

The world as it is

Summary of knowledge and thinking about asthma and diving since 1993*

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This discussion paper has a currency of 5 years from the date of publication unless superseded.

Introduction

The 1993 TSANZ discussion paper appears to have been one of the first to be published by a Thoracic Society.¹ This probably reflects the high prevalence of asthma in the Australian and New Zealand population and the high morbidity and mortality associated with the disease at that time. Since 1993 there has been a nationwide effort to improve education of doctors and patients about asthma and its treatment through advertising campaigns. Inhaled corticosteroids are more available and more widely used than they were 10 years ago. Lung function tests are more commonly requested and the testing apparatus used in laboratories is more sophisticated, permitting measurements of flow at low lung volumes. Self-monitoring of symptoms is more common and many asthmatics own peak flow meters. The finding of bronchial hyperresponsiveness (BHR) or bronchial hyperreactivity in a significant proportion of healthy young adults, with a past history of asthma, seeking employment in occupations excluding active asthma, or seeking permission to use drugs before sporting events, supports the need for objective testing before clearance to dive. It is now clear that BHR to hyperpnoea of dry air, an absolute contraindication for scuba diving, can be associated with normal values for resting spirometry.² It is also clear that responses to pharmacological challenges cannot be used to exclude BHR to dry air or to hyperosmolar aerosols.³ In 2004 most public hospital laboratories and many private laboratories provide a choice of bronchial provocation tests. These tests are now well standardised relative to 1993.⁴⁻⁸ The bronchial provocation tests recommended are those that involve the stimulus to which the intending diver is exposed, either exercise or eucapnic hyperpnoea of dry air and non-isotonic aerosols.⁸

Prevalence of Respiratory Disease

There is now excellent documentation of the prevalence of asthma in Australia and New Zealand.⁹⁻¹² Some 18-20% of school children aged 8-13 years have BHR to histamine or exercise.¹²⁻¹⁴ This group of children would now be at the age of those applying to dive and the high prevalence

underscores the importance of using appropriate tests to identify those at risk during diving. Asthma is a term that covers a disease with a wide variation in severity of symptoms and BHR. These hallmarks of asthma will change over time and in response to treatment. It is clear however that BHR usually precedes symptoms of the disease and remains long after treatment has relieved symptoms and lung function has returned to normal. Exercise-induced asthma is a good example of this.^{15,16}

The presence of other respiratory diseases in the Australian and New Zealand community are not as well described as asthma, with the exception of cystic fibrosis. However, anyone with a history of disease or symptoms consistent with a respiratory problem should be referred for assessment of lung function, including spirometry, lung volumes, diffusing capacity and bronchial provocation testing.

The Role of Bronchial Provocation Tests

The role of the bronchial provocation test in the assessment of the diver or intending diver should be to identify those persons who would be at risk from acute airway narrowing during the activities associated with diving. Those who have demonstrable BHR should be told that they may be at increased risk of pulmonary barotrauma (PBT), and the details of the possible consequences of this should be explained.

There are two types of tests used for bronchial provocation referred to as direct and indirect. The direct challenges 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. Bronchial hyperresponsiveness to these agents is not an

Footnote

* The physics of diving was presented in Jenkins C, Anderson SO, Wong R, Veale A. Compressed air diving and respiratory disease. *Med J Aust.* 1993; 158: 275-9 and is available from the TSANZ Office [www.thoracic.org.au].

absolute contraindication for diving because the BHR is not specific for identifying asthma and it is commonly recorded in healthy people without symptoms,¹¹ elite athletes,¹⁷⁻¹⁹ and in smokers.²⁰ Elite swimmers^{17,21} and people who dive regularly using scuba also have a high rate of BHR to inhaled histamine and methacholine so that it would seem unfair to exclude someone from diving on the basis of BHR to these agents.^{22, 23} It is not known if the BHR in divers is a consequence of airway injury from breathing dry air over long periods of time,²⁴ but this is suggested by the trend towards an association between BHR and number of compressed air dives performed.²²

In contrast, the indirect challenges are specific for identifying currently active airway inflammation. This has been demonstrated by the BHR to these challenges being reduced over weeks by treatment with inhaled steroids.²⁵⁻³¹ The indirect challenges include exercise, eucapnic hyperpnoea of dry air (EVH) and challenges with hypertonic aerosols.⁶⁻⁸ These challenges cause release of mediators from inflammatory cells in the airways,^{32,33} probably in response to an increase in airway surface osmolarity. These mediators, which include leukotrienes and prostaglandins, are potent and on a molar basis only one thousandth of the dose is required to induce the same degree of airway narrowing as histamine or methacholine.³⁴ The fact that these potent mediators are involved in these challenges may serve to explain why they are more sensitive for identifying people with exercise-induced asthma compared with methacholine or histamine.^{14,35} The BHR to indirect challenges is associated with the presence of inflammatory cells²⁹ and has been used successfully to assess response to treatment and withdrawal of treatment with inhaled corticosteroids.^{25,30,36}

For these reasons over the last 10 years bronchial provocation using indirect challenges has become more widely used and reported for assessment of asthma for diving and for assessment for some occupations where exercise-induced bronchoconstriction is unwanted (e.g. NSW Police Force). Findings from a recent study of athletes suggest that pharmacological stimuli should no longer be permitted as a sole measurement of BHR to assess suitability to dive because they do not exclude exercise-induced bronchoconstriction which is an absolute contraindication to diving.^{14,35} Strenuous exercise is frequently required of the diver, and there are many opportunities for accidental aspiration of sea water to occur. Inhaling dry air from a tank or fine aerosols of hyperosmolar saline through a faulty valve are stimuli also encountered by the diver. Nowadays many laboratories have the facility to exercise patients and could easily include a dry air challenge during exercise or eucapnic voluntary hyperpnoea in their assessment. The techniques for these tests have also been standardised,^{4,6-8} and there has been a big increase in the number of laboratories in Australia which have experience with the challenges using aerosols of non-isotonic solutions, and in particular 4.5% saline.

There is a growing interest in challenge with eucapnic voluntary hyperpnoea to replace exercise testing for EIB in the laboratory. This test lends itself particularly well to assessment for scuba diving. Most laboratories in Australia would not use the cold air protocol of Assoufi et al as used by Tetzlaff et al.^{22,37} Rather the EVH tests would be carried out for 6 minutes with a target ventilation of 30 times the measured FEV₁.⁶ The higher ventilation and the longer time (2 minutes) appear to compensate adequately for the reduction in temperature of the inspired air.³⁸ High ventilation rates are easily achieved during EVH. Both the ventilation rate achieved and sustained and the water content of inspired air are important determinants of EIB.³⁹ To exclude EIB for divers it is suggested that the ventilation achieved during testing is > 55 l.min⁻¹ because divers are often required to exercise at 2 l.min⁻¹ oxygen consumption. Thus, simple exercise by step testing breathing room air without the appropriate measurement of ventilation and dry inspired air condition would not be an adequate test to exclude EIB in an intending diver. It has been clearly shown that sports specific exercise is far more potent than laboratory based testing.⁴⁰ It is for this reason that EVH is now recommended for testing athletes.^{38,41}

It is particularly important to note that dry air and hyperosmolar aerosols can provoke cough in people with a history of asthma. In our experience, if inhaled hyperosmolar aerosols of saline or hyperpnoea with dry air causes a reduction in FEV₁ or excessive coughing the intending diver is immediately aware of the potential for the same thing to occur whilst diving and usually voluntarily excludes himself from diving with scuba. This voluntary abstention is important and takes the pressure off the examining physician by members of the family or friends trying to encourage a person with a history of asthma to dive.

The airway responses to 4.5% saline have been documented in one laboratory in a group of 180 intending divers with a past history of asthma who had been cleared medically fit to dive.⁴² A positive response consistent with currently active airway inflammation could be demonstrated in 30 or 17% of these applicants who were without current symptoms of asthma, who were taking no medications and

Table 1
Hypertonic (4.5%) saline challenge in 180 prospective divers with a past history of asthma but considered medically fit to dive, subject to BPT⁴²

	Fall < 15%	Fall > 15%
n	150	30
% Fall FEV₁	4.5 ± 3.7	22.3 ± 6.5
FEV₁ % Pred	106.3 ± 14.0	100.3 ± 13.7
FVC % Pred	105.5 ± 11.0	105.1 ± 12.1
FEV₁/VC %	79.8 ± 8.4	76.1 ± 8.8
FEF₂₅₋₇₅ % Pred	81.7 ± 23.5	69.6 ± 20.4

Table 2

Subjects wishing to dive with scuba who responded negatively to questions on asthma yet had a 15% fall in FEV₁ to hypertonic saline (PD₁₅) a value consistent with a diagnosis of currently active asthma

Question	Answer	PD ₁₅ to 4.5% Saline	
		n	%
1. How would you describe your asthma over the past 3 months?	None	21	10.0%
3. How often do you have symptoms from your asthma at present?	None for the past 3 months	22	10.3%
4. In the past 3 months, have you woken at night because of wheezing, chest tightness or cough?	No	43	20.2%
5. How many days in the past 2 weeks have you had a morning wheeze or chest tightness?	None	46	21.6%
6. Does exercise trigger your asthma?	No	37	17.4%
7. How often do you usually use your bronchodilator?	None for 3 months or more	29	13.6%
9. In the last 3 months, have you used your bronchodilator?	No	45	28.0%

without a recent history and who had no other medical reason to be prevented from diving (Table 1).

Since the report of these findings referrals by practitioners to the laboratory appear to have changed in that intending divers, with a history of asthma, are referred to the laboratory for assessment before, rather than after, they have their medical examination. This is both time saving to the doctor and potentially cost saving to the subject and provides important medical information to a significant number of applicants.

At one teaching hospital in Sydney an analysis was made of responses to a self-administered questionnaire in some 212 intending divers after they had each had a challenge test with 4.5% saline. They were aged 27.7 years and 44% were females. The group had a mean % predicted FEV₁ of 104% (95% CI 102.2 to 105.8). Fifty-four of the 212 recorded a 15% fall in FEV₁ in response to 4.5% saline. The mean provoking dose to cause a 15% fall in FEV₁ was 9.7 ml (7.2, 13.2) and the FEV₁% predicted in this group was 98.9% (95.8,102). Many with BHR to 4.5% saline gave negative answers to the questionnaire relating to asthma in the last three months and did not take medication (Table 2).

The lesson from this is that BHR can be common in the absence of symptoms. From the analysis of the questionnaire we found a number of questions that are useful and with each positive response the likelihood of BHR to 4.5% saline increases. These include: self-classification of asthma severity, self-admission of asthma triggers, particularly dust mite and cats, and use of bronchodilator more than once per month but less than once per two weeks.

In the last five years there has been an increasing interest in carrying out tests of BHR with hypertonic aerosols or

eucapnic voluntary hyperpnoea in a number of special groups. These include recruits for the NSW Police Force⁴³ and young athletes being evaluated for exercise-induced bronchoconstriction.⁴⁴ Many of these subjects have marked BHR to eucapnic voluntary hyperpnoea (EVH), a surrogate challenge used to identify exercise-induced bronchoconstriction in the presence of normal values for FEV₁ and FVC.^{2,43,44} The results of the findings in a group of young adults are given in Table 3.

In another study in recruits positive to EVH (% fall in FEV₁ of 25.2% +/- 11.0) the values for FEV₁% predicted were 98.8% +/- 13, with an FEV₁ / VC ratio of 79% +/- 8.6 and FEF₂₅₋₇₅% predicted 80.4% +/- 22.7, all within the normal range. In another group in the same study the lung function in those positive to hypertonic saline (PD₁₅ 6.9 ml CI 4.9, 9.6% fall in FEV₁ 21.4 +/- 4.2) was FEV₁% predicted 98.8% +/- 11.6, FEV₁/FVC 76.8 +/- 9.7, FEF₂₅₋₇₅ 73.6% +/- 24.2).⁴³ Whilst BHR to hyperpnoea or 4.5% saline cannot be excluded by normal values for these indices those with

Table 3
Eucapnic voluntary hyperpnoea –
+ 20 to 25 °C for 6 min at VE 22 to 30 x FEV₁
96 athletes < 31 years referred for possible EIB
(# P < 0.004, * P > 0.05)⁴⁴

n =	31 +ve	65 -ve
FEV ₁ % Pred	105 ± 16	109 ± 13 [#]
FVC % Pred	111 ± 15	109 ± 15 [#]
FEV ₁ /FVC	81 ± 8	86 ± 6 [*]
FEF ₂₅₋₇₅ % Pred	85 ± 24	101 ± 18 [*]
VE L/min	94 ± 24	97 ± 23 [#]
% MVV (FEV ₁ *35)	69	69
% Fall FEV ₁	23 ± 13	4 ± 3 [*]
% Fall FEF ₂₅₋₇₅	36 ± 18	12 ± 7 [*]

abnormal values, particularly of FEF_{25-75} , are more likely to have BHR. The data in the recruits have demonstrated that with good adherence to a medication regimen, the BHR to EVH and 4.5% saline can be reduced to within the normal healthy range with eight to nine weeks' treatment with 800-1000 micrograms of budesonide daily. It is important to note that budesonide only came onto the market in Australia in 1992 and that there has been a significant improvement in asthma treatment since publication of the last discussion paper.

There is recent evidence that flow rates at low lung volumes are lower in divers and are inversely related to the years of diving.⁴⁵ This same author found that those with PBT also had low flow rates at low lung volumes⁴⁶ so that measurement of these flow rates may now be considered an important part of the assessment of lung function. A reduction in FEF_{25} or FEF_{25-75} of > 20% of the predicted values could contribute to risk of PBT. However, Russi has pointed out that no firm conclusions can be drawn between PBT and pre existing lung function or structural abnormality.⁴⁷ This emphasises the importance of paying attention to the flow rates at the lower lung volumes.

There is some evidence that pulmonary abnormalities are associated with increased risk of decompression illness and obstructive airway disease has been identified as an independent risk factor.⁴⁸ Also there is evidence of patchy airway closure in asthmatics demonstrated by single photon emission tomography after inhaling technegas.⁴⁹ Airway closure results in gas trapping (an increased residual volume) and increases risk of PBT. Hyperinflation, measured by an increase in thoracic gas volume, has also been demonstrated acutely in response to challenge with 4.5% saline with the volume increasing from 4.3 l (SD 0.6) to 5.3 l (SD 1.1) at the time the fall in FEV_1 was 18% (SD 23).⁴² These data suggest that even small reductions in FEV_1 can lead to hyperinflation and gas trapping and a reduction of 15% in FEV_1 should not be considered just borderline.

If people with a past history of asthma, but without significant BHR to challenge by hyperpnoea or hypertonic aerosols and with normal lung function, are thought to have a relatively low risk of problems and permitted to dive, they should be instructed to be aware of change in their asthma status over time. Asthma exacerbations can occur particularly following viral infections and exposure to allergens to which the subject may be sensitised. Asthmatics cleared to dive should be informed that there is a risk that their asthma may become active again. They should also be informed to ensure that filtered air is used in filling their compressed air tanks as there are reports of allergen particle exposure to unfiltered air.

The British Thoracic Society Guidelines⁴⁸ suggest that measurements twice daily of peak flow should be made by asthmatics during the diving season variability may be useful but this index of asthma has limitations.⁵⁰ For

example lack of variability does not exclude exercise-induced bronchoconstriction a feature that is accepted by the diving medical community as an absolute contraindication to diving. We suggest that asthmatics may require further referral to the laboratory for testing during their diving careers.

Guidelines and Recommendations for Diving from Other Countries

Some guideline and discussion papers have recently been published and the reader is referred to these for more information on recommendations⁴⁸ and data relating to asthmatics and diving incidents.⁵¹ Recommendations have also been made by medical personnel involved in research in diving medicine.^{52,53}

The British have tended to be more tolerant towards asthma, and the findings of Farrell & Glanville (1990) may explain this continued tolerance. Similarly, the analysis by Neuman et al⁵³ in the USA suggests that there is only a 1.6 fold increase risk for arterial gas embolism in asthmatic subjects increasing to 1.98 in those with a current history of asthma. Neither of these increases reached statistical significance. No similar data are available in Australia for this type of analysis, although there are data on the medical conditions of recreational divers who dive despite medical contraindications. Taylor found 2.6% of 346 recreational divers reporting current asthma and 22.8% reporting current allergies but other respiratory disease was rare with only one subject reporting chronic obstructive lung disease and two others reporting previous history of a pneumothorax.⁵⁴

Morbidity and Mortality

Project Stickybeak is an ongoing investigation seeking to document all types and severities of diving related accidents (www.spums.org.au/diveinfo.htm). It reports 88 deaths in Australia between 1980-1990. There are some recent Canadian data on risk of decompression illness and death where the denominator used was air fills. The findings suggest that incidence of death is 0.002% of dives and for decompression illness 0.01% of dives.⁵⁵

Conclusion

With respect to asthma the approach by most Respiratory Physicians is a conservative one, with scuba to be disallowed for anyone with a history of symptoms and medication for asthma within the last five years. It would now seem to be an appropriate time to re-evaluate this suggestion in the light of the improved medication regimens, the ease with which lung function and bronchial provocation tests can be performed in Australia and New Zealand, and the move towards the informed risk assessment model. Given that bronchial hyperresponsiveness to the very stimuli experienced by the diver (hyperpnoea of dry air during exercise and possible aspiration of sea water) occurs in a

significant number of people with a past history of asthma but no current symptoms and good lung function, measurement of BHR to these stimuli is strongly recommended. The results of these tests should be part of the risk assessment approach to diving where the subject needs to acknowledge that they have been informed of potential risks and hazards of diving with asthma.⁵⁶

The Australia and New Zealand Standard

The Australian Standard for diving is still appropriate (AS/NZ 2299.1:1999) although it has been enlarged and the respiratory section is reproduced in the Appendix below. The conditions shall require a careful risk assessment and may be a consideration for disqualification.

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Additional sources of reference available on the Internet

There are now a number of diving websites that provide useful information. The website for the South Pacific Underwater Journal (<http://www.spums.org.au>), for example, provides the medical forms required for passing a recreational diver. Others from overseas include The British Sub Aqua Club (www.bsac.com) and Divers Alert Network (www.diversalertnetwork.org). For people who are excluded from scuba diving for their asthma we suggest a referral to the Asthma Australia website (www.asthmaaustralia.org.au) for education materials.

Appendix

The following Appendix is taken from AS/NZS 2299.1: 1999. The information given in this appendix is relevant only to examination of individuals considering recreational scuba diving. Document AS 2299-1992 should be referred to for criteria for medical examination of individuals intending to commence diving as an occupation.

K4.11 Respiratory System

The respiratory system should be examined as follows:

- (a) Particular attention must be paid to any condition that might cause retention and trapping of expanding gas in any part of the lungs during decompression. This includes the following conditions which are considered to be contraindications to diving.
 - (i) Any chronic lung disease, past or present.
 - (ii) Any history of spontaneous pneumothorax, perforating chest injuries, or open chest surgery.
 - (iii) Any evidence of obstructive airway disease for example asthma, chronic bronchitis, allergic bronchospasm.
 - (iv) Any fibrotic lesion of the lung that may cause generalised or localised lack of compliance in lung tissue.
 - (v) Any chest X-ray signs of pulmonary adhesions, tenting effects, emphysematous change, cysts, blebs or bullae.

A past history of asthma may be acceptable, but this and any other cases of doubt indicate the need for specialist opinion. Such opinion should include inhalational challenge testing if there is any doubt about the possibility of bronchial hyperreactivity.

- (b) A large plate posterior-anterior chest X-ray should be performed at the initial examination. Chest X-ray should be performed subsequently as part of a fitness review following serious chest infection, and should be considered at intervals not exceeding five years for

divers with extensive exposure to diving or any respiratory risk factor.

- (c) Pulmonary function tests shall be conducted as follows, using equipment capable of reading to at least 7 litres:
 - (i) At initial examination, all divers shall have pulmonary function tests to establish forced expiratory volume at one second (FEV_1) and forced vital capacity (FVC), recording the best of three measurements. This test should be repeated at intervals not exceeding five years.
 - (ii) An FEV_1 or FVC of more than 20% below predicted values or FEV_1/FVC ratio of less than 75% may indicate increased risk of pulmonary barotrauma and is an indication for specialist assessment.

While five-yearly chest X-ray and pulmonary function tests are considered sufficiently frequent for healthy divers with no risk factors for pulmonary disease, more frequent screening is indicated for smokers, and divers who had abnormalities noted on previous examination.

If no other abnormality is present, a finding of fitness may be allowable if additional specialist pulmonary function tests and opinion do not find any fixed or intermittent outflow obstruction that might predispose to pulmonary barotrauma.

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