The long-term effects of compressed gas diving on lung function in New Zealand occupational divers: a retrospective analysis

Christopher Sames, Desmond F Gorman, Simon J Mitchell, Greg Gamble

Key words
Occupational diving, lung function, pulmonary function, health surveillance, occupational health, medicals – diving

Abstract
(Sames C, Gorman DF, Mitchell SJ, Gamble G. The long-term effects of compressed gas diving on lung function in New Zealand occupational divers: a retrospective analysis. *Diving and Hyperbaric Medicine*. 2009;39(3):133-7.)
Objectives: Long-term effects of occupational diving on lung function are uncertain. No previous study has been conducted on New Zealand occupational divers. The aim of this study was to investigate changes in divers' lung function over a five-year period.
Methods: The lung function data of all occupational divers with two spirometric determinations separated by a five-year interval (N = 336 out of 1,475 currently registered divers) were entered into a database and analysed for changes (5.6 years mean). The trends were correlated against gender, smoking status and years of diving experience (as more accurate diving exposure data were not available). Spirometric indices were compared with predicted reference values derived from New Zealand (WRS), Australian (Gore), and American (NHANES III and Knudson) populations.
Results: Small, but significant, decreases were found in FEV_1 (0.27% against predicted per annum, $P = 0.02$) and PEF (0.47% per annum, $P = 0.04$) using the NHANES III equations. No other changes in lung function parameters reached statistical significance ($P < 0.05$) using any of the four sets of prediction equations. No changes correlated significantly with reported years' diving.
Conclusion: Observed changes to occupational divers' lung function tests over 5.6 years were small and unrelated to years of diving, which might be due to a 'healthy worker effect'. Clinical relevance is unlikely, but this requires further evaluation. There was significant disparity in normative values derived from the four sets of prediction equations and there is some consequential concern about the ongoing utility of such surveillance of New Zealand professional divers.

Introduction

Lung function is arguably most important in determining health risk for divers. Disparate results from a small number of studies of the long-term effects of diving on the lung have led to ongoing uncertainty (see Table 1). A literature search of the PubMed database seeking the MeSH terms 'Diving' and 'Respiratory function tests' found 438 articles, eight of which were longitudinal studies of professional divers' lung function (plus one preliminary report).[1–9] Neither the references quoted in these articles nor the 84 articles cited in the British Thoracic Society guidelines on respiratory aspects of fitness for diving revealed any further relevant longitudinal studies.[10]

Regulations introduced by the Department of Labour in 1999 require occupational divers in New Zealand to undergo annual surveillance of their medical fitness to dive by completing and submitting to the central medical directorate a health questionnaire which is augmented every five years by a comprehensive 'medical examination'. Audit of these diver health surveillance data is facilitated by New Zealand's relatively small population and the collection and scrutiny of the data centrally and by an expert censor panel that certifies occupational diver medical fitness.

The aim of this retrospective longitudinal cohort study was to audit lung function data collected from occupational divers over the past five to 15 years (minimum of five), and to examine any relationships with gender, smoking status and years of occupational diving experience.

Method

The inclusion criteria were that the diver was currently registered with the regulator, the New Zealand Department of Labour, and that the diver had completed at least two 'full' dive medical examinations, including spirometry, with an interim period of at least five years. The annual questionnaire and five-yearly medical examination data were uploaded to a customised database for analysis.

Lung function parameters: forced vital capacity (FVC); forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF), forced expiratory flow rates at 25%, 50% and 75% FVC ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$) and mean forced expiratory flow rate in the range 25%–75% FVC ($FEF_{25\%-75\%}$) were analysed for changes over time and against gender, smoking status and duration of diving experience.

Comparison was made with matched normative data derived from four sets of published spirometry prediction equations.[11–14] The results were expressed as the percentage change of these predicted values, which controlled for advancing diver age between measurements, as all equations are based on diver age, height and gender. Two of the sets of prediction equations (Knudson and NHANES III) were chosen because of their popularity worldwide, and two

Table 1
Comparison of longitudinal studies on lung function of divers

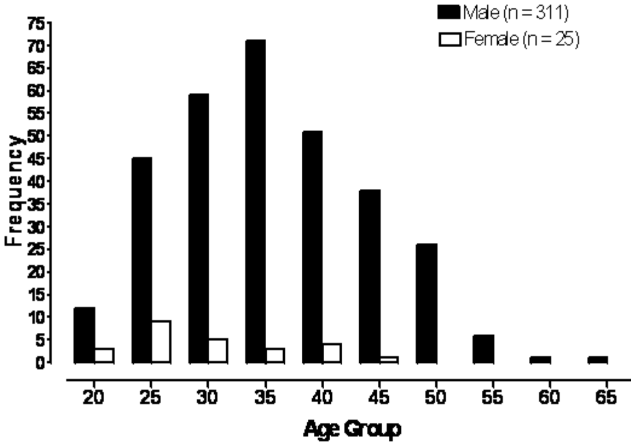
Author	Study design	Sample (n)	Time (y)	Outcome
Davey IS et al 1984[4]	Retrospective Epidemiological	255	5+	Change in FVC (but not FEV_1) related to max depth; decreased FEF_{75} compared with controls; evidence of airway narrowing possibly related to loss of elastic tissue
Watt SJ 1985[1]	Retrospective Epidemiological	224 123	3–4 5–9	Decrease in FVC > decrease in FEV_1; reduction in FVC significant compared with predicted norms, correlated with initial FVC (mostly above predicted norms); not correlated with age, max depth, yrs diving or weight change; no difference between smokers and non-smokers. Indicated either gradual return to normal values or pathological decrease in lung volume
Bermon S et al 1994[5]	Retrospective Epidemiological	20	8–9	Decrease in VC < decrease in FEV_1 so decrease in FEV_1/VC% over time; pronounced decrease in MMEF and MMEF/VC suggested chronic effect on small airways
Skogstad M et al 2002[3]	Prospective Controlled Cohort	77	6	Significant decrease in FVC, FEV_1, MEFRs and TI_{co} compared with reference group (policemen); reduction in FEF_{25} and FEF_{75} greater than in reference group and related to cumulative number of dives. No difference between smoking and non-smoking divers
Fitzpatrick DT et al 2003[6]	Retrospective Epidemiological	43 (shallow nitrox)	3	Initial FVC and FEV_1 greater than predicted; FVC and FEV_1 significantly increased after three years associated only with cumulative dive hours; no significant change in other parameters; likely training effect
Tetzlaff K et al 2005[7]	Retrospective Epidemiological	39 (O_2 rebreathers)	5.8	No significant change in FVC or FEV_1; hyperoxia not associated with decline in lung function
Tetzlaff K et al 2006[8]	Prospective Controlled Cohort	468	5	Baseline lung function of divers and controls (submariners) greater than predicted; decrease in FEV_1 faster if older, smoker or initially higher FEV_1; no difference in decline in FEV_1 between divers and controls
Chong SJ et al 2008[9]	Retrospective Epidemiological	116	5	Increase in % predicted FVC, FEV_1 and PEF; decrease in FEV_1/FVC ratio; no significant difference with age, smoking or years, naval service

sets (Gore and WRS) because of their local relevance.[11–14] Knudson's 1983 equations improved on his 1976 set and were derived from 697 non-smoking, healthy, white, non-Mexican-American residents of Tucson, Arizona.[11] The NHANES III (Third National Health and Nutrition Examination Survey) equations were based on data collected across the USA from a total of 20,627 subjects divided into three ethnic groups.[14] However, after selecting only those who were life-long non-smokers who could provide at least two acceptable FVC manoeuvres, the equations were derived from 7,429 subjects. For use in our study, only the equations derived from the data for Caucasian subjects older than 20 years (n = 1,349) were used. The Australian set of equations (Gore) was derived from 414 asymptomatic, non-smoking Caucasian adults from metropolitan Adelaide, South Australia, while the New Zealand set, the Wellington Respiratory Survey (WRS), was derived from 212 healthy, non-smoking Caucasian adults. Comparable reference equations for Maori and Pacific Island populations are not yet available.[12,13]

Student's paired t-test was used to test the hypothesis that there was no change in function over five years. The same test was used to find whether the baseline values of lung function tests differed from the normative means.

The relationship between dependent variables (recorded lung function) and several predictor variables (covariates

Figure 1
Age distribution of 336 New Zealand occupational divers by gender



such as gender, age, weight, smoking status and number of years' diving experience) was tested by univariate Pearson correlation coefficients and multiple linear regression analyses ($P < 0.15$ was considered necessary for inclusion in the multiple regression model). A variety of iterative procedures was used (stepwise regression, forward and backward selection and MaxR). The final model was chosen on the basis of goodness-of-fit and biological plausibility. All analyses were conducted using procedures of SAS (SAS Institute Inc. v 9.1). A *P*-value of less than 0.05 was considered significant and all tests were two-tailed.

Results

Of the 1,475 currently registered occupational divers in New Zealand, only 336 (23%) satisfied the inclusion criteria by having two sets of spirometric data separated by five years. Their demographic details are summarised in Table 2. The divers' occupational groupings were broadly categorised as commercial (148), scientific (122), sports and recreation industry (30) and military (15). At baseline, females (7.4% of the group) were on average six years younger and had 7.6 years less diving experience than males. The comparative gender/age distribution is shown in Figure1. Only 15 and 7% respectively of the divers reported their total number of dives and dives beyond 30 msw in the past year, compared to 96% who reported their total number of years' compressed gas diving.

Frequency of paired data varied according to spirometric parameter as shown in Table 3. The only significant difference over 5.6 years between smokers (defined as current and ex-smokers) and non-smokers (72.6% of the group) was a decrease of 3% in the % predicted FEV_1 in non-smokers according to the Knudson equations.

Three sets of normative value equations (Gore, Knudson and WRS) showed a 6% increase in % predicted FVC in females over the observation period. The WRS equations also showed that females had lower than predicted baseline FVC and FEV_1 values (7.4% and 8.5% respectively). Student's paired t-testing revealed no significant differences in lung function parameters when the group was stratified for age and years of diving experience (using the median value as the dividing point for young versus old and low versus high experience).

The NHANES III equations most accurately predicted the recorded values for FVC, FEV_1 and PEF and were the only equations to demonstrate significant change (for % predicted FEV_1 and % predicted PEF) for the group as a whole over the observation period. The mean changes in % predicted FEV_1, FVC and PEF, 95% confidence intervals and *P*-values are displayed in Figure 2. A comparison of changes in lung function over time employing all four prediction methods is shown in Table 4.

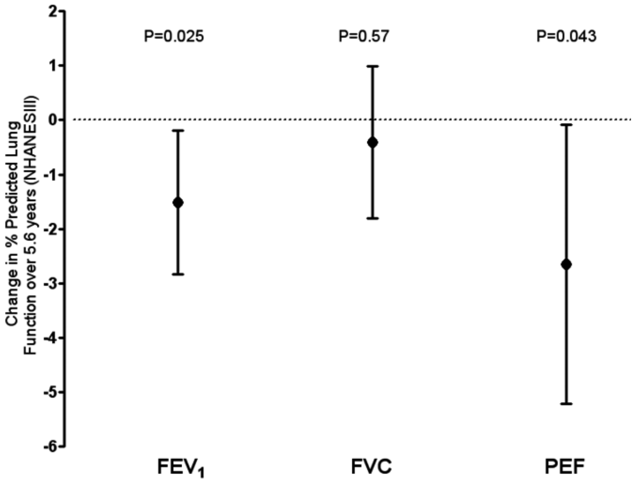
Table 2
Demographic characteristics of 336 New Zealand occupational divers at initial assessment of medical fitness for diving

	n or mean	(SD)	Range
Male / Female	311 / 25		
Height (cm)	177.9	(7.1)	158–196
Weight (kg)	82.3	(12.8)	50–116
BMI ($kg.m^{-2}$)	26	(3.4)	20–36
Age (y)	35.6	(8.6)	18–65
Smoker (current)	33		
Smoker (past)	25		
Non-smoker	278		
Years' occupational diving	13.8	(8.8)	0–42
No. dives in past year (*n* = 52)	97	(117)	0–600
No. dives > 30 msw depth in past year (*n* = 25)	5	(14)	0–50
Time to 2nd examination (y)	5.6		4.8–12

Table 3
Frequency of paired data by spirometric parameter

Spirometric parameter	Number of observations	% of sample
FVC	328	98
FEV_1	330	98
FEV_1/FVC	325	97
PEF	174	52
FEF_{25}	54	16
FEF_{50}	77	23
FEF_{75}	63	19
FEF_{25-75}	70	21

Figure 2
Change in % predicted FEV_1, FVC and PEF over 5.6 y (mean) using NHANES III prediction equations; dots are the mean values and the arms represent the 95% confidence intervals



Discussion

With few exceptions, both epidemiologic and experimental studies have concluded that compressed gas diving is detrimental to divers' lung function.[15] The mechanism for the deterioration in lung function is not completely understood, but several factors have been implicated both independently and in combination. However, the small changes in lung function found in this study and in others, suggest a low likelihood of clinical significance and raise the question of the value of regular lung function testing. The two relevant and controlled prospective studies showed similarly small and probably clinically insignificant changes over a similar timeframe.[3,8] The clinical significance of respiratory function changes from diving in terms of divers' careers, quality of life and morbidity after retirement consequently remains unknown. This contrasts with the recommendations for such studies in response to the international consensus conference in Norway in 1993.[16]

The four prediction methods used here were chosen because of their relevance to New Zealand divers and their local and global popularity.[11–14,17] However, the variable results (*P*-values ranging from 0.02 to 0.97) suggest a poor fit of at least some of these equations with this dataset. The accuracy of the NHANES III equations in predicting the FVC, FEV_1 and PEF values, together with their demonstration of significant change in % predicted FEV_1 and PEF values over the observation period, implies greater accuracy but less precision than the other sets of predictive equations for this dataset.

Divers' lung function is measured on a variety of equipment and is calibrated against different sets of reference algorithms. This study showed that the most appropriate dataset for deriving normative values with which to compare New Zealand occupational divers is the NHANES III equations; it is reassuring that these equations are the most commonly used in New Zealand.[17]

The small, mostly insignificant changes and the lack of correlation with reported number of years' diving suggests a 'healthy worker effect', which is a form of sampling bias recognised since 1885. Put simply, the working population is likely to be healthier than the general population, which includes those who are not working for health reasons. Erroneous conclusions can be drawn if this is not taken into account. In the current study, the sets of 'normative' lung function prediction equations were based on groups of healthy Caucasian non-smokers with no clinical evidence of respiratory disease. No information was available on occupation. Retired divers' files were not included in this audit, but, some divers might retire early for respiratory health reasons compounding any 'healthy worker' bias.

Previous studies, such as those of Skogstad and Tetzlaff which used control groups of occupations of similar physical nature but without any diving (such as policemen or submariners), are more likely to reach valid conclusions than those based on more heterogeneous groups.[3,8]

Recent research on New Zealand occupational divers found that regular five-yearly medical examinations result in very few divers having their certificates of medical fitness changed.[18] The observation that only 22.8% of registered occupational divers met the inclusion criteria for this study suggests that few divers continue occupational diving for longer than five to ten years. The possibility of premature health-related retirement is a subject for future research.

Table 4
Comparison of mean changes in % predicted FVC, FEV_1 and PEF over 5.6 y using four prediction methods; mean (standard deviation) and *P*-values shown

	FVC (n = 328)		**FEV_1** (n = 330)		**PEF** (n = 174)	
NHANES III	-0.41 (12.84)	0.566	-1.51 (12.14)	0.024	-2.65 (17.10)	0.043
Knudson	0.79 (13.63)	0.292	-1.06 (12.50)	0.123	-1.75 (18.56)	0.214
WRS	0.51 (12.20)	0.451	-1.05 (11.17)	0.087	-0.12 (2.63)	0.552
Gore	-0.27 (13.00)	0.707	-1.24 (12.02)	0.062	-2.09 (16.32)	0.094

Conclusions

Decreases in occupational divers' lung function over a period of 5.6 years are minimal and of doubtful clinical significance, but, any changes may be obscured due to a 'healthy worker effect'.

The mean 5.6-year observation period for this study may have been too short to observe clinically significant changes in lung function, but, does reflect the relatively short mean duration of occupational diving careers. Future study should involve the long-term follow-up of retired divers.

Apart from anatomic lung abnormalities, or a history of previous pulmonary barotrauma (PBT), the only factor reported to be associated with an increased risk of PBT or cerebral artery gas embolism is a small FVC, and, in most cases of PBT, none of the many commonly recognised risk factors is present.[19–21] Given this, and the results of the current and previous audit on the NZ occupational diver population, it is hard to justify annual comprehensive lung function testing.[18]

References

1 Watt SJ. Effects of commercial diving on ventilatory function. *Br J Ind Med*. 1985;42:59-62.

2 Skogstad M, Thorsen E, Haldorsen T. Lung function over the first 3 years of a professional diving career. *Occup Environ Med*. 2000;57:390-5.

3 Skogstad M, Thorsen E, Haldorsen T, Kjuus H. Lung function over six years among professional divers. *Occup Environ Med*. 2002;59:629-33.

4 Davey IS, Cotes JE, Reed JW. Relationship of ventilatory capacity to hyperbaric exposure in divers. *J Appl Physiol*. 1984;56:1655-8.

5 Bermon S, Lapoussière JM, Dolisi C, Wolkiewiez J, Gastaud M. Pulmonary function of a fireman-diver population: a longitudinal study. *Eur J Appl Physiol*. 1994;69(5):456-60.

6 Fitzpatrick DT, Conkin J. Improved pulmonary function in working divers breathing nitrox at shallow depths. *Aviat Space Environ Med*. 2003 Jul;74(7):763-7.

7 Tetzlaff K, Friege L, Theysohn J, Neubauer B, Muth C. Lung function in military oxygen divers: A longitudinal study. *Aviat Space Environ Med*. 2005 Oct;76(10):974-7.

8 Tetzlaff K, Theysohn J, Stahl C, Schlegel S, Koch A, Muth C. Decline of FEV1 in scuba divers. *Chest*. 2006;130:238-43.

9 Chong SJ, Tan TW, Lim JYL. Changes in lung function in Republic of Singapore Navy divers. *Diving and Hyperbaric Medicine*. 2008;38(2):68-70.

10 Godden D, Currie G, Denison D, Farrell P, Ross J, Stephenson R, et al. British Thoracic Society guidelines on respiratory aspects of fitness for diving. *Thorax*. 2003;58:3-13.

11 Knudson RJ, Lebowitz MD, Holdberg CJ, Burrows B. Changes in normal maximal expiratory flow-volume curve with growth and aging. *Am Rev Respir Dis*. 1983;127:725-34.

12 Gore CJ, Crockett AJ, Pederson DG, Booth ML, Bauman A, Owen N. Spirometric standards for healthy lifetime nonsmokers in Australia. *Eur Resp J*. 1995;8:773-82.

13 Marsh S, Aldington S, Williams M, Weatherall M, Shirtcliffe P, McNaughton A, et al. Complete reference ranges for pulmonary function tests from a single New Zealand population. *NZMJ*. 2006;119:U2281.

14 Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general US population. *Am J Respir Crit Care Med*. 1999;159:179-87.

15 Thorsen E. Long term effects of diving on the lung. Ch 11.1, In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving*, 5th ed. Edinburgh: Saunders; 2003. p. 651-8.

16 Hope A, Lund T, Elliott DH, Halsey MJ, Wiig H. *Long term health effects of diving*. An international consensus conference. Godøysund 6-10 June 1993. Bergen: John Grieg forlag A/S; 1994: p. 387-91, cited in Brubakk AO, Neuman TS, editors, *Bennett and Elliott's physiology and medicine of diving*, 5th ed. Edinburgh: Saunders; 2003. p. 656.

17 Marsh S, Aldington S, Williams M, Weatherall M, Robiony-Rogers D, et al. Pulmonary function testing in New Zealand: The use and importance of reference ranges. *Respirology*. 2007;12:367-74.

18 Sames C, Gorman D, Mitchell S, Gamble G. The utility of regular medical examinations of occupational divers. *Internal Medicine Journal*. 2009; in press.

19 Benton PJ, Francis TJR, Pethybridge RJ. Spirometric indices and the risk of pulmonary barotrauma in submarine escape training. *Undersea Hyperb Med*. 1999 Winter;26(4):213-7.

20 Elliott DH, Harrison JAB, Barnard EEP. Clinical and radiological features of eighty- eight cases of decompression barotrauma. In: Shilling CW, Beckett MW, Editors. Proceedings of the Vth symposium on underwater physiology. *Fed Am Socs Exp Biol*. 1978:527-36.

21 Gorman DF. Arterial gas embolism as a consequence of pulmonary barotrauma. In: Desola J, editor. *Diving and hyperbaric medicine*. Proceedings of the IX congress of the European Undersea Biomedical Soc. Barcelona: CRIS; 1984. p. 348-68.

Submitted: 16 April 2009
Accepted: 18 June 2009

Chris Sames, BSc, BHB, MBChB, MMedSc, is Hyperbaric Medical Officer to the Naval Health Service.
Des Gorman, BSc, MBChB, MD, PhD, is Head of the School of Medicine, and
Simon Mitchell, MBChB, PhD, FANZCA, is Senior Lecturer in the Department of Aneasthesiology,
Faculty of Medicine and Health Sciences, The University of Auckland.
All three are involved in the Diving Medical Directorate to the New Zealand Department of Labour.
Mr Greg Gamble, MSc, is biostatistician in the Faculty of Medicine and Health Sciences, The University of Auckland.

Corresponding author:
Professor Des Gorman, Head of the School of Medicine
Level 12, Support Bldg, Auckland City Hospital,
FMHS, University of Auckland, Private Bag 92019, Auckland, New Zealand.
Phone: +64-(0)9-923-2940
Fax: +64-(0)9-373-7641
E-mail: <d.gorman@auckland.ac.nz>