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## ORIGINAL RESEARCH

# Prevalence and characteristics of lung function changes in recreational scuba divers

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**Abstract**

**Aims:** To investigate the hypothesis that a salt water SCUBA dive may cause bronchoconstriction in some individuals.

**Methods:** 100 experienced recreational SCUBA divers acted as their own controls. Spirometry measures were taken with Easyone™ spirometers before and after a dive. Measures recorded included $FEV_1$/FVC ratio and forced mid-expiratory flow ($FEF_{25-75\%}$).

**Results:** 60 participants (68% male, 32% female) aged between 19-68 years (mean 47 years) produced data meeting ATS/ERS international standards. Of these, 23% exhibited pre-dive $FEV_1$/FVC ratio values less than 75%. Statistics on paired samples of pre- and post-parameters showed a significant decrease in FVC post-dive but did not show significanct reductions in $FEV_1$ or $FEV_1$/FVC. Six (10%) were current smokers and 13 (21%) were former smokers.

**Conclusions:** 25% of participants had reduced $FEV_1$/FVC ratio regardless of undertaking a dive. Consideration of the clinical implications requires further investigation.



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**Keywords** spirometry, scuba divers, pulmonary disease, airflow obstruction, field study



## Introduction

Globally, there is greater awareness of the benefits of remaining active and healthy for the whole of one's life. Knowledge of the risks that certain activities pose to health is essential for optimal health management. With greater awareness though, there is growing concern internationally about lung disease and asthma and the subsequent impact that diving with self-contained underwater breathing apparatus (SCUBA) may have on lung health. There has been limited research into the impact of diving on lung health, and whether or not recreational divers are at risk of developing lung disease.

Long-term effects on respiratory function have been found in commercial divers who perform deep dives, indicating that divers may be at risk of developing respiratory disease.[1] However, few studies have investigated those who dive in shallower water with self-contained breathing apparatus.

Tetzlaff *et al*. studied 18 male recreational divers in a hyperbaric chamber.[2] The dive profile was controlled and subjects used full-face masks rather than demand valves. The study concluded that atopic divers are more susceptible to the effects of diving on lung function and suggested that diving-related factors and diving history are associated with diminished flows in lung volumes. They also demonstrated that effects on respiratory function were consistent with small airways dysfunction which may lead to long-term effects on respiratory function in SCUBA divers.[2]

Cross-sectional studies have shown that divers frequently have unusually large lung volumes associated with a low forced expiratory volume in one second ($FEV_1$) / forced vital capacity (FVC) ratio ($FEV_1$%) suggestive of obstructive airways disease or airflow limitation.[3] Reduced airflow may be due to air trapping, which increases the risk of pulmonary barotrauma and arterial gas embolism during ascent.

One concern is that repeated pulmonary insult may result in persistent or progressive decreases in lung function.[4] Researchers have reported significant reductions in pulmonary function among professional divers over periods of only three to six years.[5,6] In commercial divers, Skogstad *et al*. found that the FVC

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decreased by 0.91% per year, $FEV_1$ by 0.84% per year, and pulmonary diffusing capacity by 1.3% a year over six years.[5]

An earlier study identified 22% of divers with pre-dive $FEV_1$/FVC ratio values below normal signifying mild airways obstruction.[7] In addition, 63.8% were overweight and 30.6% regularly took medication for hypertension, asthma, hypercholesterolaemia and cardiac irregularities. The study indicated that increased diving experience correlates with changes in pulmonary function. This is in accord with previous investigations on the long-term effects of diving on pulmonary function and may be attributed to a number of factors such as breathing dense air through breathing apparatus and an increase in the work of breathing from increased inspiratory and expiratory resistance.[3] However, a recent study reported showed no difference in spirometry readings[8] – but the small number of relatively healthy, young male (n=5) and female (n=5) sports divers in this study means that it was underpowered.

Reported here is a continuing field study investigating acute lung function changes in recreational divers. The characteristics of the reported diver population are not similar to those reported in the literature. In contrast to other research which has focused on either military[3,4] or professional[3,9] divers, we investigated recreational divers of both genders to refute the hypothesis that aerosolisation of salt water through SCUBA equipment during a dive causes acute lung function changes – in the hope that increased knowledge of the associated risks and early identification of pathological changes in lung function will enable primary care practitioners, and diving and medical specialists, to improve their management of those who have altered lung function but wish to remain active in sport.

## Methods

This cross-sectional study recruited 100 divers from dive clubs and dive shops in South Australia, as well as delegates attending an annual South Pacific Underwater Medicine Society Conference in New Zealand. Approval to conduct the

**Table 1. Divers' Questionnaire.**

Research study of pre and post dive spirometry of recreational scuba divers
DIVERS' QUESTIONNAIRE

THE UNIVERSITY OF ADELAIDE AUSTRALIA

| | |
|---|---|
| Your full initials (*including middle names)* …… | Height: ……<br>Weight: …… |
| Your age …… years | DOB ……/……/…..... |
| Your gender (*please circle*) | M / F |
| Do you have any allergies? | ☐ No ☐ Yes |
| Are you a | ☐ Current smoker<br>☐ Former smoker<br>☐ Non-smoker |
| Do you currently have, or have you previously had, any respiratory conditions? | ☐ No<br>☐ Yes current (eg asthma, a cold) *please specify* ……<br>☐ Yes, past (eg, childhood asthma) *please specify* ..... |
| Do you take any medications regularly? | ☐ No ☐ Yes (*please specify*)…… |
| Do you sometimes take medications before a dive? | ☐ No ☐ Yes (*please specify*)…… |

How often do you undertake exercise? ……days per month

Approximately, how often do you dive per month? …… times

How many dives have you done? ……

How long have you been diving? ……Months/Years (*circle whichever is appropriate*)

How long since your last diving medical? ……Months/Years (*circle whichever is appropriate*)

Your Email address to receive your spirometry results (*please write clearly*): ……

study was provided by The University of Adelaide Ethics in Human Research Committee (number H-005-2006). Spirometric data was collected by portable, battery powered EasyOne™ spirometers, shown to be robust and reliable in a variety of settings.[10] Spirometers were calibrated by standard large syringe technique. All dives were performed in seawater from either the shore or dive boats. Data collectors were trained in the correct technique to the European Respiratory Society and American Thoracic Society (ERS/ATS) standards.[11] Subjects acted as their own controls, with baseline spirometry $FEV_1$ and FVC measurements taken pre-dive and then compared with post-dive measurements. The best of three for each reading was recorded and the $FEV_1$/FVC ratio calculated.

Subjects completed a questionnaire (Table 1) requesting information on allergies, smoking habits, respiratory illnesses, medications, problems encountered during diving, frequency of exercise, frequency of diving and total number of dives completed. Dive profile data (length and depth of dive, time since exit and self-reported level of exertion) were collected at completion of the dive.

Data were grouped according to spirometry variables (e.g. normal (predicted) FVC versus abnormal FVC) and individual variables (e.g. age, weight, height). Results of descriptive statistical analyses of the data were compared with predicted normal values.[12] Chi-squared tests were applied for comparison of nominal data between groups. Multiple linear regression analysis was applied to assess the association between lung function variables and diving variables (years of diving, number of dives, and hours of diving). Interpretation of spirometric results was performed by a respiratory scientist to ERS/ATS guidelines and the Global Initiative for Chronic Obstructive Lung Diseases (GOLD) criteria.[11]

## Results

A total of 100 divers were tested with 62 subjects (62%) providing valid pre- and post-dive spirometry measurements. Two rebreather divers were excluded from analysis as their dive profiles were not truly recreational and rebreathers cause a different level of inhalation/exhalation resistance and workload. Data collection was affected by post-dive fatigue, one case of ear barotrauma and several cases of seasickness.

Of the 60 subjects reported, 41 (68%) were male and 19 (32%) were female. Ages ranged from 19 to 68 years (mean 47 years). According to body mass index (BMI) scales, 16 (27%) were normal weight (BMI <25), 35 (58%) were overweight (BMI 25-30) and 9 (15%) were obese (BMI > 30). Nineteen subjects (31.7%) were current or former smokers and 41 (68.3%) were non-smokers (see Table 2).

### Medical history

Six subjects (10%) used a variety of decongestant medication prior to diving, including pseudoephedrine (n=4), horseradish (n=1), nasal spray (n=1), and Demazin (n=1). Six subjects (10%) indicated they had a respiratory condition including hayfever (n=2), asthma (n=1), sinus congestion (n=1), sore throat (n=1) or recent upper respiratory tract infection (n=1) at the time of diving. Nearly one-third of subjects (32%, n=19) reported regular medication use at the time of data collection; this included anti-hypertensives (n=6), lipid lowering medication (n=6), glucosamine (n=2), HRT (n=3), asprin/antiplatelet (n=3), anti-inflammatory drugs (n=2), salbutamol (n=1) and various other medications (proton pump inhibitor, thyroxine, and contraceptive pill (n=6).

**Table 2. Divers' demographics.**

| N=60 | n | % |
|---|---|---|
| **Gender** | | |
| Male | 41 | 68.3 |
| Female | 19 | 31.7 |
| **Smoking history** | | |
| Current smoker | 6 | 10.0 |
| Former smoker | 13 | 21.7 |
| Non-smoker | 41 | 68.3 |
| **BMI** | | |
| Normal | 16 | 26.7 |
| Overweight | 35 | 58.3 |
| Obese | 9 | 15.0 |

**Table 3. Diving experience.**

| Diving experience | Median | Range | SD |
|---|---|---|---|
| Length of time diving | 2 years | 1month - 46 years | 10.97 years |
| Total number of dives | 300 | 3 – 5,000 | 1195.63 |

### Diving experience and diving profiles

Based on their frequency of diving and the total number of dives conducted, the majority of subjects were deemed to be experienced divers (Table 3). The length of time subjects had been diving ranged from one month to 46 years (median 2 years). The total number of dives completed ranged from 3 to 5000 dives (median 300) with 75% of subjects having conducted less than 1,000 dives.

Test dives ranged between 3-40 metres in depth (mean 19 metres) and 20-90 minutes in duration (mean 43 minutes). Water temperature varied between 18 to 23 deg Celsius. Post-dive measurements were taken as soon as possible after the diver exited the water and had removed equipment and restrictive clothing (mean 19 minutes, median 15 minutes, range 3-90 minutes). Twenty-nine (48%) subjects reported that the dive required mild exertion, 23 (38%) moderate exertion and 8 (13%) heavy exertion.

**Table 4. Pre- and post-dive spirometry comparisons – paired t tests.**

| Measurement | Pre-dive mean | Post-dive mean | Significance (2 tailed) | t value | df | sd |
|---|---|---|---|---|---|---|
| FVC | 4.75 | 4.64 | 0.03 | 2.20 | 59 | 0.37 |
| $FEV_1$ | 3.70 | 3.65 | 0.26 | 1.13 | 59 | 0.35 |
| FEVR | 77.90 | 78.60 | 0.33 | 0.99 | 59 | 0.05 |
| $FEF_{75\%}$ | 3.21 | 3.16 | 0.70 | 1.38 | 24 | 0.60 |
| $FEF_{50\%}$ | 4.20 | 3.99 | 0.20 | 1.33 | 24 | 1.10 |
| $FEF_{25\%}$ | 1.25 | 1.24 | 0.15 | 1.47 | 24 | 0.70 |
| $FEF_{25\%-75\%}$ | 3.21 | 3.16 | 0.87 | 0.17 | 24 | 0.28 |

$FEF_{25\%-75\%}$, forced mid expiratory flow at 25%, 50% 75% of vital capacity; $FEV_1$, forced expiratory volume in 1 second; $FEV_1$/FVC, $FEV_1$ as percentage of forced vital capacity; FVC, forced vital capacity.

**Table 5. Comparison of divers' spirometric measures with smoking.**

| | Current smoker n=6 | Former smoker n=13 | Non smoker n=41 |
|---|---|---|---|
| FVC | 5.31L | 4.69L | 5.27L |
| $FEV_1$ | 4.29L | 3.57L | 4.05L |
| $FEV_1$/FVC | 81% | 76% | 77% |

### Spirometry

Baseline $FEV_1$/FVC ratio values taken pre-dive showed 14 (23.3%) subjects with values below normal (<75%). Paired samples t-tests were conducted to evaluate the impact of a dive on FVC, $FEV_1$, FEVR (FVC/$FEV_1$ ratio) and forced expiratory flows at 25%, 50%, 75% and 25-75%. There was a statistically significant decrease in FVC from pre-dive (M=4.75, SD=1.03) to post-dive (M=4.64, SD=1.00), p=0.03. The eta squared statistic (0.09) indicated a moderate effect size. The decrease in $FEV_1$, $FEF_{75\%}$, $FEF_{50\%}$ and $FEF_{25\%-75\%}$, and the increase in FEVR and $FEF_{25\%}$ were all insignificant (p>0.05), (see Table 4).

Correlation of baseline spirometric findings with BMI, medication use and smoking showed significance between medication and FVC (p=0.006, M=4.74, SD=1.03) and $FEV_1$ (p=0.005, M=3.70, SD=0.84). There was no difference in FVC between smokers and non-smokers (0.03L variation is well within the error of the measurement) (see Table 5). There were no significant associations between spirometric findings and overweight/obese subjects.

## Discussion

This field-based study reports on acute lung function changes experienced by recreational divers. The advantages of field studies is that they allow researchers to observe the impact of external forces such as weather and sea conditions on the investigation and the impact of real-time interventions (such as fatigue) on the subject, which there is no other way of discovering.

Bronchoconstriction due to aerosolisation of salt water was not evident because no reduction in post-dive $FEV_1$/FVC ratio was detected. However, there was a significant decrease in FVC which may be due to increases in intra-thoracic blood volume due to immersion. Whilst these changes were statistically significant, clinically they may be of little importance. How long this reduction in FVC continues after diving before returning to baseline conditions was not investigated.

The lack of information on the prevalence of varying degrees of airways disease and pulmonary causes of diving injury in the recreational diving population presents difficulties in setting reasonable recommendations for fitness to dive. Although $FEV_1$ gradually falls over a lifetime, clinically significant airway obstruction does not usually occur.[13] Diving has been shown to have long-term effects on respiratory function in trained professional divers, indicating the development of small airway disease.[14] Whether recreational divers are at the same risk is unknown because of the different degrees of exposure and training – although we have identified in this study that one in four recreational divers has an $FEV_1$/FVC ratio < 75% of predicted norm, a possible signifier of small airways disease when considered with dive experience.

Pulmonary causes of diving injury are exceedingly rare. If we accept previous studies' suggestions that professional divers may acquire deteriorating lung function with time, then the potential for worsening lung function in our recreational diving group may have health implications in the future. This group, which has not been subjected to adequate surveillance previously, warrants improved monitoring to provide them with the best health advice to maintain physical activity.

The underlying morbidity of the study sample may also have impacted on the results. Health issues included indications of mild airway obstruction in 23%, being overweight or obese in 73%, and 31% taking regular medication. Being overweight or obese – possibly a reflection of the mean age (47 years) of the cohort – could be expected

a) Difficulties encountered during this study;
Environmental conditions cannot be factored into study design and as such field studies give the advantage of delivering information that cannot be obtained in the simulated environment of a hyperbaric chamber.

b) New questions arising from the study;
To what degree are SCUBA divers at risk of accelerated $FEV_1$ over the lifespan, compared to non-divers? Consideration of others who use self-contained breathing apartatus needs to be taken into account.

c) Lessons for clinical practice as a result of the study.
Spirometry is an important tool in screening for obstructive lung disease and as such, could be considered a routine component of diving eligibility medical examinations with comparison of measurements from each examination possible.

to have an impact on cardio-pulmonary health,[15] but the significance of this may require a larger sample. A proportion of subjects regularly used medication known to cause airflow limitation, such as anti-hypertensives, medication for asthma and cardiac irregularities, and β-blockers. The Divers Alert Network suggests that side effects of medication(s) and evidence of end-organ damage coupled with adequate control of blood pressure with no significant decrease in performance in the water is an indicator of being able to dive safely.[15]

Whilst the limitations of the convenience sampling method are acknowledged, the lack of a reliable source such as a register of divers precluded the utilisation of more sophisticated sampling techniques.

## Conclusions

Acute lung function changes and small airways disease have been associated with professional diving, but to what degree recreational divers are affected and how such a popular activity contributes to the etiology of asthma/COPD has not yet been determined. Previous research has shown that lung function can be affected by a number of risks to which divers are exposed while diving – such as the physiological reduction in lung volume on immersion, breathing in saltwater, hyperoxia or hypoxia, decompression stress, and prolonged diving experience. These studies, however, have focused on professional divers and have been conducted in artificial environments rather than in the natural environment. In this study, 25% of participants had a reduced $FEV_1$/FVC ratio regardless of undertaking a dive.

Spirometry is an important tool in screening for obstructive lung disease and as such, could be considered a routine component of diving eligibility medical examinations with comparison of measurements from each examination possible through creation of a database. In terms of identifying pathological changes early, further research could consider whether it is necessary to perform pulmonary function tests periodically depending on the frequency of diving and the age of the individual.

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**Conflict of interest declarations**

None.



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