The efficacy of this external device could be tested using the experimental model published recently (Ducharme *et al.* 2003).

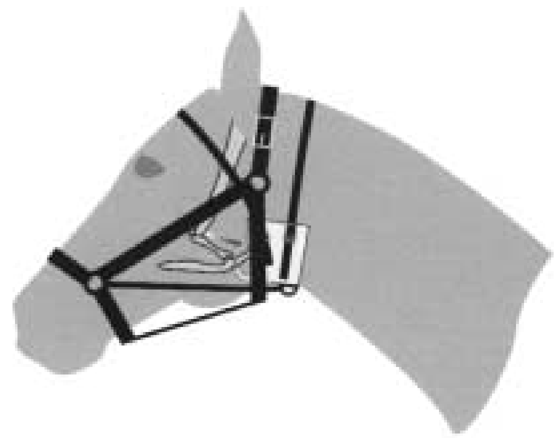

Fig 1: Drawing of the laryngohyoid support device positioned on the horse under the bridle. The tip of a 'ski-shaped' plastic device fits at the caudal aspect of the basihyoid bone. Dorsal movement of the larynx is obtained by tightening the headband. Forward traction is applied by tightening a strap extending from the ventral aspect of the support device to the halter side loop ring. The device is applied under videoendoscopic control.

Materials and methods

Experimental design

An external device that applies pressure to the caudal aspect of the basihyoid bone and ventral aspect of the thyroid cartilage (laryngohyoid support; LHS)[1] was evaluated to determine its effects on ventilation and airway patency as well as effectiveness in preventing DDSP during treadmill exercise (Fig 1). The device consisted of a rounded piece of polyethylene secured on the ventral aspect of a headband. The rounded portion was placed immediately caudal to the basihyoid bone, thereby applying pressure on the ventral aspect of the body of the thyroid cartilage. Dorsal movement of the larynx could be observed on videoendoscopy when the headband strap was tightened. To keep the device in place despite head extension during exercise, a strap was placed from the right-side front ring on the horse's halter through a 'D' ring on the ventral aspect of the headband, then tightened on the left-side front ring of the halter. By applying forward pressure on the caudal aspect of the basihyoid bone, the latter was moved forward, pulling the larynx rostrally as seen on videoendoscopy. At the beginning of the study, a standing lateral radiograph was taken to verify the position of the larynx with and without the device. Inspection of the radiographs of 10 horses confirmed that the LHS positioned the larynx rostrally and dorsally (with the tip of the epiglottic cartilage more rostral in relation to the stylohyoid bones and closed to the roof of the nasopharynx). At each trial, the position of the LHS was adjusted for consistency in each horse under videoendoscopic control.

The study was divided into 2 phases. In *Phase I*, 10 fit horses were used to ensure that the external device did not create an upper airway obstruction, by measuring blood gases, airway pressures and airflow, and calculating impedance. In *Phase II*, DDSP was created experimentally by bilateral surgical resection of the TH muscles. The effectiveness of the device was determined based on the occurrence of DDSP in horses exercising with and without the LHS. We made the diagnosis of DDSP at exercise using criteria by Rehder *et al.* (1995) (a DDSP diagnosis was made when the soft palate was positioned dorsal to the epiglottic cartilage for 8 secs or more during exercise). In each phase, the horses were submitted to 2 trials (2 trials in each of 2 phases = 4 conditions). In *Trial 1*, videoendoscopy was performed while simultaneously measuring arterial blood gases at the end of each exercise interval. In *Trial 2*, airflow and static tracheal and mask pressures were measured. All procedures complied with applicable federal and state regulations and were approved by Cornell University's Institutional Animal Care and Use Committee.

Animals

Ten mature horses (mean ± s.d. age 6.3 ± 2.7 years; 7 females, 3 castrated males; 5 Standardbreds, 5 Thoroughbreds; mean ± s.d. weight 459 ± 48 kg) were used. The horses were determined to be in good condition and athletically fit on the basis of a physical examination and haematology. Prior to the study, normal upper airway function was confirmed by videoendoscopy at rest and during exercise and a right carotid exteriorisation was performed at least 2 weeks prior to the start of the study. Within 14 days prior to each trial, maximal heart rate (HR_{max}) was determined for each horse by incrementally increasing treadmill speed until a plateau in heart rate was reached. Heart rate then was regressed on treadmill speed, and the speeds predicted to produce 75, 90 and 100% HR_{max} were determined. At the end of each workout, horses were bathed and cooled down appropriately.

Acclimatisation to treadmill and training

Horses were shod with polyurethane shoes (Nail-shu)[2]. A heart-rate meter (Polar Equine Easy)[3] allowed continuous recordings throughout the exercise programme (exercise was discontinued if the heart rate reached 240 beats/min). Close-fitting neoprene boots[4] were used on the lower limbs to prevent injuries related to interference. All horses were fasted for 3 h prior to any trial.

Conditions of examinations

- Control: horses with a normal upper airway.
- DDSP: Horses with bilateral resection of the TH muscles at least 2 weeks prior to testing (Ducharme *et al.* 2003).
- External device: custom-designed laryngohyoid support that applied rostral and dorsal pressure on the ventral aspect of the larynx and rested on the caudal aspect of the basihyoid bone (Fig 1).

Measurement

For blood gas analysis, a previously exteriorised carotid artery allowed aseptic placement of an 18 gauge, 2.5 inch catheter. A T-port was placed to allow introduction of a thermistor to measure core body temperature. During experimental trials, 3 arterial blood samples were collected rapidly in heparinised syringes at the end of each level of exercise intensity (2 mins at 75, 90 and 100% HR_{max}). Samples were stored on ice and analysed immediately after the experiment. Blood gases were corrected to body temperature and barometric pressure. The accuracy of blood-gas analyses was verified using tonometered equine blood samples.

Upper respiratory endoscopy was performed in horses exercising on the treadmill using a flexible videoendoscope (Olympus GIF-100)[5] passed into the nasopharynx via the right ventral nasal meatus and secured to the horse's halter, and was recorded using a videotape recorder (VO 5600)[6]. We used a Teflon catheter (Neoflon)[7] as described by Nielan *et al.* (1992) to measure static tracheal pressure. Positioning of the tracheal catheters 30 cm distal to the *rima glottidis* was confirmed by videoendoscopy. An additional Teflon catheter[7] was placed in the mask. The catheters were attached to differential pressure transducers (Celesco LCVR)[8] referenced to atmospheric pressure. The tracheal catheter was calibrated at 0, 50 and 70 mmHg and the mask at 0 and 5 cmH_2O. The pressure catheters were in phase from 1–20 Hz.

For airflow measurement, 2 ultrasonic transducers[9] were mounted in the mask, each in line with one of the nostrils. The ultrasonic transducers were calibrated from -60 to 60 l/sec using a rotometer (Model 2100)[10] and 5-point increments.

Heart rate (HR) was measured by an on-board HR monitor[3]. The 2 electrodes for the monitor were attached to a girth strap placed over the withers dorsally and just caudal to the axillae ventrally. The electrodes were positioned on the sternum and left side of the thorax midway between the sternum and withers. The hair at these 2 areas was clipped, and a generous amount of electrode gel and/or saline was applied to the electrode pads to ensure proper transmission of the cardiac signal. The HR was transmitted from a transmitter attached to the girth strap via telemetry to a receiver attached to the computer, and relayed automatically every 15 secs to the computer for display and storage.

Analogue signals (tracheal, mask and airflow) were processed through an analogue anti-aliasing filter, amplified, and collected at 256 Hz using a 16-bit analogue/digital data-collection board (NIPCI 6034E)[11]. Customised software[11] allowed digital filtering, conversion to mmHg and analysis of the signals. The mask pressure was subtracted from the tracheal pressure, and peak inspiratory (Pui) and expiratory (Pue) tracheal pressures were

TABLE 1: Arterial blood gases and indices (mean and s.d.) of airway mechanics in 10 horses without DDSP exercising on a high-speed treadmill with and without laryngohyoid support (LHS) device

		Exercise intensity†						
		75%		90%		100%		Adjusted
Variables	Treatment	Mean	s.d.	Mean	s.d.	Mean	s.d.	means
F (breaths/min)	Control	71	5.4	91	7.7	103	7.9	88
	LHS	71	5.1	85	8.2	98	8.1	86
HR (beats/min)	Control	172	4.8	207	2.8	226	3.7	198
	LHS	169	5.6	206	2.8	224	2.5	197
PaO_2 (mmHg)	Control	89	3.0	78	2.3	72	2.8	80
	LHS	90	2.8	78	2.7	73	2.4	80
$PaCO_2$ (mmHg)	Control	43	1.0	46	1.0	53	2.0	47
	LHS	42	1.2	46	1.1	52	2.4	47
Pui (mmHg)	Control	-11	0.8	-22	1.7	-30	2.3	-21
	LHS	-13	0.9	-21	2.0	-28	2.9	-21
Pue (mmHg)	Control	13	2.4	21	2.7	20	2.3	18
	LHS	12	2.0	18	2.4	19	3.0	16
PIF (l/sec)	Control	-31	2.0	-40	2.3	-48	2.4	-40
	LHS	-29	1.4	-42	3.0	-47	3.1	-40
PEF (l/sec)	Control	39	3.2	51	3.7	57	3.3	49
	LHS	39	2.59	53	3.6	57	4.3	50
Zi (mmHg/l/sec)	Control	0.36	0.03	0.54	0.04	0.64	0.04	0.52
	LHS	0.44	0.03	0.52	0.07	0.60	0.06	0.52
Ze (mmHg/l/sec)	Control	0.38	0.11	0.48	0.12	0.40	0.09	0.42
	LHS	0.36	0.09	0.35	0.05	0.35	0.05	0.35

†Expressed as percentage of HR_{max}. f = Respiratory frequency; HR = heart rate; PaO_2 = partial pressure of arterial oxygen; $PaCO_2$ = partial pressure of carbon dioxide; Pui = inspiratory tracheal pressure; Pue = expiratory tracheal pressure; PIF = peak inspiratory flow; PEF = peak expiratory flow; Zi = inspiratory impedance; Ze = expiratory impedance.

TABLE 2: Arterial blood gases and indices (mean and s.d.) of airway mechanics in 7 horses prior to and after inducing DDSP exercising on a high-speed treadmill and the effects of the laryngohyoid support (LHS) device on the horses with DDSP

		Exercise intensity†						
		75%		90%		100%		Adjusted
Variables	Treatment	Mean	s.d.	Mean	s.d.	Mean	s.d.	means
f (breaths/min)	Control	69	20.3	88	24.0	102	24.6	86
	DDSP	57	15.9	89	30.9	77	33.3	80
	LHS	66	20.6	87	22.7	95	22.3	80
HR (beats/min)	Control	168	10.6	206	8.9	226	11.7	200
	DDSP	166	11.4	201	15.7	214	12.1	194
	LHS	165	12.4	202	11.5	226	14.0	198
PaO_2 (mmHg)	Control	89	6.9	80	5.8	71	8.2	80
	DDSP	89	10.0	79	11.7	73	8.1	80
	LHS	90	7.1	78	12.7	71	7.4	80
$PaCO_2$ (mmHg)	Control	42	2.4	45	2.4	53	6.9	46
	DDSP	44	2.7	47	3.8	54	6.9	49
	LHS	44	2.4	48	4.5	74	6.8	48
Pui (mmHg)	Control	-11	1.7	-20	5.4	-31	6.8	-21
	DDSP	-11	2.3	-22	4.4	-33	6.5	-22
	LHS	-9	2.8	-20	3.7	-27	5.7	-20
Pue (mmHg)	Control	13	5.1	21	8.15	20	6.7	18
	DDSP	16	5.6	25	4.4	25	10.0	19
	LHS	11	2.6	21	5.5	25	8.6	21
PIF (l/sec)	Control	-30	7.8	-38	7.0	-46	8.2	$-38^{a,b}$
	DDSP	-25	6.7	-38	10.4	-40	16.0	-35^{b}
	LHS	-31	7.1	-43	6.3	-42	11.6	-40^{a}
PEF (l/sec)	Control	40	11.1	52	9.6	59	5.3	$50^{a,b}$
	DDSP	38	5.3	48	8.9	57	9.5	47^{b}
	LHS	43	8.1	56	6.2	61	3.4	53^{a}
Zi (mmHg/l/sec)	Control	0.39	0.10	0.55	0.14	0.67	0.16	0.54
	DDSP	0.45	0.11	0.63	0.18	0.81	0.23	0.63^{b}
	LHS	0.37	0.13	0.48	0.08	0.59	0.10	0.48^{a}
Ze (mmHg/l/sec)	Control	0.35	0.19	0.42	0.19	0.35	0.13	0.37^{a}
	DDSP	0.41	0.16	0.54	0.12	0.44	0.17	0.46^{b}
	LHS	0.27	0.06	0.37	0.11	0.42	0.15	0.35^{a}

†Expressed as percentage of HR_{max}. [a,b]Different superscript letters indicate corresponding adjusted means (= least squares) that are different ($P<0.05$) between groups. For definition of abbreviations, see Table 1.

measured. In addition, peak inspiratory flow (PIF), peak expiratory flow (PEF), tidal volume (V) and respiratory frequency (f) were recorded. From those variables, inspiratory and expiratory impedance (Zi, Ze) were calculated.

Statistical methods

In *Phase I* of the study, the variables ($PaCO_2$ and PaO_2, Pui, Pue, f, Zi and Ze) were evaluated at the various exercise intensities expressed as percentages of HR_{max} (75, 90 and 100%) to assess the effect of the LHS on ventilation in a normal horse (n = 10). The effect of LHS on these variables was evaluated using a 3-way analysis of variance (blocked on horse, testing exercise intensity [HR_{max}] and treatment, i.e. with or without LHS) followed by Tukey's multiple-comparison procedure. In *Phase II*, the same variables were also evaluated at the various exercise to assess the effect of the LHS on ventilation compared to the control horses and the horses with DDSP (n = 7). A McNemar's chi-square test was used to compare the proportions of horse with DDSP as determined by videoendoscopy (n = 7). Significance was set at $P \leq 0.05$, 2-sided.

Results

All horses wore the LHS for 14–20 mins during each test without any adverse reaction. No local reaction or irritation from the support mechanism was noted at the point of contact caudal to the basihyoid bone. The effect of the LHS device in normal horses exercising with and without the LHS device is summarised in Table 1.

Controlling for horses and exercise intensity, the respiratory and cardiac rates of horses exercising with and without LHS were similar. As expected, there was an exercise effect; a lower mean f was measured at 75% HR_{max} compared to 90% or 100% HR_{max}. By design, a lower adjusted mean HR was present in horses exercising at 75% compared to 90% and 100% HR_{max}. There was no effect from the LHS on arterial blood gases (controlling for horses and exercise intensity) (Table 1).

Controlling for horses and exercise intensity, the least-squares mean Pui, Pue, PIF, PEF, Zi and Ze were not significantly different whether the horse wore the LHS or not (Table 1; all $P \geq 0.20$). There were also the expected significant effects of exercise (all P = 0.0001) on all of these variables except Ze.

Following bilateral resection of the TH muscle, 7 of 10 horses (70%) experienced DDSP. These horses were retained in the study for *Phase II* (the last 2 conditions). All 7 horses experienced DDSP during exercise under videoendoscopic evaluation; 3 horses experienced DDSP only at 75% HR_{max}, one only at 90% HR_{max} and 3 horses at all 3 exercise intensities. When exercising with the LHS, none of the 7 horses displaced the palate during exercise. There was no effect of the LHS on arterial blood gases, heart rate, respiratory frequency and tracheal pressures in horses with DDSP exercising with and without the LHS (Table 2, all $P \geq 0.09$). There was a significant effect of the LHS on airflow; the least-squares mean PEF and PIF of the horses when wearing the device at exercise (PEF = 53 l/sec and PIF = -40 l/sec) was greater than in those exercising without the device (PEF = 48 l/sec and PIF = -35 l/sec) ($P \leq 0.03$). Similarly, expiratory and inspiratory impedance was improved in horses exercising with the LHS device (Ze = 0.35 and Zi = 0.48 mmHg/l/sec) compared to without (Ze = 0.46 and Zi =0.63 mmHg/l/sec) ($P \leq 0.005$). The use of the LHS device on the horses with DDSP restored all abnormal parameters to control levels so that no statistical difference was found (Table 2).

Discussion

Nonsurgical treatment 'successes' of horses with DDSP has been generally anecdotal. Parente *et al.* (2002) reported that 6 of 45 horses with DDSP (confirmed by treadmill exercise) responded to rest alone. The use of a tongue-tie is widely recommended to prevent DDSP, but there have been little scientific data supporting this practice. Cornelisse *et al.* (2001) failed to document (using computed tomography in horses under general anaesthesia placed under dorsal recumbency) a positive effect of the tongue-tie on the position of the hyoid apparatus or the diameter of the nasopharynx. More recently (also not in an ideal model), the tongue-tie did not affect airway mechanics in normal experimental horses exercising on the treadmill (Beard *et al.* 2001). Franklin *et al.* (2002) reported the first documented positive effect of a tongue-tie on the occurrence of DDSP in a clinical population where 6 horses were examined videoendoscopically on a high-speed treadmill while running with and without a tongue-tie. The tongue-tie prevented DDSP from occurring in 2 of these horses. Although this latter report failed to elucidate the mechanism for this effect, it does support its use as a management tool in horses with DDSP.

Barakzai and Dixon (2004) reported a study of 31 Thoroughbred racehorses with DDSP that were treated conservatively with rest, improved fitness and/or a tongue-tie. When comparing earnings of the 3 starts before diagnosis to the 3 starts after diagnosis and treatment, 61% had increased earnings, a figure that comparable to that seen after many surgical treatments (Harrison and Raker 1988; Anderson *et al*. 1995; Duncan 1997; Llewellyn and Petrowitz 1997; Parente *et al.* 2002).

Videoendoscopy confirmed that the external device used in this study resulted in rostral displacement of the larynx in sedated horses. This rostral displacement did not interfere with upper airway patency as assessed by measurement of arterial blood gases and airway impedance. The LHS prevented DDSP in this model, thereby improving airflow and reducing impedance. This is similar to the results observed in horses with a surgical rostral displacement of the larynx (Ducharme *et al.* 2003). Therefore, it appears that rostral positioning of the larynx enhances nasopharyngeal stability in horses susceptible to exercise-induced DDSP. However, the mechanism by which this position of the larynx confers stability of the soft palate during exercise (whether attained surgically or through an external device) remains unknown. It is still unclear whether prevention of caudal retraction of the larynx at exercise or the change in the airflow profile (reduced Bernoulli effect) of the nasopharynx is the reason for the stabilising effect on the soft palate.

Further investigation of the effect on the airflow profile in the upper airway at exercise is needed to better understand the pathophysiology of the equine larynx and nasopharynx at exercise and whether such an external device would be effective in a clinical population of horses affected with exercise-induced naturally occurring DDSP.

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[3]Polar Electro Europe BV, Fleurier, Switzerland.
[4]Professional's Choice Sports Medicine Products, Inc., Spring Valley, California, USA.
[5]Olympus Corporation, Medical Instruments Division, Lake Success, New York, USA.

[6]Sony Corp., Park Ridge, New Jersey, USA.
[7]Cole-Parmer, Chicago, Illinois, USA.
[8]Celesco Transducers Products Inc., Canoga Park, California, USA.
[9]Birmingham Research and Development Ltd., Birmingham, West Midlands, UK.
[10]KDG Flowmeters, Crawley, West Sussex, UK.
[11]National Instruments, Austin, Texas, USA.

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