A Comparison of Two Challenge Tests for Identifying Exercise-Induced Bronchospasm in Figure Skaters*

Edward T. Mannix, PhD; Felice Manfredi, MD; and Mark O. Farber, MD

Objectives: Studies documenting the increased incidence of exercise-induced bronchospasm (EIB) in figure skaters have employed a method that incorporates on-ice exercise with rink-side spirometry. The literature suggests that bronchial provocation challenge testing is better than exercise testing for identifying EIB. To test this hypothesis in figure skaters, a unique athletic population that trains and competes in cold air, we compared these two methods in the same individuals.

Patients/methods: Two challenge tests were performed on a group of competitive figure skaters (n = 29, 26 female subjects; mean ± SD age = 12.3 ± 3.5 years): (1) rink-side (temperature = 14°C, humidity = 60%) spirometry before and 1, 5, 10, and 15 min after 5 min of intense skating; and (2) eucapnic voluntary hyperventilation (EVH), breathing 5% CO₂, 21% O₂, balance N₂ at a rate of 60% of maximum voluntary ventilation (not to exceed 70 L/min) for 5 min (temperature = 18°C, humidity = 50%), with an identical pretest and posttest spirometry schedule. EIB was defined as at least one of the following: a ≥1 0% decline in Fev₁; a ≥ 20% decline in maximum midexpiratory flow rate; or a ≥ 25% decline in peak expiratory flow rate.

Results: Sixteen of 29 skaters (55%) developed EIB: 9 were positive by on-ice testing; 12 were positive by EVH testing; 5 were positive on both tests; on-ice testing missed 7 skaters with EIB; EVH testing missed 4 with EIB.

Conclusion: In the group of figure skaters studied, EVH challenge testing was better at identifying EIB than on-ice exercise testing. However, these data suggest that evaluation for EIB in athletes who train and compete in the cold should include exercise testing in cold air along with a challenge test such as EVH to increase the yield of positive responders.

(CHEST 1999; 115:649–653)

Key words: bronchial provocation challenge; exercise-induced asthma; sport science

Abbreviations: EIB = exercise-induced bronchospasm; EVH = eucapnic voluntary hyperventilation; MMEF = maximum midexpiratory flow rate; PEFR = peak expiratory flow rate; PFT = pulmonary function test

The incidence of asthma in the general population is 4 to 7%¹ and 80% of these have exercise-induced bronchospasm (EIB).² EIB in athletes appears to be more common, as the US Olympic Committee reported that 11% of Americans who competed in the 1984 Summer Games had EIB.² EIB is defined as a decrease in lung function following vigorous exercise. Bronchospasm usually occurs 1 to 15 min following exercise intense enough to elicit 85% or more of maximal O₂ consumption for 4 to 10 min.²³

The mechanism responsible for EIB appears to be evaporative water loss from the airway mucosa leading to airway hyperosmolality, which triggers bronchospasm in susceptible individuals. Airway cooling has also been shown to be a causative factor.⁵ Figure skaters may be at increased risk of EIB because they are subjected to intense exercise in cold air during all of their training sessions and competitions. Our laboratory recently reported that 43 of 124 (35%) figure skaters tested before and after on-ice exercise experienced EIB.⁶ This finding was corroborated by another investigative group who found that 30 of 100 (30%) figure skaters tested experienced EIB following on-ice exercise.⁷

*From the Division of Pulmonary, Critical Care and Occupational Medicine (Drs. Mannix, Manfredi, and Farber), Indiana University Department of Medicine, Indianapolis, IN; and The National Institute for Fitness and Sport (Dr. Mannix), Indianapolis, IN.

Manuscript received April 28, 1998; revision accepted September 3, 1999.

For editorial comment see page 608
Although rink-side pulmonary function testing before and after on-ice exercise may be a valid method for determining the presence of EIB in figure skaters, several factors may disallow its widespread usage, eg, standardization of work intensity during the on-ice exercise bout and rink availability for the performance of the testing sessions. In addition, other bronchial provocation techniques have been shown to be better at eliciting EIB than exercise itself. One solution to these potential problems may be a bronchial provocation challenge that would mimic the hyperventilation of exercise, eg, eucapnic voluntary hyperventilation (EVH) of compressed dry gas. Although this technique has been compared favorably with chemical bronchoprovocation for demonstrating the presence of EIB, to our knowledge, it has never been compared with an on-ice exercise challenge in figure skaters.

We hypothesized that EVH with prespirometry and postspirometry would be better able to detect the presence of EIB than on-ice exercise with rinkside spirometry in a group of competitive figure skaters.

**Materials and Methods**

**Subjects**

Twenty-nine figure skaters (26 female) who were participants in a figure skating training camp and who ranged in age from 8 to 25 years (mean ± SD age = 12.3 ± 3.5 years) volunteered for this study that was conducted at the Indiana/World Skating Academy in Indianapolis, IN. Written informed consent was obtained from all subjects prior to testing. The competition level of the skaters ranged from prejuvenile to senior and included one coach. Three of the skaters had been diagnosed previously with asthma, but methods and criteria for diagnosis were not known; these skaters agreed to refrain from the use of their inhaled medications for at least 18 h prior to each challenge test. All three known asthmatics were receiving a course of albuterol therapy, a medication for at least 18 h prior to each challenge test. All three were released to exercise before and after EVH. No subject was taking inhaled steroids.

**Protocol**

Each skater performed two procedures, with 24 h separating each test. Because of scheduling constraints and ice availability, all EVH testing was done on the first day of the training camp and all on-ice challenges were performed the following day. Data acquisition occurred between 8 and 10AM each day, before the performance of any vigorous exercise. Prior to the initiation of formal testing, each of the subjects participated in practice lung function testing so as to avoid a potential learning effect. It is possible that a mild, persistent refractoriness from EVH testing may have affected the pulmonary function test (PFT) results during the on-ice testing performed the following day. EVH testing was performed in a locker room (temperature = 18°C, relative humidity = 50%) immediately adjacent to the ice rink. EVH provokes EIB in susceptible individuals through hyperventilation without the use of exercise. Prior to EVH, baseline PFTs were performed on a computerized spirometer (model ST-250; Spiro Analyser, Futuremed America; Chatsworth, CA). Each skater performed three forced expiratory maneuvers, with the best of the three recorded for analysis. The skaters then breathed a mixture of dry compressed gas (5.0% CO2, 21.0% O2, balance N2) at a rate of 60% of their maximum voluntary ventilation per minute (calculated as FEV1 × 40) or a volume not greater than 70 L/min for 5 min. Gas was channeled from a cylinder into a calibrated rotometer and then through an inspiratory target balloon (3 L anesthesia bag) that was maintained half full (to ensure correct minute ventilation) and then to a two-way, low-resistance valve (model 2400; Hans Rudolph; Kansas City, MO) and mouthpiece. Spirometry was again performed at 1, 5, 10, and 15 min post-EVH, so that each skater produced three forced expirations at each time point, with the best of the three recorded for analysis. The second procedure was conducted at rink-side (temperature = 14°C, relative humidity = 60%) and consisted of each athlete performing a 3-min skating warm-up that was immediately followed by a vigorous 5-min on-ice skating routine. Spirometry was performed before exercise and at 1, 5, 10, and 15 min following exercise in a manner identical to that described above.

**Data Analysis**

The same criteria used to define the presence of EIB were used for both provocation tests. EIB was defined as either a 10% decrease in FEV1 from baseline, or a 20% decrease in maximum midexpiratory flow rate (MMEF, equivalent to forced midexpiratory flow rate) from baseline, or a 25% decrease in peak expiratory flow rate (PEFR) from baseline. Based on changes in lung function following the two challenge tests, two subgroups of subjects were formed: those who tested positive for EIB and those who tested negative for EIB. Demographic and lung function data of the two subgroups appear in Table 1. Unpaired t tests were used to determine if differences in demographic and baseline prechallenge spirometric data were present, with the level of significance set at p ≤ 0.05.

**Table 1—Demographic and Lung Function Data**

<table>
<thead>
<tr>
<th></th>
<th>Positive for EIB (n = 16)</th>
<th>% Predicted</th>
<th>Negative for EIB (n = 13)</th>
<th>% Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>12.1 ± 1.0</td>
<td>—</td>
<td>12.5 ± 0.8</td>
<td>—</td>
</tr>
<tr>
<td>Ht, m</td>
<td>1.43 ± 0.05</td>
<td>—</td>
<td>1.47 ± 0.05</td>
<td>—</td>
</tr>
<tr>
<td>Wt, kg</td>
<td>38.6 ± 2.3</td>
<td>—</td>
<td>48.3 ± 3.5</td>
<td>—</td>
</tr>
<tr>
<td>FVC, L</td>
<td>2.65 ± 0.18</td>
<td>105 ± 7</td>
<td>3.17 ± 0.26</td>
<td>114 ± 6</td>
</tr>
<tr>
<td>FEV1, L</td>
<td>2.35 ± 0.16</td>
<td>104 ± 7</td>
<td>2.61 ± 0.22</td>
<td>114 ± 5</td>
</tr>
<tr>
<td>FEV1/FVC, %</td>
<td>88.8 ± 1.8</td>
<td>99 ± 2</td>
<td>89.5 ± 1.4</td>
<td>99 ± 2</td>
</tr>
<tr>
<td>MMEF, L/s</td>
<td>2.82 ± 0.27</td>
<td>92 ± 7</td>
<td>3.44 ± 0.28</td>
<td>99 ± 5</td>
</tr>
<tr>
<td>PEFR, L/s</td>
<td>5.09 ± 0.25</td>
<td>101 ± 4</td>
<td>5.26 ± 0.41</td>
<td>101 ± 5</td>
</tr>
</tbody>
</table>

*Data presented as mean ± SEM.
RESULTS

When results from both challenge testing procedures were considered, a total of 16 of 29 skaters (55%) experienced EIB; 9 of 29 skaters (31%) were positive by on-ice testing; 12 of 29 (41%) were positive by EVH testing; 5 individuals were positive for EIB on both tests. Of primary import, on-ice testing missed seven skaters with EIB and the EVH test missed four skaters with EIB. Of the three skaters previously diagnosed as having asthma, two tested positive for EIB and the third failed to meet the criteria for EIB. Of the two known asthmatics who tested positive for EIB, one was positive on both tests and one was positive following on-ice exercise only.

Table 1 contains demographic and lung function data of those who tested positive for EIB (n = 16, 14 female subjects) and those testing negative for EIB (n = 13, 12 female subjects). Statistical analysis indicates that the two groups were demographically equivalent and that baseline, prechallenge lung function was not different across groups.

On-Ice Exercise Testing For the nine skaters testing positive for EIB following on-ice exercise, eight of nine had significant reductions in FEV₁ (range of decline = 10 to 29%, mean ± SD decline = 16 ± 7%), six of nine had significant reductions in MMEF (range of decline = 20 to 41%, mean = 27 ± 8%), and four of nine had significant reductions in PEFR (range of decline = 35 to 44%, mean = 39 ± 4%). The time points of greatest decline from baseline for each criterion measure for those testing positive for EIB following on-ice exercise were as follows: for FEV₁, 1 min (in three of eight who were positive by FEV₁) and 10 min postexercise (in three of eight who were positive by FEV₁); for MMEF, 15 min postexercise (in four of six who were positive by MMEF); for PEFR, 15 min postexercise (in three of four who were positive by PEFR).

EVH Testing For the 12 skaters testing positive for EIB following EVH, 8 of 12 had significant reductions in FEV₁ (range of decline = 10 to 18%, mean = 13 ± 3%), 8 of 12 had significant reductions in MMEF (range of decline = 20 to 28%, mean = 24 ± 3%), and 1 of 12 had a significant reduction in PEFR (25%). The point of greatest decline from baseline for each of the criterion measures for those testing positive following EVH was as follows: for FEV₁, 5 min post-EVH (in six of eight who tested positive by FEV₁); for MMEF, 5 min post-EVH (in three of eight who tested positive by MMEF); for PEFR, 5 min post-EVH (in one of one who tested positive by PEFR).

Figure 1 describes the pattern of change that occurred in each variable during on-ice and EVH testing for those skaters who tested positive for EIB by either method (n = 16). In panel A, the positive responders exhibited an immediate and progressive decline in FEV₁ from baseline following the on-ice exercise bout, which was sustained for the 15 min testing period. Following the EVH maneuver, the positive responders experienced a sharp decline in FEV₁ by 1 min post-EVH, with attainment of the nadir by 5 min post-EVH; a rebound in lung function was observed thereafter, but as a group the skaters were still displaying evidence of EIB at 15 min post-EVH. In panel B, MMEF data from on-ice and EVH testing for those testing positive for EIB by either method are presented. Following on-ice testing, an initial increase in midflows was followed by a sustained decrease in this variable for the remainder of the testing period. In sharp contrast,
the response to EVH was immediate, sustained, and more pronounced than that observed during on-ice testing for this variable. In panel C, positive responders followed a progressive downward trend in peak flows following on-ice testing, with no indication of spontaneous resolution evidenced by the 15-min mark. The immediate decline in peak flows following EVH testing was more pronounced than that following on-ice testing and it reached a plateau by the 5-min post-EVH mark that was maintained through the remainder of the testing period.

**DISCUSSION**

The most important finding of this investigation is that, in the group of competitive figure skaters studied, the EVH test was better able to identify the presence of EIB than rink-side spirometry performed before and after vigorous skating. Of further note, EVH testing was not perfect, as it failed to identify four skaters who responded positively for EIB by the on-ice exercise test.

The reason why each test failed to uncover all of those with EIB is unclear. The fact that these athletes have been training and performing for years in cold temperatures certainly may be a contributing factor. Perhaps the repetitive bouts of strenuous exercise and the accompanying hyperventilation of cold air³ have created a hypersensitive airway that is physiologically unique, so that EVH testing in near room air temperatures was not enough of a stimulus to elicit an EIB response. If this rationale is sound, it still fails to explain why the on-ice exercise test, which was conducted in cold conditions, was unable to uncover all of those with EIB.

The incidence of EIB in the present investigation demonstrated by on-ice exercise and rink-side spirometry (31%, 9 of 29 skaters) is similar to that observed by Provost-Craig and co-workers,⁷ who reported a 30% incidence of EIB in 100 figure skaters, and by our investigative team,⁶ which earlier reported a 35% incidence in 124 skaters. The incidence obtained using both methods in the present study is increased (55%, 16 of 29) when compared with these reports, but it is similar to the incidence of bronchial hyperresponsiveness noted by Weiler et al.,¹ who performed methacholine challenge testing on collegiate football players (a 50% incidence rate, 76 of 151 players tested).²

Data describing changes in airflow characteristics for skaters testing positive for EIB by either provocation (Fig 1) indicate several interesting responses. For each of the variables displayed in Figure 1, EVH produced sharper and more immediate declines than on-ice exercise. One will note that none of the decreases from baseline reported in this figure meet the criteria for EIA (ie, 10%, 20%, and 25% decline in FEV₁, MMEF, and PEFR, respectively). This is because individual skaters reacted differently from each other, so that the significant decreases experienced by each skater occurred at various time points, creating mean responses that are not necessarily significant.

Methacholine challenge testing and EVH have been shown to be equally sensitive in diagnosing EIB,⁸ and both have been noted as being more sensitive than strenuous exercise.⁸ Clearly, methacholine testing in figure skaters needs to be compared with both EVH and on-ice spirometry to determine if a single method can uncover all cases of EIB. Toward this end, we report data from our laboratory gathered from 18 figure skaters who were tested by methacholine challenge and, on a separate day, tested using on-ice exercise with prespirometry and postspirometry (unpublished observations). Results indicate that three skaters had positive methacholine responses (> 20% decline in FEV₁ at 2 mg/mL). Of these three skaters, only one had a positive response to exercise (> 10% decline in FEV₁). However, two skaters who were positive for EIB following exercise were negative for EIB using methacholine (up to 25 mg/mL); i.e., each test missed two positive responders, a situation very similar to that of the present investigation.

The high incidence of EIB in figure skaters is quite troublesome and may help explain why, as a group, figure skaters have been shown to possess only average aerobic capacity when compared with age- and gender-matched, untrained control subjects.¹²,¹³ It has long been appreciated that asthmatics have reduced aerobic capacity¹⁴ and it has recently been reported that asthmatics also have reduced anaerobic capacity.¹⁵ Perhaps the fact that so many figure skaters suffer from asthma has caused the group mean to be depressed in the few studies that have attempted to determine fitness levels of this athletic population.

It is important to note that to diagnose clinically important EIB, it is necessary to document accompanying signs and symptoms and/or a response to usual therapy. Relating this belief to the present study, we would suggest that subjects testing positive for EIB by either EVH or on-ice testing should undergo a trial of bronchodilator therapy. For those subjects who experienced a positive response to either the EVH challenge or the on-ice exercise without obvious associated symptoms, it would be important to document the absence of a PFT decrement with treatment, as well as a significant improvement in training/exercise capacity.

Based on the findings of the present investigation, we conclude that the EVH technique is better than
on-ice exercise for identifying EIB in competitive figure skaters. In addition, our data suggest that testing for EIB in athletes who train and compete in cold ambient conditions should include exercise testing in cold air plus a bronchial provocation test such as EVH or a methacholine challenge.

ACKNOWLEDGMENTS: The authors express their sincere gratitude for the expert technical assistance provided by Michael A. Bennett, Deitrick L. Gorman, MS, Nicole Thomas, MS, and Carolyn Magnes, MS. We also acknowledge the administration, coaches, and staff of the Indiana/World Skating Academy in Indianapolis, IN, for their support and assistance in the project.

REFERENCES