ORIGINAL RESEARCH

Prevalence of Airway Obstruction in Recreational SCUBA Divers

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Objective.—The prevalence of airflow obstruction in recreational self-contained underwater breathing apparatus (SCUBA) divers is unknown. Since airflow obstruction is a relative contraindication for diving, we conducted a study to determine its prevalence and magnitude in a cohort of recreational divers in Saba, Netherlands Antilles.

Methods.—Prior to diving, divers were asked to complete a diving/health questionnaire and then to perform spirometry administered by trained dive store personnel. Spirometry instrumentation provided immediate feedback regarding test quality.

Results.—Of 8365 eligible divers during the study period (November 1997–March 1999), 668 enrolled and completed questionnaires. Of those completing questionnaires, 46% reported a history of smoking, 13% were current smokers, 15% wheezed, 6% had asthma, 4% used bronchodilators, and 3% took oral steroids. Of 654 completing spirometry, 231 had acceptable spirometry quality and complete questionnaires. By forced expiratory volume in 1 second/forced vital capacity, 10% had mild, 1.7% had moderate, and 0.4% had severe airflow obstruction.

Conclusions.—The prevalence of airflow obstruction was 6% to 15% by report and 12% by spirometry, approximating the combined prevalence of asthma and chronic obstructive pulmonary disease in the general population. Study limitations include possible self-selection and low enrollment rate. Prospective lung function testing can be conducted at remote sites using nonmedical personnel as “testers.” This study could guide future investigations to determine if asthma is a risk factor for decompression illness.

Key words: pulmonary function studies, asthma, diving, fitness to dive, airway obstruction, SCUBA

Introduction

Asthma with airflow obstruction is a contraindication for self-contained underwater breathing apparatus (SCUBA)

This work was performed at Saba, Netherlands Antilles, and at LDS Hospital, Department of Hyperbaric Medicine, in Salt Lake City, UT. This work has been previously presented in abstract form at the Annual Scientific Meeting of the Undersea & Hyperbaric Medical Society, San Antonio, TX, June 2001, and was published in the proceedings of that meeting. (Abstract title: “Incidence of airways obstruction in recreational SCUBA divers is the same as in the general population”)

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diving.¹ Divers with asthma may be permitted to dive if they have no airflow obstruction following exercise provocation.² The rationale for exclusion of asthmatics and patients with airflow obstruction from diving is the potential increased risk for pulmonary barotrauma³ and decompression illness,^{4,5} and possibly death, though some reports indicate that most fatalities in asthmatic divers occur from causes other than asthma.^{6,7}

Arterial gas embolism is a form of pulmonary barotrauma and a component of decompression sickness (DCS). Divers are at risk for arterial gas embolism during ascent, when the alveolar gas expands, according to Boyle’s law.³ In the setting of airway obstruction, when alveolar gas expands during ascent, the alveoli may tear, resulting in the passage of alveolar air into the pulmo-

nary capillary circulation.³ In turn, this air is transported by blood to the arterial circulation, resulting in cerebral and other organ embolization.⁸ Decompression sickness is caused by nitrogen gaseous nuclei (caused by supersaturation of nitrogen) forming in blood and tissues during ascent from compressed air diving.³ One factor contributing to nitrogen elimination is alveolar ventilation. If alveolar ventilation and perfusion through the lung are compromised, and the matching of ventilation to perfusion is reduced because of airway obstruction, then nitrogen elimination may be reduced, thereby increasing DCS risk.³ The potential for increased risk for DCS in divers with airway obstruction is unproven. A limited report in 1991 showed a nonsignificant trend for increased risk for DCS in divers reporting a history of asthma.⁹

It is possible that asthmatics are excluded from diving since diving certifying agencies require a general health questionnaire before entry into a course of instruction. However, prior surveys of the sport-diving community indicated that 6% to 8% of divers had a current or prior diagnosis of asthma.^{10–12} We conducted an observational prospective study measuring pulmonary function, respiratory symptoms, and self-reported asthma diagnosis in a cohort of divers.

Methods

We selected Saba, an island in the Caribbean approximately 20 miles south of St Marten, on which to conduct this prospective study, which was exempted from review by our institutional review board. This site was selected because of an offer of assistance from Saba Medical School personnel, because there were only 3 diving facilities on Saba, and because all divers must register to dive in the Saba Marine Park. We reasoned that when a diver registered to dive, we could obtain health information and spirometry. In addition, the live-aboard diving boat *Caribbean Explorer* operates near Saba, so we included those diving from that boat in the group eligible for this study. We assumed that most individuals who dive from Saba would be more experienced divers, potentially biasing the sample in favor of more experienced divers.

The investigators and a representative from the spirometer manufacturer trained 2 medical students from Saba University and dive shop personnel to calibrate and use the spirometry equipment (model 2200, Sensor-Medics, Yorba Linda, CA) and to capture the data in the computers. The students calibrated the equipment daily and downloaded the data. The spirometers were calibrated using a 3-L syringe according to American Thoracic Society (ATS) standards.¹³ Representatives from

each of the 3 dive shops and the live-aboard boat were trained to perform spirometry. The spirometry instrumentation provided immediate feedback regarding the quality of the spirometry test. The researchers placed a poster describing the study in each dive shop.

As divers arrived at the dive shops prior to diving, dive shop personnel informed them of the project. After signing an informed consent, divers were asked to voluntarily complete a diving and health questionnaire and were advised that this information would remain confidential and would not affect their ability to dive.

The questionnaire was modeled from the ATS's *Recommended Respiratory Disease Questionnaire for Adults*¹⁴ but included questions about diving history (certification level, years of experience, total dives, dives in the last 12 months, and previous diving accidents). Volunteers were asked to provide information about smoking habits, recent cold or upper respiratory infections, current cough or wheezing, and history of chronic bronchitis, pneumonia, emphysema, or asthma, including when these problems started. They were asked to report heart problems, high blood pressure, and frequent indigestion or heartburn. In addition, they were asked if they had used antihistamines, asthma inhalers, or steroids within the past 3 months.

All divers on Saba are issued a unique identification number by the Saba Marine Park. This number is stamped on a tag and affixed to the diver's buoyancy compensator. In order to maintain confidentiality, the Saba Marine Park identification number was used to identify the participating divers in the spirometer and the computer. The investigators maintained the link between the name of the diver and the identification number.

Once the questionnaire was complete, the dive shop personnel fitted the spirometer with a single-use disposable mouthpiece with a bacterial/viral filter to prevent cross contamination and then coached the diver through at least 3 maximal spirometry maneuvers. Each diver performed at least 3 separate spirometry tests as the dive shop personnel observed the loops for adequacy of the technique. The best test, defined as the maneuver with the largest combined forced expiratory volume in 1 second (FEV₁) and forced vital capacity (FVC), was selected for interpretation. Spirometry data were acceptable for interpretation if ATS acceptability and reproducibility criteria were met. Specifically, the largest and next largest FVC and FEV₁ measurements had to be within 200 mL, have a back extrapolation volume of less than 5% of FVC and 0.15 L, and have an exhalation time greater than 6 seconds.¹³

Spirometry was defined as revealing obstruction if the FEV₁/FVC ratio was below the lower limit of normal (defined as values less than the lower fifth percentile)

using Crapo reference values.¹⁵ The severity of obstruction was based on the percent predicted FEV₁ according to ATS guidelines. Mild airway obstruction was present when the percent predicted FEV₁ was <100% and ≥70%. Moderate airway obstruction was present when the percent predicted FEV₁ was between 50% and 70%, and severe airways obstruction was present when the percent predicted FEV₁ was <50%.¹⁶

At the time this study was conducted, Internet communication with island personnel was unreliable. Each day the spirometry data, including all individual trials and graphs, were archived onto floppy disks and sent to the researchers by overnight mail. An additional floppy disc back-up was maintained on the island, and the information was retained on the hard drive of the computers. The archived data were restored on an identical SensorMedics system in Salt Lake City, UT, for review. An experienced clinician reviewed all spirometry graphs and values and determined if the tests met ATS acceptability and reproducibility criteria. The researchers provided regular feedback to the dive shop personnel regarding data quality and participant recruitment. Divers who participated in the study were offered a copy of their spirometry raw data, which they could subsequently have interpreted by their own health care provider.

One of the medical students assisting with this study also worked at the Saba recompression facility. This student compared the names of divers who underwent spirometry to the divers who were evaluated for decompression illness while on Saba to determine if any volunteers with airway obstruction had adverse outcomes immediately following diving.

Results

There were 8365 eligible divers during the study period (November 1997 to March 1999). We enrolled 668 divers (8%). The domiciles of the divers included the United States (67%), the Caribbean (10%), Europe (9%), Canada (8%), and "Other/Not Reported" (6%). The mean age of the divers was 38.4 ± 9.7 years (range: 21–64 years). Questionnaires were completed by 668 divers and spirometry was performed by 654 divers. Acceptable spirometry, meeting all ATS standards, was available from 415 divers (63% of divers performing spirometry). The majority of rejected studies failed to meet ATS reproducibility criteria. Both acceptable spirometry and complete questionnaires were available from 231 (35%) divers.

Questionnaire results from all participants showed that 46% of volunteers had a history of smoking, 13% were current smokers, 15% wheezed episodically, 6% had asthma, 3% reported a history of chronic bronchitis or

emphysema, 4% were using bronchodilators, and 3% were taking oral steroids. No divers reported dyspnea.

Of the 415 with acceptable spirometry, the FEV₁/FVC ratio and percent predicted FEV₁ showed 10.1% to have mild airflow obstruction, 1.7% to have moderate airflow obstruction, and 0.4% to have severe airflow obstruction. Two divers classified with mild airway obstruction had a FVC greater than 120% of predicted, associated with a FEV₁/FVC ratio less than the lower limit of normal and a FEV₁ greater than 80% of predicted. This spirometry pattern may represent actual airway obstruction or a normal variant. We classified these patients as mild airway obstruction. No diver with pre-diving spirometry was evaluated on Saba for decompression sickness or arterial gas embolism.

Of the 231 divers with complete questionnaires and acceptable spirometry, 17 (7%) reported asthma, of which 4 had airflow obstruction by spirometry. Twenty-five divers (11%) reported having had chronic bronchitis, and 4 of these had airflow obstruction by spirometry.

Discussion

Our goal was to obtain questionnaire and spirometry data from the majority of divers visiting Saba during a 1-year period. We did not accomplish that goal as a result of low enrollment. The study is therefore limited by possible self-selection bias. However, we attempted to limit self-selection by informing divers that they would not be precluded from diving by the test results. The primary limiting factors for enrollment were dive shop personnel time constraints, inadequate numbers of dive shop personnel, high dive shop personnel turnover, and lack of commitment to this endeavor on the part of some of the dive shop personnel. This study was also limited by the manner in which divers registered. Often 10 to 20 divers arrived at a dive shop simultaneously to make arrangements for diving. The shop personnel were not able to recruit divers into the study under those circumstances. We also had technical challenges associated with the spirometry equipment's sensitivity to the heat and humidity, which at times required recalibration more often than daily. Despite these limitations, we were able to gather adequate spirometry data from 415 divers and complete questionnaire and spirometry data from 231 divers prospectively, which has not been reported previously.

In our study, the prevalence of divers with airflow obstruction (12% by spirometry) is similar to that of the general population of Europe¹⁷ and the United States,¹⁸ indicating that divers with asthma may not have been screened away from diving. It is also possible that divers may have developed asthma since learning to dive. Al-

ternatively, the diver with asthma may have chosen not to participate in our study, which would result in underestimation of the prevalence of asthma in divers.

To our knowledge, this is the first study demonstrating that non-medically trained individuals can perform spirometry adequately. Quality control was a concern, as Saba is a remote location, and at the time we conducted this study, Internet communication to Saba was extremely limited. This did not allow optimal technician supervision. Also, time constraints placed on technicians and divers likely affected test quality. Despite these limitations, 63% of the tested divers had spirometry that met ATS standards for acceptability and reproducibility. While not ideal, this is comparable to the reported frequency of technically adequate spirometry obtained in family care physicians' offices (71%).¹⁹ This information may be helpful to others who contemplate remote spirometry testing.

We believe studies similar to ours could be done in the future to quantify the frequency and magnitude of asthma, chronic obstructive pulmonary disease, and lower airway obstruction in divers. We suggest on-site supervision by individuals committed to the study.

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