SPUMS Annual Scientific Meeting 2006

Are asthmatics fit to dive?

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Key words
Asthma, fitness to dive, scuba diving, safety, medical conditions and problems, pulmonary function, bronchial provocation testing, review article

Abstract

(Walker RM. Are asthmatics fit to dive? *Diving and Hyperbaric Medicine*. 2006; 36: 213-19.)
There are many theoretical reasons why asthmatics should be at increased risk when scuba diving: exertion, inspiration of cold and dry air, increased respiratory effort from regulator resistance and increased density of gas. Diving could provoke an acute attack of asthma or increase the asthmatic's susceptibility to pulmonary barotrauma. However, an asthmatic's sensitivity to many of the stimuli encountered during diving is reduced following treatment with inhaled steroids so that lung function and bronchial responsiveness fall within the normal predicted range. The SPUMS medical states that any current evidence of asthma is a contra-indication to diving. The United Kingdom Sports Diving Medical Committee guidelines, however, recommend that individuals who are currently well controlled and have normal pulmonary function tests may dive if they have a negative exercise test. Is it time for a new recommendation regarding fitness to dive for asthmatics?

A brief review of asthma

Asthma is a chronic inflammatory disorder of the airways in which many cells and cellular elements play a role, in particular, mast cells, eosinophils, T-lymphocytes, macrophages, neutrophils, and epithelial cells. In susceptible individuals, this inflammation causes recurrent episodes of wheezing, breathlessness, chest tightness, and coughing, particularly at night or in the early morning. These episodes are usually associated with widespread but variable airflow obstruction that is often reversed either spontaneously or with treatment. The inflammation also causes an increase in bronchial responsiveness to a wide variety of stimuli.[1]

ASTHMA PREVALENCE

Asthma is becoming increasingly common in Western countries, affecting between 15 and 35% of children aged 13–14 years.[2] The National Asthma Council Australia estimates that about 40% of all Australians will have respiratory symptoms consistent with asthma at some time in their lives.[3] The European Community Respiratory Health Survey (ECRHS) states that the prevalence of asthma in centres from the United Kingdom, New Zealand and Australia varies from 7.5 to 11.9%.[4] During 1982–1992 in the age range from five to 34 years, the overall annual age-adjusted prevalence rate of asthma increased from 34.6 to 52.6 per 1000 in the United States.[5] Since that time the increase in prevalence in the USA has slowed somewhat.

NATURAL HISTORY

For most children, wheezing before the age of six years is probably a benign condition reflecting smaller airways that will improve or resolve in a few years. In a substantial minority of infants, however, wheezing episodes are probably related to a predisposition to asthma.[6]

Robertson reports that the outcome of childhood asthma is dependent on the pattern of asthma through childhood.[7] Episodic asthma in childhood tends to resolve in adolescence and through mid-adult years, with no impairment of lung function. Persistent asthma is more likely to continue into adult years, with modest impairment of lung function that occurs early in the disease process and is not progressive, despite continuing symptoms.[7]

Taylor et al evaluated the frequency and risk factors for relapse of asthma in a group of 18-year-old patients with previous asthma but in remission.[8] Approximately one-third of study members (35%) with asthma in remission at 18 years of age relapsed by 21 or 26 years of age. Atopy and lower forced expiratory volume in one second (FEV_1)/ forced vital capacity (FVC) ratio at 18 years of age were significant independent prognostic factors for relapse in multiple logistic regression analyses. Increased responsiveness to methacholine or bronchodilator at 21 years of age was more common among those with relapse, but the positive and negative predictive values for a previous positive methacholine challenge test result at 15 years of age were low. Asthma after relapse was generally mild. Totally new adult asthma developed by 26 years of age in 9% of study members who had no asthma or wheezing at any time up to 18 years of age. Taylor et al concluded that subsequent relapse of previously diagnosed asthma in remission at 18 years of age occurs in one in three young adults. Such relapse is not easily predicted, especially by measurements of airway responsiveness to methacholine.[8]

RISK FACTORS FOR ASTHMA

Abnormal bronchial responsiveness is a central feature in the definition of asthma; however, not all patients with bronchial hyperresponsiveness to a pharmacological agent have symptoms of asthma.[9] Atopy, exposure to indoor allergens, outdoor pollution, exposure to tobacco smoke, respiratory infections and obesity are all known risk factors for the development of asthma. Common trigger factors for asthma include allergens, respiratory infections, irritants, chemicals, physical activity and emotional stress.

EXERCISE-INDUCED BRONCHOCONSTRICTION

Exercise is a trigger of bronchoconstriction in patients with asthma.[10] The prevalence of exercise-induced bronchoconstriction in patients with asthma has been reported to range from 40-90 per cent.[11] Whilst the severity of exercise-induced bronchoconstriction in many asthmatics may relate to underlying hyperresponsiveness to pharmacological agents, some can have exercise-induced bronchoconstriction yet not have bronchial hyperresponsiveness to a pharmacological agent.[12] Thus in many patients with mild, episodic asthma and minimally increased airways responsiveness, even strenuous exercise does not cause significant bronchoconstriction. Exercise-induced bronchoconstriction results from the thermal and osmotic effects of conditioning large volumes of relatively cool, dry air in a short time during vigorous activity.[11,13] Exercise-induced bronchoconstriction most commonly occurs post exercise, following a period of initial bronchodilation during exercise. Bronchoconstriction begins within three minutes post exercise, generally peaking within 10–15 minutes, and resolves spontaneously over 3–60 minutes depending on the severity.

DIAGNOSIS

The clinical diagnosis of asthma is based on the symptomatic triad of cough, shortness of breath and wheezing occurring simultaneously. Spirometry and, in particular, the FEV_1 measure the degree of airflow obstruction. Administration of a bronchodilator is indicated if the baseline spirometry reveals obstruction. However, many patients do not present with the classical picture described above, and many asthmatics have normal spirometry despite the presence of asthma symptoms. Other patients give a past history of asthma but deny current symptoms. Bronchial provocation testing may be useful in these situations (Table 1).[14]

BRONCHIAL PROVOCATION TESTS

Bronchial provocation tests include the pharmacological agonists methacholine and histamine that act directly on receptors on bronchial smooth muscle causing it to contract and the airways to narrow. Whilst these tests have good sensitivity they are not specific for identifying asthma. Bronchial provocation tests that act indirectly to cause airway narrowing are more specific for identifying current airway inflammation and include exercise, eucapnic hyperventilation of dry air, and inhalation of hypertonic aerosols such as saline and mannitol. The bronchial hyperresponsiveness documented in response to indirect stimuli is associated with the presence of inflammation that is responsive to inhaled corticosteroids. Tests that use indirect stimuli have been used successfully to assess both the response to treatment and the withdrawal of treatment with inhaled steroids.[15] Approximately 50% of asthmatics lose their bronchial hyperresponsiveness to these stimuli following 3–6 months' treatment.[16] Twenty per cent of people with a past history of asthma, no current symptoms or current use of medication, with normal spirometry and who have been passed medically fit to dive have bronchial hyperresponsiveness to hyperosmolar saline.[17]

TREATMENT

Current asthma management plans encourage the use of peak expiratory flow (PEF) monitoring in patients with moderate to severe asthma. The utility of PEF to measure airflow limitation, however, is not particularly good, as variability among individuals is very large. The variability of PEF readings in healthy non-asthmatic individuals can be up to 31% in children and 19% for adults limiting the value of the measurements. However, PEF is useful in monitoring changes or trends in the patient's lung function.[18] Pharmacologic treatment of asthma includes the use of short- and long-acting inhaled beta-agonists, inhaled and oral corticosteroids, mast-cell stabilizing agents and leukotriene-modifying agents.

Intermittent use of short-acting inhaled bronchodilators is recommended for symptomatic relief for those with mild intermittent asthma and prophylactically prior to a known exposure in order to prevent the symptoms, e.g., exercise-induced asthma. Mast-cell stabilizing drugs taken immediately prior to exercise constitute effective

Table 1
Usefulness of bronchoprovocation testing

- Failure to show airway hyperresponsiveness strongly argues against diagnosis of asthma
- Airway hyperresponsiveness may be the sole evidence of airways dysfunction
- Airway hyperresponsiveness is quantitatively associated with the presence and severity of disease
- The occurrence of airway hyperresponsiveness in an asymptomatic person may help predict the future development of asthma
- The degree of airway hyperresponsiveness in a symptomatic person can have prognostic and potentially therapeutic implications
- The periodicity of asthma exists in parallel with changes in the degree of airway hyperresponsiveness.

preventive treatment and provide additive protection when used in combination with a beta-agonist.[19] Regular anti-inflammatory medications (e.g., inhaled corticosteroids) are recommended when symptoms become frequent. Inhaled corticosteroids reduce inflammation and by doing so reduce bronchial hyperresponsiveness to many triggers of asthma. Long-acting oral bronchodilators, e.g., theophylline, are effective when used in combination with anti-inflammatory therapy. However, they have a narrow therapeutic index, a relative lack of bronchodilator potency and their use is associated with frequent side effects. Drugs such as theophylline cause pulmonary vasodilatation and may reduce the bubble-filtering effect of the lungs and, therefore, increase the risk of venous bubbles becoming arterialised.

SUMMARY

In summary, in Australia, the United Kingdom and the United States, asthma has become increasingly prevalent in the age group of potential scuba-diving candidates. Mild asthma in childhood is likely to mean mild disease as an adult; remission in teenage years does not equate to lifelong remission and totally new asthma may present in adult years. This implies that there must be some individuals in Australia and New Zealand who were passed medically fit to dive in their teenage years who have later gone on to develop adult-onset asthma (and probably have not had another diving medical). Similarly it could be inferred that there are current divers whose asthma was in remission or not identified at the time of their diving medical.

The predictive value of bronchial hyperresponsiveness testing with methacholine in identifying those individuals with a previous history of asthma who are currently asymptomatic and who would likely relapse is low and therefore is not a useful screening test. Provocation testing by indirect challenge identifies those with bronchial hyperresponsiveness but who may have no current symptoms of asthma. However, bronchial hyperresponsiveness to a direct challenge is indicative of currently active asthma.

Asthma and scuba diving – why the concern?

There are many theoretical reasons why asthmatics should be at increased risk of an exacerbation of their disease when scuba diving. The exertion of diving may promote bronchospasm (exercise-induced asthma) and the inspiration of cold and dry air may cause release of inflammatory mediators in the airways triggering an attack.[20] The increased respiratory effort required as a consequence of regulator resistance and the increased density of gas at depth increases the work of breathing. Gotshall et al have demonstrated that compressed-air breathing via a scuba regulator at ambient pressure unimmersed increased the severity of exercise-induced bronchoconstriction in asthmatics but not in non-asthmatics.[20]

Diving could provoke an acute attack of asthma on the surface or, if at depth, increase the asthmatic's susceptibility to pulmonary barotrauma. Pulmonary barotrauma is the clinical manifestation of Boyle's law as it affects the lungs and is the result of over-distension and rupture of the lungs by expanding gases during ascent. The gas trapping and the increased airway resistance of asthmatics may predispose them to potentially fatal pulmonary barotrauma of ascent.

For these reasons, Australian and New Zealand diving medical practitioners have considered asthma to be a contra-indication to diving. However, the evidence to support these theoretical risks is limited (Table 2). Edmonds reports that asthmatics are over represented in diving fatality reports,[21] whilst Glanvill et al report no mortality and little morbidity

Table 2
Studies of asthma in diving and its prevalence in relation to fatal and non-fatal diving accidents

Author	Report	Outcome
Edmonds 1991[21]	Series of 100 diving deaths in Australia and New Zealand	9 deaths despite < 1% of divers reported having asthma
Neuman et al 1994[23]	5% prevalence of asthma in recreational divers in the USA	Fatal accident rate of 1 asthmatic in 2,132 deaths
DAN report 1996[24]	Retrospective review of DAN accident data 1988–1994	23/369 cases of arterial gas embolism and 123/2720 cases of decompression illness had coexistent asthma
Corson et al 1991[25]	Retrospective review of DAN accident data 1987–1990	16/196 divers with AGE had asthma, (AGE: current asthmatics odds ratio (OR) 1.98), 30/755 with DCS Type 2 had asthma (DCS 2: current asthmatics OR 1.16), neither statistically significant
Glanvill et al 2005[22]	Longitudinal cohort study of 100 UK divers with asthma	12,697 dives, 20 divers reported problems during diving, 12 reported wheeze underwater; one person reported two episodes of DCI (later confirmed to have a PFO). Current UKSDMC and BTS guidelines would have excluded all of the divers who reported either wheezing underwater or problems on the surface.

in a series of 12,697 dives.[22] Recent advances in asthma therapy may explain some of these differences; however, current diving death statistics in countries where medical examinations are not mandatory do not report a significant excess of asthma-related diving deaths.

Current position

SPUMS

SPUMS has consistently advocated the requirement for all diving candidates to undergo a diving medical examination by a medical practitioner with experience in diving medicine.[26] The SPUMS diving medical states that

"*A full (respiratory) history and examination should be normal. Any abnormal findings should be fully investigated. Such investigations should include provocation testing if any doubt concerning the possibility of bronchial hyperreactivity exists. Particular attention must be paid to any condition that might cause retention and trapping of expanding gas in any particular part of the lungs during decompression (e.g., asthma). The following conditions may disqualify:*

i any chronic lung disease past or present

ii any history of spontaneous pneumothorax, penetrating chest injuries or open chest surgery

iii any fibrotic lesion of the lung that may cause generalised or localised lack of compliance in lung tissue

iv any evidence of obstructive disease e.g., current asthma, chronic bronchitis, allergic bronchospasm.

All divers shall have a pulmonary function test to establish the FEV_1 and FVC. An FVC or FEV_1 of more than 20% below predicted values and/or a FEV_1/FVC ratio of less than 75% requires further assessment."[26]

AUSTRALIAN STANDARD FOR RECREATIONAL DIVERS

The Australian Standard AS 4005-2000, Training and Certification of Recreational Divers, reiterates the advice in the SPUMS medical but in addition states that

"*asthma...is an absolute contra-indication to breathing air under pressure. A normal FEV_1/FVC ratio but clinical signs of bronchospasm, especially on forced deep, rapid ventilation, is an indication of unfitness to dive. Treatment with drugs is not suitable as the effects can wear off underwater and the combined effects of pressure and bronchodilator drugs are uncertain*."[27]

THORACIC SOCIETY OF AUSTRALIA AND NEW ZEALAND

The Thoracic Society of Australia and New Zealand advised in 1993 that spirometric tests before and after bronchodilation should be performed on all intending divers. If there is an increase in FEV_1 of more than 15% post-bronchodilator bronchial provocation testing should be performed on a subsequent occasion. Intending divers with a history of current asthma should be advised not to dive. Intending divers with a past history of asthma and asthma symptoms within the previous five years should be advised not to dive. Those who have had asthma in the past, but who are asymptomatic and have normal spirometric tests and have taken no medication at all in the past five years should proceed to bronchial provocation testing.[28]

This advice has recently been reviewed.[15] Anderson et al note that since 1993 there has been a nationwide effort to improve asthma education, inhaled steroids are more widely available and more frequently used, lung-function tests are more commonly requested and the tests are more sophisticated. Self-monitoring of symptoms is more common and many asthmatics own peak flow meters. Anderson et al also state that

"*the finding of bronchial hyperresponsiveness or bronchial hyperreactivity in a significant proportion of healthy young adults, with a past history of asthma, seeking employment in occupations excluding current asthma, or seeking permission to use drugs before sporting events, supports the need for objective testing before clearance to dive.*"[15]

They recommend those bronchial provocation tests that involve the stimulus to which the intending diver is exposed, either exercise or eucapnic hyperpnoea of dry air and non-isotonic aerosols. In their experience, if either of these challenges produces symptoms, the intending diver is immediately aware of the potential for the same thing to occur whilst diving and may voluntarily withdraw from scuba training.

Anderson et al also state that bronchial hyperresponsiveness to exercise, eucapnic hyperpnoea of dry air and hypertonic aerosols has been demonstrated to be reduced over weeks by treatment with inhaled steroids. They make no recommendation as to whether treated asthmatics with no symptoms and negative bronchial provocation tests should be certified fit to dive.[15]

Anderson et al conclude that the 1993 approach that scuba should be disallowed for anyone with a history of symptoms and medication for asthma within the last five years should be re-evaluated in light of improved medication regimes, the ease with which lung-function and bronchial provocation tests can be performed and the move towards the informed risk assessment model. They strongly recommend the measurement of bronchial hyperresponsiveness in those individuals with a past history of asthma but no current symptoms and good lung function.

BRITISH THORACIC SOCIETY GUIDELINES

The British Thoracic Society established a working party to formulate national recommendations for assessment

of fitness to dive.[29] Their specific recommendations with respect to assessment of respiratory fitness include

> "*FEV_1, FVC and PEF should be measured. FEV_1 and FVC should normally be greater than 80% of predicted and the FEV_1/FVC ratio greater than 70%. Routine measurement of expiratory flow-volume loop, exercise testing, or bronchial provocation testing* [is] *not considered necessary although these tests may be useful in specific cases*."

Specific recommendations on asthma include

> "*subjects with asthma should be advised not to dive if they have wheeze precipitated by exercise, cold or emotion. Subjects with asthma may be permitted to dive if, with or without regular inhaled anti-inflammatory agents, they are free of asthma symptoms, have normal spirometry and have a negative exercise test. Subjects with asthma should monitor their asthma with regular twice daily peak flow measurement and should refrain from diving if they have active asthma (symptoms requiring relief medication in the 48 hours preceding the dive), a reduced peak expiratory flow (more than 10% fall from best value), or increased peak flow variability (more than 20% diurnal variation)*".[29]

The discussion accompanying the guidelines expands to state that there has been no prospective testing of the relationship between bronchial hyperresponsiveness and risk in divers and current evidence does not support the routine use of bronchial provocation testing in assessing fitness to dive. However, they do recommend an exercise test and advise that a step or free running test to raise the heart rate to 80% of maximum followed by measurement of FEV_1 at 1, 3, 5, 10, 15, 20, and 30 minutes after exercise is acceptable. A decrease in FEV_1 of 10% or more from the baseline is abnormal and a decrease of 15% or more is diagnostic of exercise-induced bronchoconstriction and would contradict diving.

UNITED KINGDOM SPORT DIVING MEDICAL COMMITTEE

The United Kingdom Sport Diving Medical Committee advises the British Sub-Aqua Club, the Sub Aqua Association and the Scottish Sub-Aqua Club on aspects of medical fitness to dive. Their guidelines state that

> "*asthma may predispose to air-trapping leading to pulmonary barotrauma and air embolism, which may be fatal. An acute asthma attack can also cause severe dyspnoea which may be hazardous or fatal during diving. These theoretical risks should be fully explained to the asthmatic diver. There is little if any evidence that the mild, controlled asthmatic who follows the guidelines below is at more risk: Asthmatics may dive if they have allergic asthma but not if they have cold, exercise or emotion induced asthma. All asthmatics should be managed in accordance with British Thoracic Society Guidelines. Only well controlled asthmatics may dive. Asthmatics should not dive if he/she has needed a therapeutic bronchodilator in the last 48 hours or has had any other chest symptoms*."[30]

Discussion

The dichotomy between the Australian/New Zealand and United Kingdom approaches to asthmatics diving deserves further discussion. Whilst both groups acknowledge the relevance of potential risks for asthmatics when diving, the United Kingdom approach places the decision in the intending diver's hands. Whilst the UK approach is to exclude asthmatics with exercise-induced asthma, evidence previously presented in this paper indicates that up to 90% of patients with symptomatic asthma have some degree of exercise-induced bronchoconstriction. However, if their symptoms are controlled (with or without anti-inflammatory medication) and they have normal spirometry and a negative exercise test, they are permitted to dive. However, unless the exercise test is conducted under standard conditions its reproducibility would be expected to be low. The UKSDMC advise that the medical examiner should perform an exercise test such as the 18-inch (43 cm) step test for three minutes, or running outside (duration not stated) to increase the heart rate to 80% of maximum (210 minus age in years beats per minute). A decrease in PEF of 15% at three minutes post exercise is evidence of exercise-induced bronchoconstriction and indicates disqualification. Exactly how the general practitioner would assess if the required heart rate was reached and maintained at 80% during this test is not explained. The British Thoracic Society guidelines on exercise testing are more rigorous yet may prove a logistic challenge for some general practices and therefore require specialist referral. It is then up to the patient to monitor their symptoms and lung function and for the medical practitioner to provide guidelines on when not to dive.

The Thoracic Society of Australia and New Zealand strongly recommends the use of bronchial provocation testing by hyperpnoea or hypertonic aerosols in the assessment of individuals with a past history of asthma but no current symptoms and good lung function. This testing will, however, identify those whose bronchial hyperresponsiveness is likely to be resolved by treatment with inhaled steroids. The newly available mannitol test (which is approved by the Australian Therapeutic Goods Administration) should be added to the list of existing bronchial provocation tests.

Advances in asthma treatment have occurred over the last 20 years and if medication reverses or abolishes bronchial hyperresponsiveness then theoretically the adequately treated asthmatic should be at no greater risk than the non-asthmatic. It is very unlikely that a prospective double-blind randomised trial will be conducted to prove this theory but there are sound theoretical reasons to support this statement (just like the theoretical reasons that argue against people with asthma diving).

Anderson reports that at least 50% of well-controlled asthmatics on steroids are negative to challenge by exercise, hypertonic saline and mannitol after 12 hours off all medication.[31] There may be some benefit in conducting challenge testing on prospective asthmatic divers after at least 12 hours off medication as this gives some confidence that the inflammation has resolved and the short-term effects of vasoconstriction will have dissipated.

It appears clear that an assessment of bronchial responsiveness is required for the prospective diver with treated asthma or with current symptoms but normal spirometry. It does not appear so clear that provocation testing should be mandatory in all of those with a past history of asthma, no symptoms and normal spirometry. It should, however, be kept in mind that 20–30% of those are likely to develop bronchial hyperresponsiveness to exercise or the inhalation of hyperosmolar aerosols that may be encountered during diving.[17,32] Many of these individuals will have bronchial hyperresponsiveness on indirect challenge testing but the relationship to morbidity or mortality when diving is not proven. Measurement of airway hyperresponsiveness would at least provide both the general practitioner and the patient a measurable marker on which to assess the perceived level of risk.

The UKSDMC position appears rational with the caveat that exercise or other indirect challenge testing (eucapnic hyperpnoea, inhaled hypertonic saline or mannitol) is an acceptable way to assess current asthmatic status and this testing should be done at least 12 hours after the last dose of asthma medication was taken. Whatever test is used it should be quantifiable and be reproducible under controlled conditions. The inhaled mannitol test (Aridol™, Pharmaxis Ltd., Frenchs Forest, NSW) may allow many more general practitioners to undertake bronchoprovocation testing in their surgeries and provide a greater degree of sensitivity and specificity than the exercise test as proposed by the UK authors.

The diving medical practitioner must explain all potential risks and give detailed written guidelines on how the individual should monitor their symptoms and when they should not dive. The individual diver must fully understand the instructions and accept responsibility for their actions.

Recommendations

1 Moderate to severe asthmatics should not dive due to the unpredictability of their disease, and the potential risk from pulmonary barotrauma and an exacerbation of their disease either underwater or on the surface.
2 There may be a subset of asthmatics who, either on anti-inflammatory medication or not, have a negative response to either exercise or indirect airway challenge, have normal lung function, are asymptomatic and who are fit to dive. These individuals should use PEF to monitor their lung function. The requirement of symptomatic relief with inhaled bronchodilators within 48 hours excludes diving.
3 Consideration should be given to the measurement of bronchial hyperresponsiveness in those patients with a past history of asthma and who have no symptoms and normal spirometry.
4 All potential divers must be informed of the potential risks of diving and the additional risk active asthma may pose. Written guidelines should be provided and the individual should accept responsibility for following these guidelines.

Acknowledgements

The author wishes to thank Dr Sandra Anderson for her assistance in reviewing this paper.

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SPUMS Award, HTNA ASM 2006

The SPUMS Award for the best presentation by a member of the Hyperbaric Technicians and Nurses Association Annual Scientific Meeting, held in Townsville in August 2006, was given to Carol Baines, Clinical Nurse Manager, Department of Hyperbaric and Diving Medicine, Royal Hobart Hospital. Her presentation, on behalf of Corry van den Broek and herself, was entitled
"Maggots! Can they handle the "pressure"?

The database of randomised controlled trials in hyperbaric medicine maintained by Dr Michael Bennett and colleagues at the Prince of Wales Diving and Hyperbaric Medicine Unit is at:

<www.hboevidence.com>