Original articles

Severity of exercise-induced bronchoconstriction during compressed-air breathing via scuba

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Key words
Diving, asthma, exercise, scuba, pulmonary function, research

Abstract

(Gotshall RW, Fedorczak LJ, Rasmussen JJ. Severity of exercise-induced bronchoconstriction during compressed-air breathing via scuba. *SPUMS J*. 2004; 34: 178-82.)
Introduction: Cool, dry air is a potent stimulus for bronchoconstriction in those individuals susceptible. Thus, diving with compressed air potentially increases the risk of airway narrowing in those with exercise-induced bronchoconstriction (EIB). However, this has not been investigated.
Objective: The purpose of this study was to determine the influence of breathing compressed air via self-contained underwater breathing apparatus (scuba) regulators while exercising on the severity of EIB.
Methods: Ten non-asthmatic controls and ten subjects with diagnosed EIB volunteered. Pre- and post-exercise pulmonary function was measured by spirometry. Subjects performed a treadmill run for five minutes at approximately 80% of their age-predicted maximal heart rate. On one occasion they breathed ambient air and on another they breathed compressed air via scuba regulators. Oral breathing was forced via the use of a nose clip. Forced expiratory volume in one second (FEV_1) was used to determine changes in pulmonary airway function.
Results: Both groups had normal pulmonary function prior to the exercise. Control subjects had no change in pulmonary function after exercise on either occasion. The EIB subjects demonstrated post-exercise reductions in FEV_1 of -15.1 ± 5.3% (mean ± SD) at 1 min, -15.1 ± 1.7% at 5 min, and -13.9 ± 1.4% at 15 min post exercise during ambient-air breathing. With compressed-air breathing the reductions in FEV_1 further increased to -27.0 ± 6.0% (P = 0.0002) at 1 min, -24.1 ± 2.4% (P = 0.0001) at 5 min, and to -20.5 ± 1.3% (P = 0.0001) at 15 min.
Conclusions: This study demonstrated that compressed-air breathing via scuba regulators increased the severity of EIB in EIB subjects. The results have implications for those individuals with EIB wishing to dive.

Introduction

Exercise-induced bronchoconstriction (EIB), or exercise-induced asthma (EIA), refers to airways narrowing associated with vigorous exercise. Up to 90% of those with chronic asthma and 10 to 50% of athletes demonstrate significant airways narrowing, EIB, triggered by six to eight minutes of strenuous exercise.[1,2] Post-exercise reductions of the forced expiratory volume in one second (FEV_1) vary depending on the severity of the EIB.[3] While the mechanism by which exercise triggers airways narrowing is debatable, all agree that breathing cold, dry air while exercising results in the most severe EIB.[4,5] Anderson et al recently published a diagnostic exercise protocol that uses cycling exercise while breathing cool, dry air from a compressed-air tank in order to optimally provoke the airways.[3]

Certain activities, including scuba diving, force the individual to breathe cold, dry air. Scuba (self-contained underwater breathing apparatus) diving requires breathing from a tank of compressed gas, thus producing inspired air characterised as cold and dry. For compressed-air diving, a standard air tank contains approximately 21% oxygen and 79% nitrogen. In the United States, most scuba tanks have pressures of 3000 psi, some up to 6000 psi. A first-stage regulator attached to the tank valve reduces the delivered pressure to approximately 150 psi. This pressure is delivered to the demand regulator incorporated into the scuba mouthpiece, delivering inspired gas at ambient pressure. The reduction in pressure at the first-stage regulator causes the gas to greatly expand (adiabatic expansion) which, in turn, reduces the temperature of the inspired gas as the gas flows through the valves: the Joule-Thompson effect. The higher the tank pressure is, the greater the pressure drop, and the larger the reduction in temperature of the delivered air. Temperature falls of 10° Celsius are common. In addition to being cool, the air delivered is very dry: approximately 0.1% relative humidity.[6]

Despite the fact that scuba divers breathe cold, dry air, there has been no investigation of the potential increase in severity of EIB in those breathing via scuba regulators and tanks. Because of the perceived increase in risk for diving in individuals with asthma and/or EIB, diving is generally contraindicated in those with these conditions.[7–10] Thus, the purpose of this study was to evaluate the potential effect of compressed-air breathing via scuba on the severity of EIB. We hypothesised that those with EIB would demonstrate greater reductions in post-exercise pulmonary function while breathing compressed air via scuba than when breathing room air. In order to separate the single effect of breathing compressed air from the potential influence of other components of diving such as hyperbaria and/or hyperoxia on pulmonary function, all testing took place on land in the laboratory, as opposed to while diving.

Methods

This study was approved by the Colorado State University Human Research Committee. Each research subject completed a health and physical activity history questionnaire and signed an informed consent prior to participation. Twenty subjects volunteered for this study. Subjects were recruited by the investigators on the campus and in the surrounding community through posted announcements and word of mouth. Ten subjects were non-asthmatic (control group). Ten subjects had been diagnosed by their personal physician as having EIB at least one year prior to the study (EIB group). All EIB subjects were confirmed positive with EIB by a treadmill exercise test and demonstrated a minimum of a 10% decrease in FEV_1 post exercise. Control subjects were confirmed negative for EIB by the same exercise protocol and criteria. All subjects were non-smokers and recreationally active, exercising most days of the week for at least 30 minutes a day. EIB subjects were not on steroid medications, but used a physician-prescribed inhaler with a short-acting beta-2 adrenergic agonist, typically used prior to their normal exercise bout.

PROTOCOL

Resting pulmonary function was determined before exercise and again at 1, 5 and 15 min post exercise. Treadmill running was used as the exercise stimulus. Subjects completed two different treadmill tests, three to five days apart. Subjects were alternately assigned to the normal (ambient air) breathing or scuba breathing (compressed air) first, and then they switched for the second test day.

Exercise was performed on a treadmill for eight minutes.[11] Subjects chose a comfortable running speed that was maintained throughout. The treadmill grade was increased as required during the first three minutes of the exercise to increase subjects' heart rate to 85–90% of their age-predicted maximum.[11] The subjects then ran at this intensity for the remaining five minutes. For the normal-breathing test day, subjects wore a nose clip to force mouth breathing and inspired room air. Ambient conditions were 22.2° C and 50% relative humidity. For the scuba-breathing day, subjects wore a nose clip and breathed from a tank of compressed air (3000 psi) through a first-stage regulator (150 psi) via a demand second-stage regulator at the mouth (SCUBAPRO™ MK2 Plus first stage, SCUBAPRO™ R190 second stage; El Cajon, CA). Air delivered at the mouth by the scuba regulator averaged 18.1° C and 0% relative humidity. Heart rate was determined with a Polar™ heart-rate monitor, and oxygen saturation was monitored for safety with a pulse-oximeter on the ear (Ohmeda, Louisville, CO). All testing occurred on the campus of Colorado State University during the months of September and October. The testing site is at an altitude of 1,519 metres (4,984 feet).

MEASUREMENTS

Spirometry (Vmax 22™, SensorMedics, Loma Linda, CA) was performed using forced vital capacity (FVC). Subjects were required to perform three acceptable spirograms

Table 1
Subject characteristics and resting pulmonary function prior to each treatment (ambient air, compressed air) in control and EIB subjects. Values are mean ± standard deviation. Age-predicted normal pulmonary function values are in parentheses.[20] No significant differences between groups or treatments. Statistical P values for pulmonary function for corresponding ambient-air pulmonary function comparisons between control and EIB subjects were: 0.88, 0.08, and 0.98, respectively. (BMI – body mass index; FVC – forced vital capacity; PEF – peak expiratory flow; FEV_1 – forced expiratory volume in one second)

	Control	Exercise-induced bronchoconstriction
Age	23.6 ± 1.0	24.4 ± 6.6
Gender (m,f)	6,4	4,6
Height (m)	1.76 ± 0.13	1.68 ± 0.07
Weight (kg)	75.6 ± 18.3	70.4 ± 13.3
BMI (kg/m²)	24.2 ± 3.4	24.8 ± 3.4

	Control: Ambient air	Control: Compressed air	EIB: Ambient air	EIB: Compressed air
FVC (l)	5.4 ± 1.6 (5.39)	5.4 ± 1.6	4.4 ± 0.6 (4.40)	4.1 ± 0.7
PEF ($l.sec^{-1}$)	9.7 ± 2.6	10.4 ± 3.8	7.8 ± 1.9	7.7 ± 1.4
FEV_1 (l)	4.55 ± 1.32 (4.52)	4.6 ± 1.35	3.76 ± 0.56 (3.79)	3.65 ± 0.84

Table 2
Post-exercise forced expiratory volume in one second (l) in control and EIB subjects. Values are mean ± standard deviation. No significant differences for control subjects. All compressed-air breathing via scuba values for the EIB group were significantly different to the corresponding ambient-air values: * P = 0.003, ** P = 0.023, *** P = 0.043

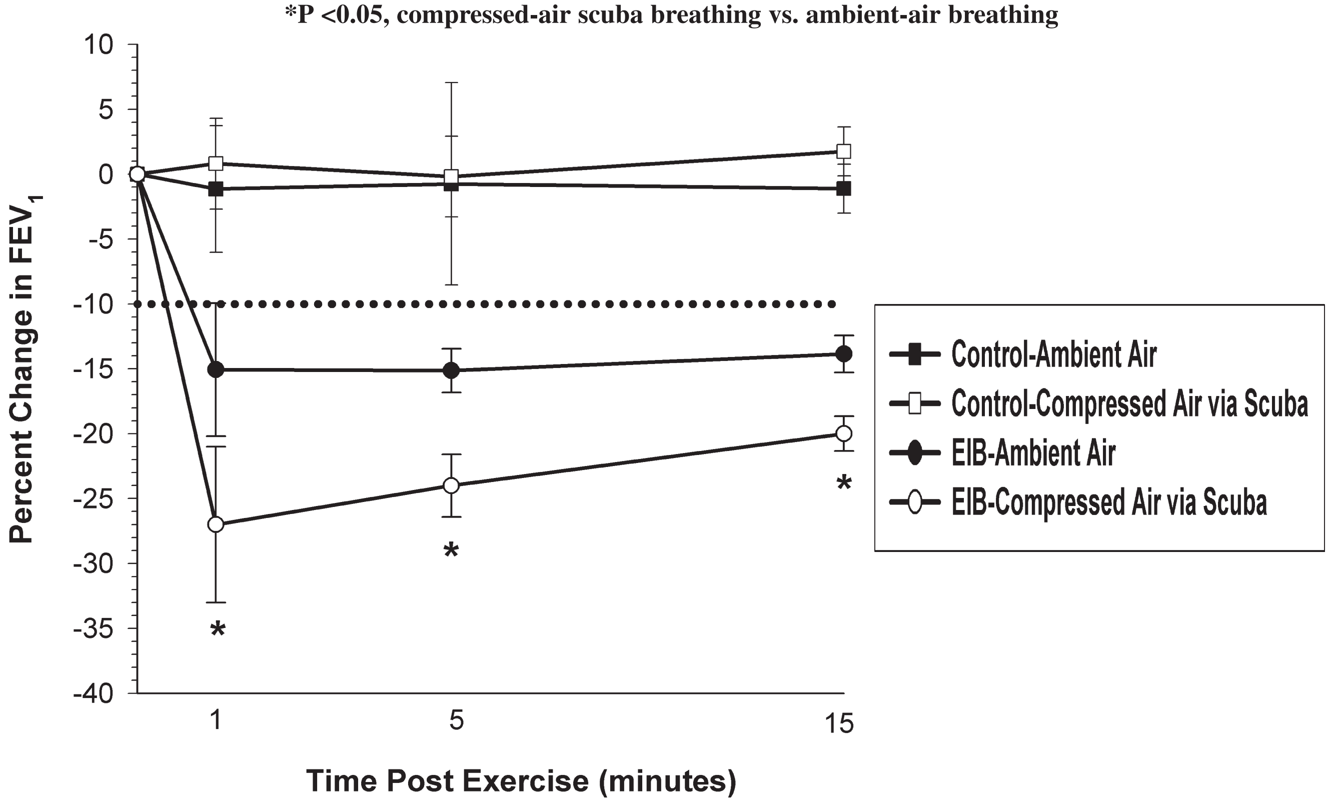
	Control		Exercise-induced bronchoconstriction	
	Ambient air	Compressed air	Ambient air	Compressed air
1 min	4.54 ± 1.43	4.66 ± 1.42	3.19 ± 0.43	2.66 ± 0.21*
5 min	4.53 ± 1.34	4.60 ± 1.36	3.19 ± 0.53	2.77 ± 0.38**
15 min	4.50 ± 1.29	4.69 ± 1.39	3.25 ± 0.49	2.92 ± 0.62***

according to the American Thoracic Society Standardization of Spirometry.[12] FVC, peak expiratory flow rate (PEF), and forced expiratory volume in one second (FEV_1) were the principal variables to monitor pulmonary function. All spirograms were measured and calculations were performed electronically by the Vmax 22™ Spirometer. Normal values for pulmonary function were predicted as per Crapo et al.[13] FEV_1 was used principally to reflect airway narrowing. A 10% or greater decrease in FEV_1 post exercise compared with pre-exercise values was indicative of EIB.[14]

DATA ANALYSIS

The sample size of ten was determined based on the standard deviation of the percentage change in FEV_1 pre to post exercise, and the ability to detect a difference of two percentage units between two means, with a power of 95% and P = 0.05.[15] Data are expressed as means and standard deviations. Post-exercise pulmonary function is expressed as a percentage change from pre-exercise pulmonary function values. Subject characteristics were compared using an unpaired *t*-test. Pulmonary function across the four conditions was analysed with a two-factor (treatment, group), repeated-measures (treatment) ANOVA. Post-exercise FEV_1 was analysed with a two-factor (treatment, time), repeated-measures (treatment, time) for each group. When a significant *F*-ratio occurred for a main effect, a Bonferroni's post-hoc test for multiple comparisons was performed. Significance for a two-tailed test was set *a priori* at P <0.05.

Figure 1
Percentage change in forced expiratory volume in one second (FEV_1) from pre to post exercise in non-asthmatic control subjects and exercise-induced asthmatic (EIB) subjects when breathing either ambient or compressed air via scuba. Dotted line indicates a 10% decrement in FEV_1, indicative of abnormal pulmonary function. *P <0.05, compressed-air scuba breathing vs. ambient-air breathing



Results

Subject characteristics are presented in Table 1. As shown, there were no significant differences in subject characteristics between the two groups. Baseline, pre-exercise pulmonary function was normal and did not differ between the two groups or between the two visits to the laboratory (Table 1). Post-exercise FEV_1 was not altered by compressed-air breathing via scuba in control subjects (Table 2). In contrast, for EIB subjects, all post-exercise values for FEV_1 were reduced further by compressed-air breathing via scuba (Table 2).

The percentage change (pre to post exercise) in FEV_1 was the principal diagnostic measure of EIB and is presented in Figure 1. Figure 1 indicates that non-asthmatic control subjects had no decrement in pulmonary function with regard to airways narrowing post exercise when breathing ambient air. For the three post-exercise time periods (1, 5, and 15 min) the change in FEV_1 was, respectively, -1.1 $\pm$ 4.8%, -0.75 $\pm$ 7.8%, and -1.12 $\pm$ 1.9%. Additionally, post-exercise FEV_1 was not affected by compressed-air breathing via scuba in control subjects: 0.85 $\pm$ 3.5% ($P = 0.31$), -0.19 $\pm$ 3.1% ($P = 0.83$), and 1.75 $\pm$ 1.9% ($P = 0.15$).

In contrast, subjects with EIB had marked reductions in FEV_1 post exercise while breathing ambient air, exceeding the diagnostic value of 10% reduction compared with pre exercise (Figure 1). This post-exercise reduction in FEV_1 was significantly exacerbated by compressed-air breathing via scuba. At 1 min post exercise, FEV_1 decreased from -15.1 $\pm$ 5.3% during ambient-air breathing to -27.0 $\pm$ 6.0% ($P = 0.0002$) with compressed-air breathing via scuba; at 5 min this change was from -15.1 $\pm$ 1.7% to -24.1 $\pm$ 2.4% ($P = 0.0001$); and at 15 min it was from -13.9 $\pm$ 1.4% to -20.5 $\pm$ 1.3% ($P = 0.0001$).

Discussion

This study shows for the first time that breathing compressed air through scuba regulators worsens post-exercise pulmonary function in those with EIB, while having no measurable effect on those without EIB. FEV_1 is an indicator of airway calibre and characteristically is decreased in those with EIB. Compressed-air breathing via scuba caused a significantly greater decrease in FEV_1 in those with EIB when compared with the same subjects breathing ambient air. Thus, severity of EIB was increased when exercising while breathing compressed air via scuba.

In general, exercise hyperpnoea while breathing cold, dry air is the most potent stimulus for airway obstruction or EIB.[16] For example, Mcfadden et al recently demonstrated that cold, dry air was a more potent stimulus for EIB than ambient air when ventilation was voluntarily increased in those susceptible.[5] In their study, voluntary isocapnic hyperpnoea of cold, dry air by EIB subjects exacerbated the percentage drop in post-exercise FEV_1, from a 16% reduction to approximately a 30% reduction in post-hyperpnoea FEV_1. Thus, in the present study, the cold, dry air from the compressed-air tank was likely the stimulus for the exacerbation of the EIB observed in these subjects.

Boutet et al suggested previously that scuba diving with a compressed-gas cylinder would be likely to exacerbate EIB in susceptible individuals.[17] The results of the present study support this hypothesis. They further proposed that divers with EIB would have airways narrowing associated with the hyperpnoea, and that potentially the airways narrowing/obstruction could be hazardous upon ascent. Upon ascent, gas volumes increase and complete expiration is required to prevent barotrauma. With airways obstruction, the danger of trapped gas and barotrauma would be greater. Recently, Leddy et al evaluated the possibility of air trapping and barotrauma in EIB subjects exercising while immersed in water.[18] They demonstrated a fall in FEV_1 and other lung volumes in their subjects, and some of the data suggested that airways narrowing may be increased due to the immersion. This potentially could lead to air trapping.

Current epidemiological data are insufficient to determine the risk of diving for asthmatics. There is a consensus, however, that asthmatic subjects with acute bronchoconstriction and individuals with exercise-induced bronchoconstriction should exercise caution before considering diving.[9,10] Asthmatic divers should consult their physician and may want to read Tetzlaff et al for a better review of the potential risks of diving.[9] The diver's level of understanding of the risks of diving contributes to making diving more safe. The more recent guidelines for asthmatics who wish to dive published by the British Thoracic Society state that "*asthmatic individuals who are currently well controlled and have normal pulmonary function tests may dive if they have a negative exercise test*."[19] Thus, the results of the present study emphasise the importance of this statement.

The sample size in the current study is small. However, this design was based on a power analysis, and the results are statistically supported. Subjects were pre-assigned to ambient or scuba as the first treatment. Though this was not a random design, for small sample studies a balanced assignment precludes the potential of a markedly unbalanced result of randomisation, with one treatment occurring first more frequently than the other. Furthermore, this study was conducted on land, so any influence of the hyperbaria associated with diving on these results has not been determined. Thus, some care must be used when generalising these results to the diving population.

The scuba apparatus likely added some resistance to breathing. It is not known if ventilation during scuba breathing was impaired and carbon dioxide retention occurred, potentially affecting bronchoconstriction. There was the possibility that minute ventilation differed between the air and the scuba conditions as scuba breathing occurred via the scuba apparatus and air breathing did not. Though ventilation was not determined during exercise, both control subjects and those with EIB received the same treatment. Subjects did not remark about increased resistance to breathing or dyspnoea with scuba apparatus. The scuba regulator itself was adjusted to reduce the pressure differential required to initiate flow from the tank. Thus, the probability is low that there was a marked influence on the EIB subjects imparted by breathing via the scuba apparatus during exercise.

The exercise intensity used in this study is generally higher than the typical recreational dive. Recreational divers generally operate at low exercise intensities in order to conserve air, prolonging the dive time. However, EIB severity is determined both by the intensity and the duration of the exercise.[20] Concern would arise if an increased intensity of exercise were required, such as in an emergency. Occupational divers may be working at exercise intensities that can induce EIB. Therefore, the results of this study are relevant to divers and support the consensus that those with EIB should not dive without careful medical and self-monitoring of their condition.

In conclusion, exercise while breathing compressed air via scuba regulators induced an additional decrement in pulmonary function in those with EIB. Non-asthmatics had no significant changes in pulmonary function. Because the study was conducted on land, any specific effects of diving, such as hyperbaria and hypoxia, were eliminated. These results indicate that individuals with EIB should carefully consider their condition, become very well informed, and obtain medical clearance prior to considering scuba diving.

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