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Can asthmatic subjects dive?

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ABSTRACT Recreational diving with self-contained underwater breathing apparatus (scuba) has grown in popularity. Asthma is a common disease with a similar prevalence in divers as in the general population. Due to theoretical concern about an increased risk for pulmonary barotrauma and decompression sickness in asthmatic divers, in the past the approach to asthmatic diver candidates was very conservative, with scuba disallowed. However, experience in the field and data in the current literature do not support this dogmatic approach. In this review the theoretical risk factors of diving with asthma, the epidemiological data and the recommended approach to the asthmatic diver candidate will be described.



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The theoretical risks of diving with asthma, epidemiological data and the recommended approach to asthmatic divers <http://ow.ly/105KuZ>

Introduction

Recreational diving with self-contained underwater breathing apparatus (scuba) has grown in popularity and millions of dives are performed in USA each year. Asthma is a common disease with a prevalence of ~7% in the general population and probably has a similar prevalence among divers [1]. There is obvious theoretical concern for asthmatic divers. While pulmonary obstruction, air trapping and hyperinflation would seem to place the asthmatic diver at increased risk for pulmonary barotrauma, to date, there has been little evidence of increased risk in this diving population. During diving the asthmatic diver may be exposed to several environmental factors that may increase the risk of bronchospasm and the development of an acute asthmatic attack. An acute asthmatic attack can lead to panic and drowning. Therefore, traditionally, asthmatics were excluded from diving [2]. However, real world experience showing a low incidence of adverse events has altered thinking about the prohibition of diving in asthmatics. The evidence is equivocal for the risk of pulmonary barotrauma (PBT) or decompression sickness among divers with asthma and there is no epidemiological evidence for an increased relative risk of pulmonary barotrauma, decompression sickness or death among divers with asthma. Nevertheless, the current evidence may be biased, because it only accounts for asthmatics with mild disease that have chosen to dive under the current guidelines for diving with asthma [3, 4]. Therefore, the actual risk for all asthmatics, particularly severe or uncontrolled asthmatics, may be higher than what is documented in published studies. Consequently, the topic of asthma and diving has long been a controversial subject in the recreational diving community and some of the most frequently asked questions include whether asthmatic subjects can dive and under what circumstances diving is safe for a diver with asthma.

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Diving physiology and pulmonary barotrauma

During a dive the surrounding pressure increases in proportion to the depth. At sea level, normal atmospheric pressure or one atmosphere absolute is equivalent to the pressure of a column of 760 mmHg (1.013 bar). Every 10 m of seawater descended will exert an additional pressure of 1 bar, so at a depth of 40 m seawater the surrounding pressure is 5 bar. Sport divers usually use self-contained underwater breathing apparatus that allows the diver to breathe air supplied from a high-pressure tank carried by the diver and delivered through a pressure regulator that accommodates the changing ambient pressure of the diving environment.

Boyle's law states that, if the temperature of a fixed mass of an ideal gas is kept constant, volume and pressure are inversely related. Consequently, when the pressure is doubled, the volume is reduced to one half of the original volume.

PBT refers to lung injury induced by rapid changes in intrapulmonary pressures related to the surrounding ambient pressure during diving. PBT may occur even at small pressure differences, and symptoms include pneumomediastinum, pneumothorax and the most feared complication: arterial gas emboli (AGE). PBT can occur during the descent or ascent of a dive [5–8], but the significant concern occurs during ascent from depth while breathing compressed air that must expand based on the physical principles of Boyle's law.

During ascent, in accordance with Boyle's law, the lung volume will expand as the surrounding pressure decreases. Therefore, the diver must exhale during ascent in order to equalise the intrapulmonary pressure to the surrounding pressure. Theoretically, in asthmatic divers with airways obstruction and air trapping, during ascent, the lung volume in lung regions with air trapping will increase, with overdistension of the alveoli and bronchi leading to lung rupture. A transpulmonary pressure of 95–110 cmH₂O is sufficient to disrupt the pulmonary parenchyma and force gas into the interstitium [9, 10]. When alveolar rupture occurs, gas infiltrates the peribronchial space and causes pulmonary interstitial emphysema, pneumomediastinum or pneumothorax [11, 12]. Gas may also enter the systemic circulation by several mechanisms and cause AGE [13, 14].

Does asthma increase the risk for pulmonary barotrauma during diving?

During a dive there are several mechanisms by which an asthmatic diver may be exposed to the risk of an acute bronchospasm. Breathing cold and dry air throughout the dive, aspiration of salty seawater, inhalation of aerosolised hypertonic saline from faulty regulators and excessive exertion during the dive, especially in the nontrained diver, may all lead to an acute bronchospasm. A more rare possible cause of bronchospasm is contamination of the air tank through the use of nonfiltered air containing pollens, to which the diver may be allergic [15, 16]. D'AMATO *et al.* [15] described a 37-year-old who developed a severe asthma attack while diving. On further investigation, the diver's tank was found to have been filled with unfiltered air that was contaminated with granules of *Parietaria* pollen, which the diver was allergic to.

In asthma, chronic airways inflammation with airway remodelling with loss of elastic recoil may predispose to PBT. Furthermore, asthmatic patients may have normal spirometry but still have an abnormal increase in peripheral airway resistance and loss of elastic recoil [17]. In 14 healthy divers who suffered PBT during shallow water diving, COLEBATCH and NG [18] found that the static recoil pressure at maximum inspiration and an index of lung distensibility were significantly increased and decreased, respectively, when compared with a control group of 10 divers and 34 healthy volunteers. The authors concluded that the decreased lung distensibility reflected a decreased airspace size and relatively stiff airways, which may magnify the elastic stresses in the peribronchial alveolar tissue increasing the possibility of rupture of alveolar walls with interstitial gas dissection.

Recent studies highlight the role of the small airways in the pathophysiology of asthma and there is evidence of small airway dysfunction in asthmatic patients with normal spirometry [19, 20]. Currently, there are no methods for clinical evaluation of small airway disease using spirometry and forced expiratory flows. However, studies have discussed the association between reduced mid-expiratory flow rate and PBT. TETZLAFF *et al.* [20] described significantly reduced mid-expiratory flow rates at 50% and 25% of vital capacity in 15 patients with PBT compared with 15 cases of decompression sickness without PBT. The authors speculated that the reduced mid-expiratory flow rates indicate irreversible peripheral airway obstruction due to small airways disease. Closure of the small airways might cause air trapping in regions distal to the site of obstruction and thus may contribute to PBT. Two out of the 15 PBT patients had childhood asthma. In contrast to these findings, analysis of 10 cases of PBT that occurred during submarine escape training in the Royal Navy from 1975 to 1997 found an association between low forced vital capacity (FVC) and PBT [21]. A possible explanation may be that the small-for-size lung contained within a normal size (or near-normal size) chest is able to expand past the total lung capacity (TLC) during a rapid ascent and so ruptures more easily than the normal lung, which is prevented from

expanding beyond TLC by an appropriately sized chest wall. Unfortunately, however, low FVC is insufficiently specific to serve as a risk factor for a PBT.

Another possible risk factor in the asthmatic diver is impaired exercise capacity due to a reduction in maximum ventilation caused by increased airway resistance. Airway resistance increases secondary to the effect of immersion and by breathing dense air through regulators during a dive. The increased ambient air pressure results in increased air density with turbulent ventilator flow eventually leading to a decrease in dynamic lung volumes and flows and an increase in airway resistance. These changes will be prominent during exercise with higher ventilatory demands, increasing the work of breathing that might cause a respiratory limitation on exercise [22, 23].

Asthma and diving: what is the evidence?

Due to the theoretical risks and a few small studies, asthma had long been considered as an absolute contraindication to recreational scuba diving. However, in reality the prevalence of asthmatic divers in the diving community is similar to the general population and many asthmatic individuals are able to scuba dive without diving events or injuries. Furthermore, the current epidemiological data on the risks of asthma and diving are limited. Most of the studies were retrospective, questionnaire based or involved a retrospective review of diving accident registries with controversial results [24–29]. *WEAVER et al.* [30] conducted a study to determine the prevalence and magnitude of airway obstruction in a cohort of recreational divers. Of 231 divers who had acceptable quality spirometry 10% had mild, 1.7% had moderate and 0.4% had severe airflow obstruction, with an overall prevalence of airflow obstruction by spirometry of 12%. The authors did not mention if the divers with airway obstruction had any complications. *FARRELL et al.* [24] carried out a questionnaire-based study that included 104 divers aged 16–40 years old. 89 of the respondents had had asthma since childhood and 22 wheezed daily, of whom nine divers thought they were safe to dive 1 h after wheezing. Those divers who thought it was safe to wheeze 1 h before diving logged 1241 dives and the remaining asthmatics logged 12,864 dives, all of which were accident free dives. *NEUMAN et al.* [25] reported that 5.3% of 696 divers surveyed admitted to having been diagnosed with asthma. No cases of PBT were reported during 6000 dives. A retrospective review of 1213 cases of decompression sickness [27], of which 196 had suffered AGE, identified 16 divers out of the 196 with AGE had a history of asthma, seven of whom were current asthmatics. The control group was 696 divers selected from diving alert network members who completed a questionnaire, of whom 37 had a history of asthma and 13 had current asthma. The data suggested an increased risk for AGE in asthmatic divers, with an odds ratio of 1.58 for all asthmatics and 1.98 for current asthmatics, but the confidence intervals were large and the data did not reach statistical significance suggesting that if there is an increased risk for AGE in asthmatic divers the risk is small and larger controlled studies are needed [27]. Another survey of asthmatic divers performed by the diving alert network included 279 divers who participated in 56334 dives. The majority of the 279 divers had active asthma and were using medications, 55% took medication prior to diving and 20.7% had been hospitalised due to asthma in the past. 11 cases of decompression sickness were reported in eight divers and the calculated risk of decompression sickness in their questionnaire data exceeded the estimated risk for unselected recreational divers [28]. However, a physiological link between decompression sickness related to excess inert gas loading and PBT has not been established. *EDMONDS and WALKER* [29] reported that, in a series of 100 diving deaths in Australia and New Zealand, nine occurred in asthmatics despite the fact that less than 1% of divers reported a history of asthma, suggesting an increased risk for asthmatic divers. Two case reports suggested that breathing compressed air contaminated by pollen may cause symptomatic bronchoconstriction during diving in divers with allergic asthma and increase the risk of PBT [15, 16].

The current recommendations

Since asthma is not a single disease, with differences among patients with regards to precipitating factors, pulmonary function and degree of airway obstruction and reversibility, each asthmatic diving candidate should be assessed individually evaluating their asthma history and severity.

There are several published guidelines with a variety of recommendations for diving with asthma. *STRAUSS* [7] suggested that contraindications to diving should include the following: significant obstructive pulmonary disease with minimal values for forced expiratory volume in 1 s (FEV₁), FVC and maximum voluntary ventilation of 75% of predicted; any attack of asthma occurring within the past 2 years; the need for preventive therapy; or any episode of bronchospasm associated with exertion or inhalation of cold air. However, other diving experts or diving societies have more liberal approaches with other viewpoints [3, 4, 31–34]. Most experts recommend that asthmatic subjects with tremendous airway variability who may get worse for no apparent reason, those with poorly defined triggers and abnormal pulmonary function tests, and asthmatics with exercise-, cold- or emotion-induced asthma should be excluded from diving. *JENKINS et al.* [31] are more conservative, suggesting that any asthma symptoms in the preceding 5 years should

prompt advice against diving. The UK Sport Diving Medical Committee suggests that asthmatic individuals who are currently well controlled and have normal pulmonary function tests may dive if they have a negative exercise test [32]. However, during the diving season, asthmatic divers should monitor their asthma symptoms and perform twice daily peak flow measurements, and should not dive if they have any of the following: active asthma, *i.e.* symptoms requiring relief medication in the 48 h preceding the dive; reduced peak expiratory flow (PEF) (>10% reduction from best values); or increased PEF variability (>20% diurnal variation). Allergic asthmatic subjects in whom allergy is the only precipitating factor for wheezing may dive if they have normal pulmonary function. The Undersea and Hyperbaric Medical Society in the USA recommends that asthmatics requiring rescue medication should not dive. If a patient has mild-to-moderate asthma with normal screening spirometry then he/she can be considered a candidate for diving. However, if a patient suffers from an asthma attack they should not dive until their airway function on spirometry returns to normal. An exercise challenge test may be performed [33].

The Thoracic Society of Australia and New Zealand recommends that asthmatic patients with active disease in past 5 years do not participate in recreational diving [31]. If the history of asthma is more remote than 5 years, a bronchial provocation test should be performed to determine airway hyperresponsiveness (AHR). The preferred challenge is one that mimics conditions during diving such as hyperosmolar saline, mannitol, cold dry air hyperventilation or exercise challenge test [4]. A discussion paper for the Thoracic Society of Australia and New Zealand [34] states that bronchial hyperresponsiveness to the very stimuli experienced by the diver (hyperpnoea of dry air during exercise and possible aspiration of seawater) occurs in a significant number of people with a past history of asthma but no current symptoms and good lung function; therefore, measurement of bronchial hyperresponsiveness to these stimuli is strongly recommended. The results of these tests should be part of the risk assessment approach to diving. However, this protocol identifies many asthmatics that could dive safely and would be excluded, and is not generally used in other countries. Other investigators suggest that mid-expiratory flow at 25% and 50% of FVC can help distinguish between those at higher risk of complications and those with a lower risk, even when FEV₁ exceeds 80% of predicted [20, 35].

Airway hyperresponsiveness and diving

Only a few studies have systematically investigated the association between AHR and diving, and the value of nonspecific pharmacological inhalation challenges has been debated. TETZLAFF *et al.* [36] determined the prevalence of AHR using a histamine bronchial challenge in compressed air divers in a cross-sectional sample of 59 healthy male volunteers (28 divers and 31 diving candidates (controls)). AHR to histamine was significantly increased among divers and positively related to diving experience, suggesting that chronic exposure to compressed air in a hyperbaric environment may enhance airway reactivity to nonspecific bronchoconstriction stimuli. In a study evaluating diving candidates who may be at risk for PBT, a bronchial challenge with carbachol was performed in 76 diving candidate with current or past asthma or with allergic rhinitis. Bronchial hyperresponsiveness was found in nearly half of the subjects (47%), and was much more frequent in the current asthmatic subjects [37]. Furthermore, the prevalence of bronchial hyperresponsiveness was fairly high (36%) in the allergic group [37]. ANDERSON *et al.* [38]. studied 180 divers with a history of asthma. 90 divers had normal pulmonary function tests and no bronchial hyperresponsiveness. In 30 subjects, the bronchial provocation test with hypertonic saline was positive (a fall in FEV₁ of more than 15%) and they were excluded from diving. In subjects with a borderline post-saline fall in FEV₁ (10–14.9%), the authors speculate that diving may be permissible if tests of static lung volumes and expiratory flows at low lung volumes derived from the flow–volume loop are normal [39]. The Thoracic Society of Australia and New Zealand [38] suggests that direct challenge tests are nonspecific and bronchial hyperresponsiveness to agents such as methacholine should not be considered an absolute contraindication for diving. However, indirect challenges such as exercise, eucapnic hyperpnoea of dry air and challenges with hypertonic aerosols are more appropriate for evaluation of asthmatic diver candidates. Using inhaled hyperosmolar aerosols of saline or hyperpnoea with dry air may cause a reduction in FEV₁ or excessive coughing in the diver candidate, which may result in voluntary exclusion from diving. However, interpretation of provocative tests must be done cautiously, due to the high sensitivity and low specificity of these tests in truly reflecting the risk for diving related complications in asthmatics. 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.

Diving-related airway hyperactivity

The question of whether diving may have a detrimental effect on lung function in asthmatic divers is also still open. IVKOVIC *et al.* [40] reported that a single, shallow, swimming pool scuba dive caused a reduction in FEV₁, FEV₁/FVC ratio and forced expiratory flows in a group of asthmatic divers after the dive compared with a control group of healthy divers. The authors concluded that even a single dive at 5 m may impair the function of the small airways in asthmatic divers. CIRILLO *et al.* [41] evaluated the effect of

scuba diving at a depth of 50 m on lung function and airway responsiveness to methacholine in atopic nonasthmatics and healthy subjects. 15 atopic nonasthmatic subjects and 15 controls underwent spirometry and skin prick testing for common environmental allergens. Methacholine challenge was performed 24 h before, and 20 min and 24 h after a standardised scuba-dive test and after a hyperbaric-chamber test. Scuba diving was associated with development of early AHR to methacholine in atopic subjects. However, the high sensitivity and low specificity of methacholine testing renders much of the methacholine data uncertain. An interesting study by TETZLAFF *et al.* [36] found that chronic exposure to compressed air in a hyperbaric environment may enhance airway reactivity to nonspecific bronchoconstriction stimuli in healthy divers.

The approach to the asthmatic diver candidate

While evaluating asthmatic candidates for clearance for recreational diving we should evaluate each subject individually. As noted previously, the initial conversation with the diving candidate should emphasise prudence in selecting the diving environment. Ideally, this should be done by a physician trained in diving medicine, who has some personal experience of diving. This conversation should consider the individual diver's physical capacity, understanding of the sea conditions (temperature, currents, surface state, *etc.*) and adherence to recommended sport diving depth–time limits.

Evaluation should include a detailed history and physical examination, spirometry with a reversibility test at rest and exercise pulmonary function tests to ~75% of predicted maximum exercise capacity, with the understanding that reaching 60% of maximal exercise capacity during diving would be a rare event in the prudent diver. Testing airway reactivity using provocative testing, such as methacholine or hypertonic saline, has been abandoned in most countries due to the high false positive rate, and criteria based on rest and exercise pulmonary function tests have been found to provide the evaluation needed for safe diving.

If spirometry is abnormal ($FEV_1 < 80\%$, FEV_1/FVC ratio < 0.8), or in cases where there is normal spirometry with a positive reversibility test or positive exercise challenge test we should advise against diving. Any asthmatic subjects with severe asthma or uncontrolled asthma, or asthmatic subjects with cold-, exercise- or emotion-induced asthma should not be considered for clearance to dive.

Asthmatic subjects, including subjects with chronic preventive treatment with inhaled corticosteroids, who have well controlled asthma, normal spirometry with negative variability tests and negative exercise tests may be allowed to dive. However, asthmatic divers should not dive within 48 h of having chest symptoms and needing to use a rescue bronchodilator. Following the UK guidelines [3], peak flow measurements should be followed for asthmatic divers especially during the diving season. A fall of 10% or more in the peak flow measurement should exclude diving for the asthmatic patient. The asthmatic diver should not scuba dive again until their peak flow measurement is within 10% of their best value. This should occur at least 48 h prior to the dive [3].

“Large lungs” in diving candidates may be confused with obstructive airway disease. In this population, despite abnormal spirometry manifesting as a normal FEV_1 but a low FEV_1/FVC ratio, further evaluation revealed no evidence of obstructive airways disease. These divers have a large FVC, which results in a reduced FEV_1/FVC ratio, no asthma symptoms, no air trapping and a negative challenge test for asthma, with no contraindication for diving.

Conclusion

While there is a strong theoretical risk of a serious complication from diving with asthma [42], real world experience has shown that adverse events related to asthma and diving are rare. Because it is highly unlikely that a randomised clinical trial could be conducted to answer this question, use of real world experience, registry data and surveys are the only means to gain insight into the risk incurred by diving with asthma or a history of asthma. To date, this approach has not identified an increased risk for divers with asthma or a history of asthma. Indeed, this approach to using real world data has become more common, particularly through analysis of propensity matched data from large registries. While there are data describing small airway compression while diving, many of these studies were carried out at depths deeper than the recommended recreational diving depths. Most sport divers limit dive depths to 130 feet (39.6 m), and avoid stressful environments. Usually sport diving is conducted at an energy level of 3–4 metabolic equivalents (METS), and a capacity for up to 6 METS would allow a diver to handle occasional higher exercise demands [43, 44]. In advising any diver, prudence is always a key word to ensure the diver understands that avoidance of stressful diving should always be a first consideration. This approach to divers with asthma or a history of asthma should minimise any adverse events related to diving with asthma. In general, the effects of the various changes induced by asthma are minimal in usual sport diving exposure, in spite of the strong theoretical risk derived from physiological studies, which are usually carried out at high workloads.

References

- 1 Corson KS, Moon RE. Risk of diving injury to asthmatics. *Alert Diver* 1991; (Sept–Oct): 12–13.
- 2 Krieger BP. Diving: what to tell the patient with asthma and why? *Curr Opin Pulm Med* 2001; 7: 32–38.
- 3 British Thoracic Society Fitness to Dive Group, a Subgroup of the British Thoracic Society Standards of Care Committee. British Thoracic Society guidelines on respiratory aspects of fitness for diving. *Thorax* 2003; 58: 3–13.
- 4 Gorman D, Veale A. SPUMS policy on asthma and fitness for diving. Melbourne, South Pacific Underwater Medicine Society, 1995. www.spums.org.au/page/spums-policy-asthma-and-fitness-diving Date last accessed: January 25, 2016.
- 5 Divers Alert Network. Report on decompression illness, diving fatalities and project dive exploration. DAN's annual review of recreational scuba diving injuries and fatalities based on 2001 data. Durham, Divers Alert Network, 2003.
- 6 Strauss MB, Wright PW. Thoracic squeeze diving casualty. *Aerosp Med* 1971; 42: 673–675.
- 7 Strauss RH. Diving medicine. *Am Rev Respir Dis* 1979; 119: 1001–1023.
- 8 Tetzlaff K, Thorsen E. Breathing at depth: physiologic and clinical aspects of diving while breathing compressed gas. *Clin Chest Med* 2005; 26: 355–380.
- 9 Schaefer KE, McNulty WP Jr, Carey C, et al. Mechanisms in development of interstitial emphysema and air embolism on decompression from depth. *J Appl Physiol* 1958; 13: 15–29.
- 10 Malhotra MS, Wright HC. The effects of a raised intrapulmonary pressure on the lungs of fresh unchilled cadavers. *J Pathol Bacteriol* 1961; 82: 198–202.
- 11 Oh ST, Kim W, Jeon HM, et al. Massive pneumoperitoneum after scuba diving. *J Korean Med Sci* 2003; 18: 281–283.
- 12 Muth CM, Shank ES. Gas embolism. *N Engl J Med* 2000; 342: 476–482.
- 13 Gerriets T, Tetzlaff K, Liceni T, et al. Arteriovenous bubbles following cold water sport dives: relation to right-to-left shunting. *Neurology* 2000; 55: 1741–1743.
- 14 Schwerzmann M, Seiler C, Lipp E, et al. Relation between directly detected patent foramen ovale and ischemic brain lesions in sport divers. *Ann Intern Med* 2001; 134: 21–24.
- 15 D'Amato G, Noschese P, Russo M, et al. Pollen asthma in the deep. *J Allergy Clin Immunol* 1999; 104: 710.
- 16 Astarita C, Gargano D, Di Martino P. Pollen trapped in a scuba tank: a potential hazard for allergic divers. *Ann Intern Med* 2000; 132: 166–167.
- 17 Bousquet J, Jeffrey PK, Busse WW, et al. Asthma. From bronchoconstriction to airways inflammation and remodeling. *Am J Respir Crit Care Med* 2000; 161: 1720–1745.
- 18 Colebatch HJ, Ng CKY. Decreased pulmonary distensibility and pulmonary barotrauma in divers. *Respir Physiol* 1991; 86: 293–303.
- 19 Wilmshurst P, Davidson C, O'Connell G, et al. Role of cardiorespiratory abnormalities, smoking and dive characteristics in the manifestations of neurological decompression illness. *Clin Sci* 1994; 86: 297–303.
- 20 Tetzlaff K, Reuter M, Leplow B, et al. Risk factors for pulmonary barotrauma in divers. *Chest* 1997; 112: 654–659.
- 21 Benton PJ, Francis TJR, Pethybridge RJ. Spirometric indices and the risk of pulmonary barotrauma in submarine escape training. *Undersea Hyperb Med* 1999; 26: 213–217.
- 22 Lundgren CEG, Miller JN. The lung at depth. New York, Marcel Dekker, 1999.
- 23 Maio DA, Farhi LE. Effect of gas density on mechanics of breathing. *J Appl Physiol* 1967; 23: 687–693.
- 24 Farrell PJS, Glanvill P. Diving practices of scuba divers with asthma. *BMJ* 1990; 300: 166.
- 25 Neuman TS, Powers AT, Osborne DE. The prevalence of asthma, diabetes, and epilepsy in a population of divers. *Undersea Biomed Res* 1988; 15: Suppl, 62–63.
- 26 Walker D. New Zealand diving-related fatalities 1981–82. *SPUMS J* 1984; 14: 12–16.
- 27 Corson KS, Dovenbarger JA, Moon RE, et al. Risk assessment of asthma for decompression illness [abstract]. *Undersea Biomed Res* 1991; 18: Suppl, 16–17.
- 28 Corson KS, Moon RE, Nealen ML, et al. A survey of diving asthmatics [abstract]. *Undersea Biomed Res* 1992; 19: Suppl, 18–19.
- 29 Edmonds C, Walker D. Scuba diving fatalities in Australia and New Zealand. 1. The human factor. *SPUMS J* 1989; 19: 94–104.
- 30 Weaver LK, Churchill SK, Hegewald MJ, et al. Prevalence of airway obstruction in recreational SCUBA divers. *Wilderness Environ Med* 2009; 20: 125–128.
- 31 Jenkins C, Anderson SD, Wong R, et al. Compressed air diving and respiratory disease. A discussion document of the Thoracic Society of Australia and New Zealand. *Med J Aust* 1993; 158: 275–279.
- 32 UK Diving Medical Committee. Asthma. <http://ukdmc.org/2015/09/29/asthma/> Date last accessed: January 2, 2016.
- 33 Harrison D, Lloyd-Smith R, Khazei A, et al. Controversies in the medical clearance of recreational scuba divers: updates on asthma, diabetes mellitus, coronary artery disease, and patent foramen ovale. *Curr Sports Med Rep* 2005; 4: 275–281.
- 34 Anderson SD, Wong R, Bennett M, et al. Summary of knowledge and thinking about asthma and diving since 1993*: discussion paper for the Thoracic Society of Australia and New Zealand, November 2004. *Diving Hyperb Med* 2006; 36: 12–18.
- 35 Bove AA. Pulmonary barotrauma in divers: can prospective pulmonary function testing identify those at risk? *Chest* 1997; 112: 576–578.
- 36 Tetzlaff K, Neubauer B, Reuter M, et al. Atopy, airway reactivity and compressed air diving in males. *Respiration* 1998; 65: 270–274.
- 37 Neuman TS, Bove AA, O'Connor RD, et al. Asthma and diving. *Ann Allergy* 1994; 73: 344–350.
- 38 Anderson SD, Brannan J, Trevillion L, et al. Lung function and bronchial provocation tests for intending divers with a history of asthma. *SPUMS J* 1995; 25: 233–248.
- 39 Badier M, Guillot C, Delpierre S, et al. Value of bronchial challenge in scuba diving candidates. *J Asthma* 2000; 37: 661–665.
- 40 Ivkovic D, Markovic M, Todorovic BS, et al. Effect of a single pool dive on pulmonary function in asthmatic and non-asthmatic divers. *Diving Hyperb Med* 2012; 42: 72–77.
- 41 Cirillo I, Vizzaccaro A, Crimi E. Airway reactivity and diving in healthy and atopic subjects. *Med Sci Sports Exerc* 2003; 35: 1493–1498.

- 42 Van Schoor J, Joos GF, Pauwels RA. Indirect bronchial hyperresponsiveness in asthma: mechanisms, pharmacology and implications for clinical research. *Eur Respir J* 2000; 16: 514–533.
- 43 Bove AA. The cardiovascular system and diving risk. *Undersea Hyperb Med* 2011; 38: 261–269.
- 44 Pendergast DR, Tedesco M, Nawrocki DM, *et al.* Energetics of underwater swimming with SCUBA. *Med Sci Sports Exerc* 1996; 28: 573–580.