



Contents lists available at ScienceDirect



Exercise-induced vocal cord dysfunction and exercise-induced laryngomalacia in children and adolescents: the same clinical syndrome?

Stephen A. Tilles, MD^{*,†}; Andrew G. Ayars, MD^{*,‡}; Joseph F. Picciano, PhD^{*}; and Kathryn Altman, BA^{*}

^{*} ASTHMA Inc Clinical Research Center, Seattle, Washington

[†] Northwest Asthma and Allergy Center, Seattle, Washington

[‡] Division of Allergy and Infectious Diseases, University of Washington School of Medicine, Seattle, Washington

ARTICLE INFO

Article history:

Received for publication May 28, 2013.

Received in revised form July 11, 2013.

Accepted for publication July 22, 2013.

ABSTRACT

Background: Exercise-induced respiratory symptoms associated with paradoxical laryngeal motion are relatively common and often mistaken for asthma. Exercise-induced vocal cord dysfunction (VCD) and exercise-induced laryngomalacia (LM) have been described separately in the literature but have never been systematically compared.

Objective: To compare subjects with a confirmed diagnosis of exercise-induced VCD or exercise-induced LM by performing a retrospective chart review of subjects who had symptoms provoked by a free running exercise challenge and documented concurrent paradoxical laryngeal motion.

Methods: Demographic and clinical characteristics were analyzed in patients with confirmed paradoxical motion of the vocal cords (VCD) and those with paradoxical arytenoid motion without abnormal vocal cord movement (LM) during symptoms.

Results: Sixty subjects with exercise-induced LM and 83 subjects with exercise-induced VCD were identified. Subjects with confirmed exercise-induced VCD were slightly older, had a higher body mass index, and higher grade point averages compared with subjects with exercise-induced LM without abnormal vocal cord movement. There were no differences in sex distribution, presenting symptoms, reported aggravating factors other than exercise, atopic status, confirmed bronchospasm during symptoms, mean number of asthma controller medications at time of evaluation, level of athletic competition, reported history of acid reflux, reported history of psychiatric disorders, baseline lung function, or lung function during symptoms. Most subjects were not “elite” athletes and did not have a history of anxiety or depression.

Conclusion: There were remarkably few differences between subjects with exercise-induced VCD and those with exercise-induced LM. Prospective controlled studies are needed to determine whether exercise-induced VCD and exercise-induced LM are in fact distinct syndromes.

© 2013 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

Introduction

Vocal cord dysfunction (VCD) is characterized by adduction of the vocal cords during inspiration that is associated with symptoms of shortness of breath, tightness in the throat or chest, cough, and/or stridor.^{1–4} Laryngomalacia (LM) refers to inspiratory prolapse of supraglottic structures. In exercise-induced LM, there are typically anterior and medial movements of the arytenoids and aryepiglottic folds during symptoms of dyspnea and/or stridor.^{5–8} Exercise-induced phenotypes of VCD and LM have been described and appear to be more common in athletic girls^{3,8–11} who were initially misdiagnosed with exercise-induced asthma and treated unsuccessfully with asthma medications. Exercise-induced VCD has been

reported in multiple case series, including many subjects who did not undergo laryngoscopy to confirm the diagnosis.^{3,10} There have been reported associations between exercise-induced VCD with psychiatric issues,^{3,9} high academic achievement,⁹ postnasal drip,¹² and acid reflux.¹¹ The 2007 National Heart, Lung, and Blood Institute's Expert Panel Report 3 has recommended considering VCD in elite athletes whose exercise-induced dyspnea is unresponsive to asthma treatment.¹³

The present study compared the characteristics of patients younger than 21 years with exercise-induced VCD vs exercise-induced LM. The authors hypothesized that exercise-induced VCD and exercise-induced LM are the same syndrome.

Methods

A retrospective chart review was performed of subjects with documented paradoxical laryngeal motion during symptoms elicited by a free running exercise challenge. All subjects were

Reprints: Stephen A. Tilles, MD, ASTHMA Inc Clinical Research Center, 9725 Third Avenue NE, Suite 500, Seattle, WA 98115; E-mail: stilles@nwasthma.com.

Disclosures: Authors have nothing to disclose.

Funding Sources: No financial support was provided for this work.

referred to the authors' private practice clinic for confirmation of suspected VCD. Their evaluations included a history and physical examination, spirometry, baseline laryngoscopy, free running exercise challenge, postexercise laryngoscopy during symptoms, and repeat spirometry immediately after and 10 minutes subsequent to postexercise laryngoscopy.

History

An extensive history was obtained from all subjects and included a brief psychiatric history. Criteria for defining anxiety or depression included persistent or intermittent symptoms that resulted in (1) a specific assessment by their physician (regardless of whether formal treatment was suggested); (2) clear interference with normal social/family activities or academic performance; or (3) a "yes" answer to this question: "Has anxiety (depression) been a problem for you?" All patients also were queried for prior "major psychological trauma," such as witnessing a gruesome accident, experiencing an unexpected death of a family member, or being a victim of emotional, physical, or sexual abuse at some previous time. Subjects were categorized based on the level of their athletic competition. "Elite" was defined as collegiate varsity, pre-Olympic, national team, or premier level. "Competitive" was defined as high school varsity, select club, or competitive master's level. "Recreational" included competition in a recreational club team or other regular exercise. "Nonathletic" was defined as not participating in regular exercise other than as part of their physical education class requirement (many school districts in Washington State require periodic exercise testing of all students, typically a "mile run" and/or a series of timed running sprints).

Spirometry

Spirometry was performed using KoKo spirometer (Grace Medical Marketing, Inc, Kennesaw, Georgia) before exercise, immediately after exercise, and approximately 15 minutes after the start of exercise. Exercise-induced bronchospasm was defined as a persistent, greater than 10% decrease in forced expiratory volume in 1 second (FEV₁) after exercise that subsequently reversed with an inhaled bronchodilator. Spirometry data collected at baseline and after exercise included FEV₁, forced vital capacity (FVC), FEV₁/FVC ratio, and the ratio of forced expiratory flow at 50% vital capacity (FEF50) to forced inspiratory flow at 50% vital capacity (FIF50).

Exercise Challenge Protocol

Exercise challenge involved free running outdoors on a hard surface approximately 40 m long with continuous heart rate monitoring. The protocol sequence was as follows: initial "warm-up" jog for 1.5 minutes, a 40-m run repeated 6 times at "3/4 speed" with an approximately 5-second rest between each sprint, and after approximately 1 minute of additional rest, subjects sprinted at least 1 set of "lines" involving progressive short intense sprints of increasing length. Each of these sets of "lines" lasted approximately 30 seconds. Heart rate monitoring was performed continuously. Goals during the challenge were to sustain greater than 80% of predicted maximum heart rate (220 – age) for at least 6 minutes and reproduce the nature and intensity of the reported symptoms. Subjects were queried on the nature and severity of symptoms after each stage of the challenge. The provocations were terminated when the nature and intensity of symptoms matched the subjects' primary presenting complaint, typically after 6 to 10 minutes. Symptoms were successfully reproduced approximately 85% of the time using this protocol. Only subjects whose symptoms were reproduced during the exercise provocation were included in this study. This protocol has not been scientifically validated for diagnosing asthma or VCD, although compared with treadmill exercise

protocols, the authors have found it to be a considerably more sensitive way of provoking exercise-induced VCD symptoms. The authors presume this is because their protocol enables their patients to achieve higher intensity exercise and is a close approximation to the demands of the patients' sports.

Laryngoscopy

After verbal consent was obtained, the right and left nasal passages were sprayed with 2 squirts of oxymetazoline nasal spray (Afrin, MSD Consumer Care, Inc, Whitehouse Station, New Jersey) and 2 squirts of 4% lidocaine spray. A baseline laryngoscopy was performed by passing a flexible fiberoptic laryngoscope (Olympus Type ENF, Olympus, Tokyo, Japan) through the nasal passage and observing the larynx during resting breathing, phonation, relaxed deep inhalation, and forced inhalation. During exercise-induced symptoms, the rhinolaryngoscope was reinserted through the nares without repeat anesthesia. Subjects were included in the study if they had confirmed paradoxical inspiratory motion of the vocal cords and/or arytenoids during symptoms provoked by exercise challenge. The cases were separated into a VCD group (those with confirmed paradoxical motion of the vocal cords with or without associated paradoxical arytenoid motion) and an LM group (those with paradoxical motion of the arytenoids only).

Statistical Analysis

Participant characteristics were summarized using means, standard deviations, and proportions. Independent *t* tests (continuous measurements) and χ^2 tests (categorical measurements) were used to determine between-group differences in demographic characteristics, symptoms at diagnosis, factors reported to contribute to symptoms, controller medications, associated history, laryngoscopy findings, and spirometry measurements. A *P* value of .05 was considered significant for all statistical comparisons. SPSS 16 (SPSS, Inc, Chicago, Illinois) was used to conduct all analyses.

Results

Patient Characteristics

One hundred forty-three subjects were included in the study, of whom 83 (58%) met the criteria for VCD and 60 (42%) were classified as having LM (Table 1). The 2 groups showed a female predominance (76.7% of LM group and 84.3% of VCD group) and there was no difference in sex mix (*P* = .25). Most subjects in the 2 groups were competitive athletes, and there was no difference

Table 1
Demographic characteristics for all subjects

	LM (n = 60)	VCD (n = 83)	<i>P</i> value ^a
Girls, %	76.7	84.3	.25
Age at diagnosis (y), mean (SD)	13.40 (2.61)	14.29 (2.27)	.03 ^b
Age at clinic evaluation (y), mean (SD)	13.90 (2.52)	14.76 (2.27)	.03 ^b
BMI (kg/m ²), mean (SD)	20.27 (2.85)	21.41 (3.24)	.04 ^b
Level of competition, %			.55
Nonathlete	5.0	3.6	
Recreational	25.0	36.1	
Competitive	63.3	55.4	
Elite	6.7	4.8	
Grade level, %			.08
Elementary	15.1	6.2	
Middle	37.7	28.8	
High school	41.5	60.5	
College/university	5.7	2.5	
GPA, mean (SD)	3.51 (0.54)	3.72 (0.39)	.03 ^b

Abbreviations: BMI, body mass index; GPA, grade point average; LM, laryngomalacia; SD, standard deviation; VCD, vocal cord dysfunction.

^a*t* tests for continuous measurements and χ^2 tests for proportions.

^bStatistically significant.

between groups with respect to their level of athletic competition. The VCD group was slightly older (14.76 years) and had a slightly higher average body mass index (BMI; 21.41 kg/m²) than the LM group (13.40 years and 20.27 kg/m²), and these differences were significant ($P = .03$ and $.04$, respectively; Fig 1A and 1B). Although the 2 groups were high academic achievers, the average grade point average (GPA) in the VCD group was significantly higher (VCD = 3.72 vs LM = 3.51, $P = .03$; Fig 1C). A subgroup analysis of high school age (grades 9–12) subjects showed no difference in mean BMI (VCD = 21.68 vs LM 21.89, $P = .76$), although the difference in GPA persisted (VCD = 3.73 vs LM = 3.46, $P = .04$).

Symptoms

There were no significant differences in the nature of presenting symptoms between the 2 groups (Table 2). The most common symptoms were dyspnea, symptoms on inhalation, chest tightness, and throat tightness. There also was no difference between groups with respect to cofactors reported to contribute to exercise-induced symptoms, including cold air, upper respiratory tract infections, irritants, postprandial exercise, or anxiety (Table 3).

Associated Conditions Including Asthma Diagnosis and Mean Number of Asthma Controller Medications

The vast majority of patients in the 2 groups had received treatment for asthma before their referral to the authors' clinic. The mean number of asthma controller medications per patient was similar between the 2 groups (1.42 for VCD group and 1.23 for LM group; eTable 1). After the clinical evaluation, in addition to confirmed VCD or LM, asthma was listed as a diagnosis if there was

Table 2

Symptoms at diagnosis

	VCD (n = 60)	LM (n = 83)	P value ^a
Dyspnea/shortness of breath, %	96.7	96.4	.93
Chest tightness/discomfort, %	68.3	73.2	.53
Choking, %	1.7	1.2	.82
Throat tightness/discomfort, %	73.3	80.7	.30
Cough, %	13.3	7.3	.24
Nocturnal awakening with respiratory symptoms, %	5.0	1.2	.18
Stridor, %	43.3	54.9	.17
Heartburn, %	25.0	22.9	.77
Upset stomach, %	3.3	9.8	.14
Voice change, %	6.7	17.7	.07
Symptoms on inhalation, %	95.0	86.4	.07
Symptoms on exhalation, %	35.0	36.1	.89

Abbreviations: LM, laryngomalacia; VCD, vocal cord dysfunction.

^a χ^2 tests.

objective evidence of exercise-induced bronchoconstriction during the evaluation ($>10\%$ decrease in FEV₁ during symptoms that persisted for ≥ 20 minutes past the start of the provocation) or if the combination of clinical history and prior testing suggested a clinical diagnosis of asthma (eg, a reported symptom complex that differed from the VCD or LM symptoms that reliably responds to asthma treatment). Using these criteria, there was no difference in the proportion of subjects with concurrent asthma in the LM and VCD groups (25% and 22.9%, respectively; Table 4). Other associated conditions at the time of evaluation were evaluated, and the VCD and LM groups had similar proportions of subjects with atopy and chronic sinusitis. Psychopathology was relatively uncommon in the 2 groups, and there was no difference between groups with respect to depression, anxiety, or major psychological trauma. There were proportionately more patients in the LM group with attention-deficit disorder (ADD) or attention-deficit/hyperactivity disorder (11.7%) compared with the VCD group (2.4%, $P = .02$).

Spirometry

A complete set of exercise provocation spirometry data (FEV₁, FVC, FEV₁/FVC, and FEF50/FIF50 at baseline, immediately after exercise, and 15 minutes after exercise) was obtained in approximately 70% of subjects. On average, the VCD and LM groups had normal baseline lung function that did not change significantly after exercise (eTable 2). The FEF50/FIF50 ratio was not a predictor of paradoxical laryngeal motion at baseline or during symptoms.

Discussion

To the authors' knowledge, this 143-patient case series is the first to systematically compare exercise-induced VCD with exercise-induced LM, and the present findings suggest that these disorders overlap significantly. There were no differences in many of the hallmark features of these disorders, including sex distribution,

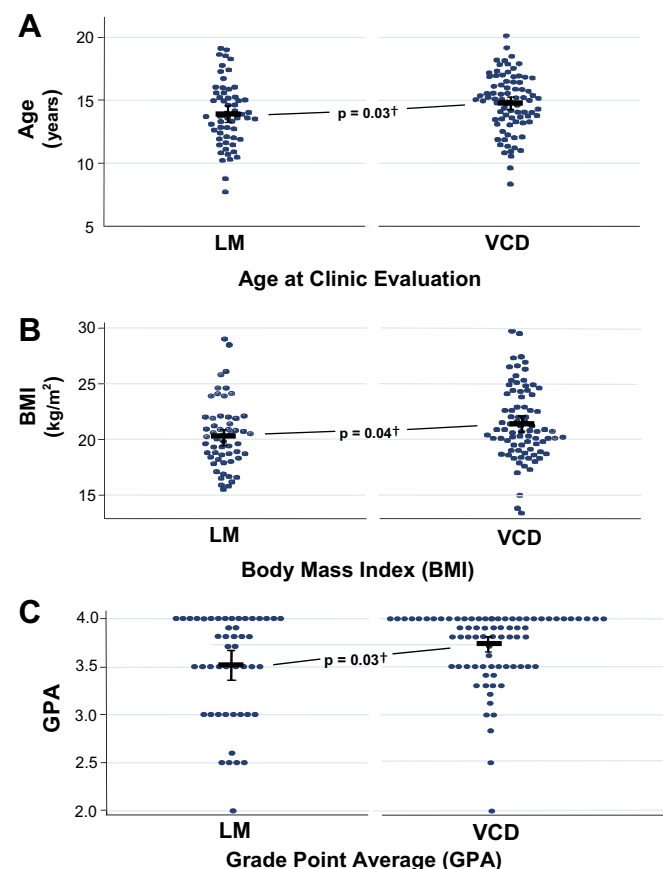


Figure 1. Dot plots of laryngomalacia (LM) and vocal cord dysfunction (VCD) group data displaying differences in age (A), body mass index (BMI) (B), and grade point average (GPA) (C). †Statistically significant.

Table 3

Factors reported to contribute to exercise-induced symptoms

	LM (n = 60)	VCD (n = 83)	P value ^a
Cold air, %	28.3	28.9	.94
URI, %	21.7	25.3	.61
Irritants, %	23.3	26.5	.67
Postprandial, %	5.0	1.2	.18
Anxiety, %	33.3	26.5	.38

Abbreviations: LM, laryngomalacia; URI, upper respiratory tract infection; VCD, vocal cord dysfunction.

^at test.

Table 4

Associated history

	LM (n = 60)	VCD (n = 83)	P value ^a
Clinical asthma (in addition to VCD), %	25.0	22.9	.77
Atopy, %	43.3	44.6	.88
Sinusitis, %	6.7	9.6	.53
Anxiety, %	18.3	18.1	.97
Depression, %	8.3	10.8	.62
ADHD/ADD, %	11.7	2.4	.02 ^b
Major psychological trauma, %	3.3	3.6	.93

Abbreviations: ADD, attention-deficit disorder; ADHD, attention-deficit/hyperactivity disorder; LM, laryngomalacia; VCD, vocal cord dysfunction.

^a χ^2 tests.

^bStatistically significant.

symptom description, level of athletic competition, aggravating factors other than exercise, atopic status, baseline or postexercise spirometry, or comorbid conditions such as anxiety, depression, acid reflux, or clinical asthma. The differences found included age at time of diagnosis, BMI, concurrent diagnosis of ADD, and GPA. The clinical relevance of these differences is not clear for several reasons. As shown in Figure 1, there was significant overlap between groups with respect to age, BMI, and GPA. In addition, when the analysis of BMI was repeated for only those subjects of high school age (grades 9–12), there was no longer a significant difference. Whether the BMI difference in the younger groups is clinically meaningful requires further study. There also was a larger percentage of subjects with exercise-induced LM who had a concurrent diagnosis of ADD or attention-deficit/hyperactivity disorder, although this represents only a small minority of subjects (11%) and thus is unlikely to explain why the paradoxical motion seen during symptoms involved only the arytenoids. When the analysis of GPA was repeated in just the high school age subjects, the higher average GPA in subjects with VCD persisted. As illustrated in Figure 1C, most subjects in the 2 groups were good students, and the proportion with “straight A’s” (4.0 GPA) was larger in the VCD group. Controlled studies are necessary to determine whether a higher GPA is an independent risk factor for developing VCD rather than LM.

The major strengths of this study include its large samples and the large quantity of data extracted from each subject’s medical record. This was facilitated by the fact that the authors’ clinic has consistently used the same free running exercise symptom provocation protocol for more than 10 years. In addition, by including only those subjects who had successfully provoked symptoms and documented paradoxical laryngeal motion, the authors avoided including subjects with exercise-induced hyperventilation or other syndromes that are likely different from VCD and LM.

The weaknesses of this study include its retrospective design and the lack of continuous visualization of the larynx during the exercise provocations. Therefore, important changes in the position of the larynx during the peak of symptoms may have been missed. This risk was minimized by including only subjects in whom postexercise laryngoscopy was performed while remaining symptomatic. The laryngoscope typically could be reinserted less than 1 minute after stopping exercise. However, the authors recognize the possibility that paradoxical vocal cord motion during the peak of symptoms may have been missed, resulting in the misclassification of some subjects.

The present results raise several interesting questions regarding exercise-induced paradoxical motion in pediatric patients. For example, might exercise-induced VCD and LM be different ends of an anatomic spectrum of the same clinical syndrome? If so, it may not be necessary or helpful to classify patients as having “VCD” or “LM.” Separate from the data presented in this article, the authors

have observed selected cases of subjects in whom mild symptoms were associated with paradoxical arytenoid motion; then, after resuming more intense exercise, there were more dramatic symptoms with stridor and corresponding paradoxical vocal cord motion (unpublished data). Other investigators have observed paradoxical motion of the arytenoids and vocal cords at different times in the same subject.^{14,15} These observations suggest the possibility that in many patients paradoxical arytenoid motion may be a prodrome to paradoxical vocal cord motion, and that this pattern may be more common than the occasionally described syndrome of stridor owing purely to dramatic paradoxical arytenoid motion. Indeed, the concept of combining VCD and “intermittent arytenoid region prolapse” into a common classification called “periodic occurrence of laryngeal obstruction” has been recently proposed.¹⁶ The authors agree that the term “periodic occurrence of laryngeal obstruction” is likely a more accurate way of describing this disorder, although they believe that, because the term “VCD” has been repeated in the respiratory literature for 3 decades, it is ingrained in several generations of specialists and primary physicians. Therefore, the authors favor keeping the term “VCD” and encouraging more education of physicians in the association between symptoms and other parts of the laryngeal anatomy.

The present data are at odds with common stereotypes of exercise-induced paradoxical laryngeal motion in adolescent athletes, and this raises other important questions regarding who is at risk for developing these disorders. As with most other reports of exercise-induced laryngeal obstruction in the literature, most of the present subjects were girls. However, most subjects in the present VCD and LM groups were “competitive” rather than “elite” athletes. This finding differs from a large exercise challenge study¹⁰ that reported a 5% prevalence of laryngeal obstruction with stridor in Olympic-level athletes. In fact, in the present study, the proportion of elite athletes in each group was about the same as the proportion of nonathletes (Table 1). The authors realize that a fair comparison of Olympic-level athletes with the present case series would require a different study design, although they believe their data provide an important general message: most patients with exercise-induced VCD or LM are not elite athletes and many are not even competitive athletes. Another provocative finding in the present study was that obvious psychopathology was not common in the VCD or LM group. This is in sharp contrast to an often-cited reference suggesting that exercise-induced VCD is a “psychogenic” problem that preferentially affects individuals who are “extremely vulnerable to internal and/or external pressure not to fail.”³ Although there have been other reports that have not highlighted psychopathology in patients with exercise-induced VCD, in the authors’ opinion there is still a stigma, without appropriate supporting data, that a diagnosis of VCD implies some sort of underlying psychopathology. A more rigorous approach to this question is clearly needed.

A condition called “the irritable larynx syndrome” was proposed in 1999 to explain observations of intermittent paradoxical laryngeal motion triggered by acid reflux, psychological problems, dystonia, or postnasal drip during upper respiratory infections,¹⁷ although there is little scientific evidence explaining a mechanism for this. To help explain the present findings, the authors propose the term “susceptible larynx syndrome” that would apply to adolescents and young adults who have a tendency to develop paradoxical arytenoid motion during intense exercise (Fig 2). The authors speculate that a combination of this susceptibility plus intense exercise is required for developing bothersome symptoms. Paradoxical motion during intense exercise may occur from an inability to withstand the high negative inspiratory laryngeal pressures and/or alterations in muscular tone (perhaps related to the extreme discomfort experienced during intense exercise).

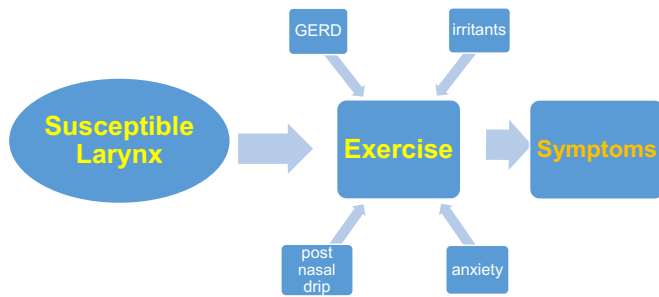


Figure 2. Cartoon illustrating a hypothesis that may explain the relation between intrinsic susceptibility and environmental influences that determine whether a young person develops vocal cord dysfunction or laryngomalacia during exercise. The authors call this “susceptible larynx syndrome.” GERD, gastroesophageal reflux disease.

Patients with severe anxiety might have increased risk because of alterations in laryngeal muscular tone. However, many others who are generally not pathologically motivated to succeed might be susceptible to paradoxical motion because, during the discomfort endured with sustained maximal exercise, they literally “forget how to breathe,” which results in laryngeal symptoms associated with inspiratory prolapse of the arytenoids and/or vocal cords. Elite athletes would be more likely to develop symptoms because of the high frequency and intensity of their exercise, but because there are relatively few elite athletes in the population, the overall numbers of symptomatic elite athletes would account for only a small fraction of symptomatic patients. Conversely, there may be much larger number of symptomatic “competitive” young athletes, not because of their increased risk compared with elite athletes, but rather by virtue of their very large numbers. Factors such as anxiety or acid reflux may potentiate their exercise-induced symptoms but would not be required cofactors. “Nonathletic” subjects are less likely to engage in regular intense exercise, but when required to do so (as in the Washington State public school system), a subset of this group also would be expected to develop symptoms.

In summary, 60 subjects with exercise-induced LM were compared with 83 subjects with exercise-induced VCD and no differences in symptoms, sex mix, level of athletic competition, or symptom triggers were found. Although small differences in age, BMI, and prior diagnosis of ADD or attention-deficit/hyperactivity disorder were identified and these deserve further study, none of these differences showed obvious clinical relevance. Because most subjects were not elite athletes, did not have 4.0 GPAs, and did not have histories of anxiety or depression, clinicians who consider only VCD or LM in patients who fit these stereotypes may be missing most cases. The authors propose a hypothesis called

“susceptible larynx syndrome” to explain the lack of a single at-risk stereotype for these disorders. They further propose that clinicians consider paradoxical laryngeal motion a potential masquerader of exercise-induced asthma in all adolescent patients who do not respond adequately to asthma therapy. Well-designed, prospective, controlled studies are needed to clarify the pathophysiology of this disorder.

Supplementary Data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.anai.2013.07.025>.

References

- [1] Newman KB, Mason UG III, Schmalzing KB. Clinical features of vocal cord dysfunction. *Am J Respir Crit Care Med*. 1995;152:1382–1386.
- [2] Wood RP, Milgrom H. Vocal cord dysfunction. *J Allergy Clin Immunol*. 1996;98:481–485.
- [3] McFadden ER Jr, Zawadzki DK. Vocal cord dysfunction masquerading as exercise-induced asthma. A physiologic cause for “choking” during athletic activities. *Am J Respir Crit Care Med*. 1996;153:942–947.
- [4] Morris MJ, Christopher KL. Diagnostic criteria for the classification of vocal cord dysfunction. *Chest*. 2010;138:1213–1223.
- [5] Bittleman DB, Smith RJ, Weiler JM. Abnormal movement of the arytenoid region during exercise presenting as exercise-induced asthma in an adolescent athlete. *Chest*. 1994;106:615–616.
- [6] Chemery L, Clech G, Delaval P, Carre F, Gogibu J, Dassonville J. Exercise-induced laryngomalacia. *Rev Mal Respir*. 2002;19:641–643.
- [7] Smith RJ, Bauman NM, Bent JP, Kramer M, Smits WL, Ahrens RC. Exercise-induced laryngomalacia. *Ann Otol Rhinol Laryngol*. 1995;104:537–541.
- [8] Fahey JT, Bryant NJ, Karas D, Goldberg B, Destefano R, Gracco LC. Exercise-induced stridor due to abnormal movement of the arytenoid area: video-endoscopic diagnosis and characterization of the “at risk” group. *Pediatr Pulmonol*. 2005;39:51–55.
- [9] Landwehr L, Wood RP, Blager FB, Milgrom H. Vocal cord dysfunction mimicking exercise-induced bronchospasm in adolescents. *Pediatrics*. 1996;98:971–974.
- [10] Rundell KW, Spiering BA. Inspiratory stridor in elite athletes. *Chest*. 2003;123:468.
- [11] Powell DM, Karanfilov BI, Beechler KB, Treole K, Trudeau MD, Forrest LA. Paradoxical vocal cord dysfunction in juveniles. *Arch Otolaryngol Head Neck Surg*. 2000;126:29.
- [12] Brugman SM. The many faces of vocal cord dysfunction: what 36 years of literature tell us. *Am J Respir Crit Care Med*. 2003;167(Suppl):A588.
- [13] National Heart, Lung, and Blood Institute. *National Asthma Education and Prevention Program. Expert Panel Report 3: Guidelines for the Diagnosis and Management of Asthma. Full Report 2007*. Publication 97–4051. Bethesda, MD: National Institutes of Health/National Heart, Lung and Blood Institute; 2007.
- [14] Lim K, Li JT. Exertional dyspnea and inspiratory stridor of 2 years duration: a tale of 2 wheezes. *J Allergy Clin Immunol*. 2011;128:1135–1136.e1–10.
- [15] Heimdal JH, Roksund OD, Halvorsen T, Skadberg BT, Olofsson J. Continuous laryngoscopy exercise test: a method for visualizing laryngeal dysfunction during exercise. *Laryngoscope*. 2006;116:52–57.
- [16] Christopher KL, Morris MJ. Vocal cord dysfunction, paradoxical vocal fold motion or laryngomalacia? Our understanding requires an interdisciplinary approach. *Otolaryngol Clin North Am*. 2010;43:43–66.
- [17] Morrison M, Rammage L, Emami AJ. The irritable larynx syndrome. *J Voice*. 1999;13:447–455.

eTable 1

Treatment of shortness of breath at time of diagnosis

	LM (n = 60)	VCD (n = 83)	P value ^a
Controller medications (n), mean (SD)	1.23 (1.29)	1.42 (1.27)	.39
ICS dose, %			.54
Moderate/high	26.7	27.7	
Low	21.7	28.9	
None	51.7	43.4	
Albuterol alone, %	41.7	30.1	.15

Abbreviations: ICD, inhaled corticosteroids; LM, laryngomalacia; SD, standard deviation; VCD, vocal cord dysfunction.

^at tests for continuous measurements and χ^2 tests for proportions.

eTable 2

Spirometry

Spirometry	LM (n = 60)	VCD (n = 85)	P value ^a
FEV ₁ , mean (SD)			
Baseline	96.6 (12.2)	97.6 (12.5)	.64
Postexercise time 10 min	92.4 (11.9)	93.8 (13.2)	.55
Postexercise time 20 min	94.9 (13.1)	96.1 (13.0)	.59
FEV ₁ /FVC, mean (SD)			
Baseline	86.8 (6.55)	87.9 (7.18)	.37
Postexercise time 10 min	87.5 (7.59)	88.7 (7.91)	.42
Postexercise time 20 min	87.8 (7.24)	88.3 (7.34)	.72
FEF50/FIF50, mean (SD)			
Baseline	1.32 (0.91)	1.37 (0.55)	.70
Postexercise time 10 min	1.30 (0.61)	1.42 (0.79)	.39

Abbreviations: FEF50, forced expiratory flow at 50% vital capacity; FEV₁, forced expiratory volume in 1 second (percentage predicted); FIF50, forced inspiratory flow at 50% vital capacity; FVC, force vital capacity (percentage predicted); LM, laryngomalacia; SD, standard deviation; VCD, vocal cord dysfunction.

^at tests for continuous measurements and χ^2 tests for proportions.