ORIGINAL ARTICLE

Lung function over six years among professional divers

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Aims: To analyse longitudinal changes in pulmonary function in professional divers and their relation with cumulative diving exposure.
Methods: The study included 87 men at the start of their education as professional divers. At follow up one, three, and six years later, 83, 81, and 77 divers were reexamined. The median number of compressed air dives in the 77 divers over the follow up period was 196 (range 37–2000). A group of non-smoking policemen (n = 64) were subjected to follow up examinations in parallel with the divers. Assessment of lung function included dynamic lung volumes, maximal expiratory flow rates, and transfer factor for carbon monoxide (Tl_{CO}). The individual rates of change of the lung function variables were calculated by fitting linear regression lines to the data, expressed as percent change per year.
Results: The annual reductions in forced vital capacity (FVC) and forced expired volume in one second (FEV_1) were 0.91 (SD 1.22) and 0.84 (SD 1.28) per cent per year in divers, which were significantly higher than the reductions in the policemen of 0.24 (SD 1.04) and 0.16 (SD 1.07) per cent per year ($p < 0.001$). The annual reduction in the maximal expiratory flow rates at 25% and 75% of FVC expired ($FEF_{25\%}$ and $FEF_{75\%}$) were related to the log_{10} transformed cumulative number of dives in a multiple regression analysis ($p < 0.05$). The annual reductions in Tl_{CO} were 1.33 (SD 1.85) and 0.43 (SD 1.53) per cent per year in divers and policemen ($p < 0.05$).
Conclusions: FVC, FEV_1, maximal expiratory flow rates, and Tl_{CO} were significantly reduced in divers over the follow up period when compared with policemen. The contrasts within and between groups suggest that diving has contributed to the reduction in lung function.

Divers are exposed to several factors that have effects on lung function. During diving the lungs are exposed to increased partial pressure of oxygen (po_2) and venous gas microembolism caused by decompression stress. These factors may induce inflammatory reactions in the lungs and gas exchange abnormalities.[1–2] Increased work of breathing as a result of submersion and increased gas density may result in respiratory muscle training and increased vital capacity.[3–5]

Earlier studies have shown that divers in general have larger lungs than predicted.[3–5] This phenomenon could be a result of selection of subjects with large lungs for diving, or an adaptation to diving because of respiratory muscle training. In a study of lung function over the first year of the professional career of divers, we have found that a selection mechanism may predominate over adaptation.[6]

Studies during the past 10 years have shown that divers tend to have a reduction in maximal expiratory flow rates at low lung volumes. This indicates the development of small airway dysfunction, and it has been related to cumulative diving exposure.[7 8] Furthermore, reduced transfer factor for carbon monoxide (Tl_{CO}) has been reported immediately after deep saturation dives.[9–11] In a cross sectional study,[7] and in a follow up study over six years of 15 rescue divers,[12] Tl_{CO} has been shown to be reduced compared with a control group or the predicted values.

Most of the studies of divers have been cross sectional. Longitudinal studies were therefore recommended in the consensus statement by selected experts in diving medicine and physiology who met at the international consensus conference on long term health effects of diving at Godøysund, Norway in 1993.[13]

We have previously reported results from the first phase of this study, characterising the divers' pulmonary function at the start of their professional career.[6] The aim of this follow up study was to analyse the longitudinal changes in their pulmonary function and its relation to diving activity.

MATERIALS AND METHODS

The cohort

The divers were all male students attending the basic course at The Norwegian Commercial Diving School in Oslo, Norway. The cohort was established during the period 1992–94, and has been described in detail previously.[6] It included subjects from seven successive courses, each lasting 15 weeks. Among the 93 students who were asked to participate in the study, 87 agreed to do so. They participated in two tests of pulmonary function at the start and end of the course. Eighty three divers participated in the follow up study one year after leaving school, 81 three years after, and 77 six years after. Among the 77 who participated at the six year follow up, and were included in this study, one had missed the one year follow up, and another had missed the three year follow up. Among those who did not show up for the last examination, five lived temporarily in Norway and had moved abroad, three had stopped diving and refused further participation in the study, one did not answer the invitation to participate, and one had a non-diving related disease. At the start of the professional training, 69 of the 87 students had SCUBA diving experience.[6] At the six year follow up 61 of these divers met for re-examination. Only two of the 18 subjects without previous diving experience dropped out at the six year examination.

At baseline, 26 of the 77 divers were daily smokers, and 28 were smokers at the six year follow up. Five divers reported having quit smoking, and seven divers had begun to smoke during follow up. In the analysis smokers were characterised as subjects who were smokers at the baseline in addition to those who had started smoking during follow up (n = 33).

Abbreviations: DCS, decompression sickness; FEF, forced mid-expiratory flow; FEV, forced expiratory volume; FVC, forced vital capacity; PEF, peak expiratory flow; Tl_{CO}, transfer factor for carbon monoxide

Table 1 Lung function in the 77 divers who attended the six year follow up examination

	Baseline n=77 Mean (SD)	1 year n=76 Mean (SD)	3 year n=76 Mean (SD)	6 year n=77 Mean (SD)
FVC (l)	6.23 (0.82)	6.39 (0.88)*	6.32 (0.91)	6.10 (0.88)*†‡
FEV_1 (l)	5.15 (0.67)	5.22 (0.75)	5.09 (0.69)†	4.98 (0.72)*†
PEF (l/s)	12.43 (1.77)	13.15 (1.80)*	12.95 (1.75)*	12.10 (1.80)†‡
$FEF_{25\%}$ (l/s)	9.86 (1.66)	9.89 (1.81)	9.80 (1.83)	9.38 (1.84)*†‡
$FEF_{50\%}$ (l/s)	6.12 (1.58)	5.97 (1.55)	5.69 (1.47)*†	5.67 (1.56)*†
$FEF_{75\%}$ (l/s)	2.58 (0.78)	2.50 (0.89)	2.27 (0.73)*†	2.20 (0.75)*†
$FEF_{25-75\%}$ (l/s)	5.20 (1.23)	5.11 (1.33)	4.84 (1.18)*†	4.99 (1.44)*
Tl_{CO} (mmol/min/kPa)	14.2 (2.2)	14.1 (2.0)	13.4 (1.9)*†	13.1 (1.8)*†
K_{CO} (mmol/min/kPa/l)	1.97 (0.28)	1.86 (0.24)*	1.76 (0.22)	1.75 (0.22)*†
V_A (l)	7.26 (1.00)	7.66 (1.09)*	7.68 (1.05)*	7.54 (1.07)*‡

*Significantly different from baseline, p<0.05; †significantly different from 1 year follow up, p<0.05; ‡significantly different from 3 year follow up, p<0.05.

At the baseline registration five of the 77 divers answered "yes" to the question "Do you have or have you ever had asthma?". Initially the divers were 181.0 cm (SD 5.8) tall and 24.9 years (SD 4.4) old. Their mean number of hours of physical training per week was 4.0 hours (SD 3.9) at the start of the study and 3.3 hours (SD 5.0) six years later. At the six year follow up the divers showed a mean increase in weight from 80.2 kg (SD 10.5) to 84.7 kg (SD 11.5).

The reference group

At baseline all male students in five different classes at the Norwegian Police Academy in Oslo were selected as referents. Five of a total of 20 classes were randomly chosen by one of the teachers at the school. The baseline examination of the policemen was in the first year of their education, and they were followed up one, three, and six years later. Follow up of this group was carried out in parallel with the follow up of the divers.

All the 87 policemen asked to participate did so initially. Six smokers were excluded at the start of the study. At follow up after one year, 78 non-smokers attended the examination, after three years 61 did so, and after six years 64. Sixty one policemen completed the follow up from the one year examination. None of the policemen started smoking during follow up. The policemen who did not attend for re-examination had either moved a long way from Oslo, or refused to participate in the follow up examinations for other practical reasons.

At baseline the policemen were 22.4 years (SD 1.87) old, 182.7 cm (SD 5.7) tall, and had a mean weight of 79.8 kg (SD 7.9) which had increased to 85.3 kg (SD 8.8) by the end of the six years of follow up. Initially, two of the 64 policemen answered "yes" to the question "Do you have or have you ever had asthma?". Physical training was 8.0 hours (SD 3.8) per week at the start of the study and 4.5 hours (SD 2.9) at the six year follow up. The drop in physical activity was between the baseline and first year follow up examination, when physical training no longer was on the daily schedule at school.

All divers and policemen gave their informed consent. The study was approved by the Regional Ethical Committee for Medical Research in Oslo, Norway.

Diving exposure

All divers reported diving activity in a questionnaire, including number of dives between the follow up examinations, depth, and maximal depth. The reporting of professional activity was considered adequate for most subjects and based on the divers' professional log books. Recreational diving was not properly registered in log books, if at all, although the importance of this information was emphasised on each examination. The divers had to memorise to give their best estimate of the number of recreational dives and depths.

The diving activity decreased during the six year follow up. Seventy of 76 divers reported diving activity during the first year of follow up. At three year follow up, 65 of the 76 who met at this examination had dived during the previous two years. Fifty eight of 77 had performed diving activity either professionally or recreationally during the last three years of follow up. A subgroup of 14 divers had a very low activity of 10 dives or less (range 0–10) between the one and six year follow up examinations.

The median number of dives performed during the six year follow up was 196 (range 37–2000). The vast majority of dives was with compressed air as breathing gas either with SCUBA equipment or by surface supported diving. The median depth of the deepest professional dive was 44 metres (range 10–100), and the deepest recreational dive was 30 metres (range 9–97). Sixty per cent of all dives performed by the cohort was to depths shallower than 10 metres.

Only five divers had followed up with further education for saturation diving. They had done 91 bounce dives with mixed gas (nitrogen and oxygen), and 19 saturation dives with helium and oxygen mixture. In the analysis the 91 bounce dives were handled as air dives. The time integral of exposure to hyperoxia in excess of 21 kPa in saturation diving is on average 24 kPa every day in saturation, when the average Po_2 during the saturation dive is 45 kPa. This oxygen exposure corresponds to 12 dives of two hours duration to a depth of 10 metres.[9] The equivalent of 12 dives per day in saturation was added to the saturation divers' cumulative number of dives. The number of saturation divers (n = 5) and their experience is too low to justify a separate independent exposure factor such as number of days in saturation in the analysis.

Twenty six divers had quit occupational full time or part time diving because of other jobs. Problems or difficulties in getting a steady job as a diver, better paid jobs, and another course of education were the reasons for quitting. Eleven subjects never worked as divers during the period of follow up. At the six year follow up 26 divers were working either full time or part time as occupational divers.

Diving related disease and accidents

During the first follow up period of three years, 10 episodes of decompression sickness (DCS) occurred, and four episodes of middle ear barotrauma.[6] One joint DCS and one neurological DCS occurred during the last three years of follow up, all cases being treated with recompression in hyperbaric chambers. In addition, three other divers reported middle ear barotrauma. Four of the divers had quit diving during the six year follow up because of diving related disease, including sequelae of neurological decompression sickness and hand eczema.

Pulmonary function tests

Pulmonary function testing was performed using the Jaeger MasterLab (Erich Jaeger GmbH&CoKG, Würzburg, Germany). The same equipment was used during the follow up period, and it was annually checked by a technician according to the service

Table 2 Lung function in the 64 non-smoking policemen who attended the six year follow up examination

	Baseline n=64 Mean (SD)	1 year n=61 Mean (SD)	3 year n=56 Mean (SD)	6 year n=64 Mean (SD)
FVC (l)	6.48 (0.79)	6.34 (0.70)	6.35 (0.66)	6.31 (0.74)*
FEV_1 (l)	5.45 (0.62)	5.23 (0.57)*	5.24 (0.53)*	5.23 (0.61)*
PEF (l/s)	13.33 (1.78)	12.97 (1.64)	13.15 (1.70)	12.25 (1.50)*†‡
$FEF_{25\%}$ (l/s)	10.13 (1.92)	9.82 (1.98)	9.88 (1.93)	9.35 (2.04)*†‡
$FEF_{50\%}$ (l/s)	6.30 (1.45)	6.07 (1.38)	6.05 (1.40)*	5.91 (1.48)*
$FEF_{75\%}$ (l/s)	2.94 (0.83)	2.60 (0.65)*	2.57 (0.70)*	2.34 (0.70)*†‡
$FEF_{25-75\%}$ (l/s)	5.70 (1.23)	5.26 (1.18)*	5.24 (1.20)*	5.37 (1.42)*
Tl_{CO} (mmol/min/kPa)	15.3 (2.0)	15.2 (2.1)	14.7 (2.1)*	14.8 (2.0)*
K_{CO} (mmol/min/kPa/l)	2.05 (0.26)	1.98 (0.22)*‡	1.90 (0.23)*†	1.91 (0.23)*†
V_A (l)	7.58 (0.96)	7.68 (0.86)*‡	7.85 (0.88)*†	7.75 (0.93)*‡

*Significantly different from baseline, p<0.05; †significantly different from 1 year follow up, p<0.05; ‡significantly different from 3 year follow up, p<0.05.

standards set up by the manufacturer. The same person performed all tests on the divers. As regards the divers the lung function at each follow up examination was measured at least two days after the last dive had been performed, because transient changes in pulmonary function have been shown immediately after open sea bounce dives.[14] Both divers and policemen were given standardised instructions on the forced maximal expiratory manoeuvres and the transfer test, with demonstration of the procedures. The tests were performed with the subjects sitting, breathing through the mouth piece with a nose clip. The spirometer was calibrated by means of a two litre syringe twice daily, and test gas calibrations were also performed twice daily using the instrument's automatic calibration programme. The best results, according to ATS criteria, of at least three maximal flow-volume manoeuvres were used in the analysis.[15] Peak expiratory flow rate (PEF), forced vital capacity (FVC), forced expired volume in one second (FEV_1), forced mid-expiratory flow rate ($FEF_{25-75\%}$), and forced expiratory flow rates at 25%, 50%, and 75% of FVC expired ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$) were measured. The transfer factor for carbon monoxide (Tl_{CO}) was measured by the single breath holding method.[16] Two measurements of Tl_{CO} were taken on each occasion. The average of the two measurements was used in the analysis. Effective alveolar volume (V_A) was measured simultaneously by helium dilution, and the transfer per unit effective alveolar volume (K_{CO}) was calculated. All measurements were corrected to the BTPS conditions.

Statistics

For both divers and policemen the time course of the changes in lung function parameters were approximately linear between the one and six year examinations (tables 1 and 2). In the first year, there were changes in different directions in the two groups that could be ascribed to adaptation to diving,[6] or changing level of physical activity. The individual rate of change of each lung function parameter was therefore calculated by fitting linear regression lines to the data over the last five year observation period,[17] and expressed as per cent change per year. Student's *t* test for two independent groups was used to test differences between divers and policemen. Multiple linear regression analysis was used to analyse the effect of diving exposure (log_{10} transformed number of dives performed within the six year observation period), smoking habit, and age, on the annual per cent change in the lung function parameters. All tests were two sided and the data expressed as mean (SD). A p value less than 0.05 was considered significant.[18] SPSS for Windows (SPSS Inc., 1989–92) was used in the data analysis.

RESULTS

Tables 1 and 2 show the results of lung function testing for the divers and policemen during the six year follow up. In the divers there was a small increase in FVC and FEV_1 in the first year. In the policemen there was a small decrease in FVC and FEV_1 in the same time period. Between the one and six year examination there was an approximately linear change in all lung function parameters with time in both groups, the policemen being at a plateau for FVC and FEV_1.

The annual reduction over the last five years of follow up for FVC and FEV_1 was significantly greater in the divers compared with the policemen (table 3). In the subgroup of non-smoking divers the reduction in $FEF_{25-75\%}$ was also greater compared with policemen. The annual reduction in Tl_{CO} and V_A was greater in divers compared with policemen, but for K_{CO} the difference was not statistically significant (table 3).

There were no differences in the annual reduction in any of the lung function variables between smoking and non-smoking divers. There were no differences between the 16 divers without diving experience prior to the course compared with those who had, and the five divers who reported "ever having had asthma" were not significantly different from those who did not.

The five divers with experience as saturation divers had twice as many dives during follow up compared with the others, and they had a greater loss in FEV_1 and maximal expiratory flow rates as shown in table 4. The subgroup of 14 divers with less than 10 dives during the last five years of follow up, had less reduction in FEV_1 and maximal expiratory flows compared with the 58 divers with more than 10 dives, but without saturation diving experience (table 4).

The regression analysis showed a significant relation between diving exposure (log transformed number of dives) and the reduction in $FEF_{25\%}$ and $FEF_{75\%}$ (table 5, fig 1). There was also a significant relation between diving exposure and

Table 3 Annual per cent change in lung function variables during the last five years of follow up in all divers, the non-smoking divers, and the policemen

	All divers n=76 Mean (SD)	Non-smoking divers n=43 Mean (SD)	Policemen n=61 Mean (SD)
FVC	−0.91 (1.22)***	−1.01 (1.28)***	−0.24 (1.04)
FEV_1	−0.84 (1.28)***	−1.06 (1.20)***	−0.16 (1.07)
PEF	−1.58 (1.91)	−1.69 (1.82)	−1.19 (1.56)
$FEF_{25\%}$	−0.98 (2.20)	−1.29 (1.84)	−0.63 (2.11)
$FEF_{50\%}$	−0.82 (2.63)	−1.09 (2.62)	−0.62 (2.00)
$FEF_{75\%}$	−2.05 (3.00)	−2.89 (2.56)	−2.12 (2.47)
$FEF_{25-75\%}$	−0.32 (2.61)	−0.95 (2.14)*	0.26 (2.10)
Tl_{CO}	−1.33 (1.85)*	−1.33 (1.83)*	−0.43 (1.53)
K_{CO}	−1.04 (1.71)	−0.91 (1.69)	−0.50 (1.44)
V_A	−0.30 (1.20)*	−0.43 (1.02)*	0.05 (0.77)

Significantly different from the change in policemen: *p<0.05; ***p<0.001.

Table 4 Annual per cent change in lung function variables during the last five years of follow up in compressed air divers with low exposure of less than 10 dives, divers with saturation and mixed gas diving exposure, and compressed air divers with exposure of more than 10 dives

	Low exposure air divers n=14 Mean (SD)	Saturation and mixed gas divers n=5 Mean (SD)	High exposure air divers n=58 Mean (SD)
FVC	−0.24 (1.21)	−0.60 (0.99)	−0.55 (0.88)
FEV_1	−0.21 (1.16)*	−0.98 (0.83)	−0.76 (0.87)
PEF	−0.76 (1.59)	−1.53 (0.88)	−0.64 (1.62)
$FEF_{25\%}$	0.09 (2.21)*	−1.34 (0.82)	−1.07 (1.77)
$FEF_{50\%}$	−0.99 (1.78)	−2.16 (1.23)	−1.21 (1.96)
$FEF_{75\%}$	−1.18 (1.62)*	−4.27 (1.14)	−2.63 (2.20)
$FEF_{25-75\%}$	0.28 (1.93)*	−1.88 (0.76)	−0.94 (1.78)
Tl_{CO}	−1.48 (1.44)	−0.67 (0.70)	−1.26 (1.49)
K_{CO}	−1.95 (0.82)	−1.16 (0.69)	−1.60 (1.47)
V_A	0.49 (1.13)	0.49 (0.73)	0.37 (0.89)

*Significantly different (p<0.05) from the change in the high exposure compressed air divers.

Table 5 Regression coefficients for the effect of cumulative number of dives (log_{10}), corrected for age and cigarette smoking, on the annual per cent change in the lung function variables

	Number of dives (log_{10})	SE	95% CI	R^2
FVC	−0.305	0.26	−0.82 to 0.21	0.048
FEV_1	−0.423	0.26	−0.94 to 0.09	0.042
PEF	−0.242	0.44	−1.11 to 0.62	0.037
$FEF_{25\%}$	−1.140*	0.50	−2.14 to −0.14	0.074
$FEF_{50\%}$	−0.620	0.52	−1.65 to 0.41	0.053
$FEF_{75\%}$	−1.180*	0.59	−2.35 to −0.001	0.059
$FEF_{25-75\%}$	−0.936	0.50	−1.94 to 0.06	0.049
Tl_{CO}	0.722	0.40	−0.07 to 1.51	0.060
K_{CO}	0.736*	0.37	−0.001 to 1.47	0.057
V_A	−0.019	0.26	−0.53 to 0.49	0.024

*Regression coefficient significant, p<0.05.

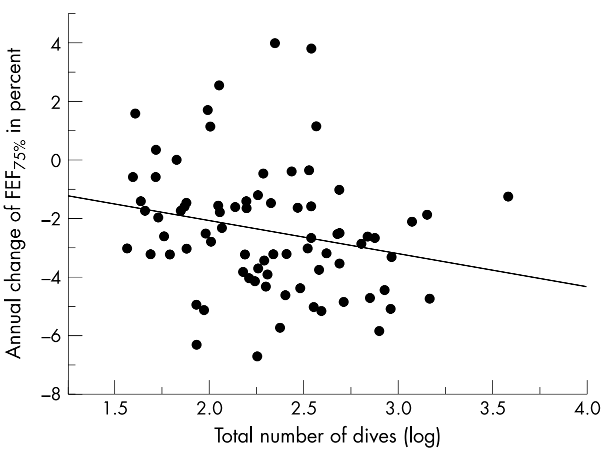

Figure 1 Relation between the annual per cent change in $FEF_{75\%}$ and cumulative number of dives (log_{10}).

the change in K_{CO}, but indicating a lesser reduction in K_{CO} in those with a high exposure.

DISCUSSION

After an initial small increase of the FVC in the first year, we observed a greater annual reduction in FVC, FEV_1, and maximal expiratory flow rates in divers compared with policemen. The diving activity was most intense during the first year of follow up, including the activity at the school. Others have reported an increased FVC in divers.[3–5] This increase has formerly been suggested as being caused either by adaptation to diving or a positive selection of men to diving.[3–5] Increased breathing resistance as a result of higher gas density,[19] swim training,[20] and breathing equipment may all contribute to a training effect of respiratory muscles and increased vital capacity. After the first year there was a continuous loss in FVC despite ongoing diving activity. A decrease in FVC with continued diving has also been reported by Watt.[21]

The policemen were extremely active physically at the time of baseline examination, and it cannot be excluded that this may have influenced the results of lung function testing. It could be because of the high activity level itself or because of measurements having been taken too shortly after exercise training, which should be avoided according to the ATS recommendations.[16] Because of these transient changes in both groups in the first year of follow up, the calculations of annual changes and comparisons between the divers and policemen were based on the last five years of follow up.

There was no change in FVC or FEV_1 in the policemen over the five year follow up period. This is consistent with longitudinal studies showing a plateau of FVC and FEV_1 in the age range 20–30 years.[22] In a recent cross sectional study of healthy, non-smoking Norwegians where a quadratic model was used for describing the relation between FVC and FEV_1, and age, the plateau in this age range was confirmed.[23] In the present study there was a reduction in FVC, FEV_1, and maximal expiratory flow rates in divers in this age range, regardless of smoking habits.

Airway reactivity to non-specific bronchoconstrictor stimuli could be increased among divers, and may play a role in the reduced expiratory flow rates in divers. Hyperoxia and venous gas microemboli may induce inflammatory responses in the lung.[24] In the present study, the subgroup of subjects reporting "having had asthma" was not different from the others. In a cross sectional study of German Navy divers, the prevalence of atopy was less than 2%.[8]

The reductions in $FEF_{25\%}$ and $FEF_{75\%}$ were found to be associated with the total number of dives during follow up. In the internal comparison of different groups of divers, including those with more or less than 10 dives during the five year observation period, and the subgroup of saturation divers, those with the highest exposure also had the greatest fall in maximal expiratory flow rates. In a four year follow up study of saturation divers,[25] those having done deep dives to depths deeper than 300 metres, had a larger reduction in FEV_1 and maximal expiratory flow rates compared with those diving to depths shallower than 150 metres.[25] A reduction in maximal expiratory flow rates at low lung volumes has been a consistent finding in all previous studies of divers' lung function,[3–5 8 21] and it has been related to number of years of diving experience or cumulative number of dives performed. In a recent study by Reuter and colleagues,[26] however, there was no radiological evidence of air trapping to support the view that experienced commercial divers develop small airway dysfunction.

The annual reduction in Tl_{CO} was greater in divers compared with policemen. The same trend was seen for K_{CO}, but was not statistically significant. A reduction in Tl_{CO} was present even among the low exposure divers, suggesting a possible association with the early exposure in the first year of all divers.[6] The positive association between change in K_{CO} and cumulative diving exposure is consistent with this observation. Otherwise we have no explanation for this finding, but it might be speculated that induction of antioxidant defence mechanisms takes place early in the career and is sustained by continued exposure. Studies among saturation divers have shown a decrease in Tl_{CO}, at least temporarily, after deep saturation dives.[10 11 27] A transient reduction of shorter duration has been found after single, shallow bounce dives.[14] In the six year follow up study of firemen and rescue divers by Bermon and colleagues,[12] a larger than predicted reduction in Tl_{CO} was found. Transient changes in Tl_{CO} after single exposures must be accounted for in studies of long term changes. The time for lung function testing was at least two days after the last dive, at all follow up examinations in the present study.[28]

Age and smoking are confounders that might be associated with the observed changes in lung function. We controlled for these variables in the regression analysis. We also know that a few subjects reported having "ever had asthma" and that there was an increase in weight in the divers and policemen during the six year follow up, but not when it occurred. The increase in weight and history of ever having had asthma were equally distributed among the divers and policemen.

With regard to the quality of the exposure information, all divers were asked to bring their log books to each follow up examination. The quality of the data varied greatly among the divers. Most of the divers working full or part time as commercial divers had logged their professional dives in their "log books" and could report reliable data. If such data were not available, the divers had to recall the diving history, and to give the best information possible on depth, maximal depth, and number of dives. Thus, misclassification could occur and could dilute any association between exposure and outcome. As the time interval between the examinations was short, it is assumed that we at least obtained a good estimate of the cumulative diving exposure in terms of total number of dives. Five divers had done saturation diving. The exposure to hyperoxia in the saturation dives was transformed to the equivalent of compressed air dives, but any method of transforming decompression stress to a common exposure variable with different forms of diving is lacking. Misclassification of exposure may therefore still be a problem in this study.

In conclusion, the results obtained during this follow up of young divers from the start of their professional diving career, show a greater reduction in FVC, FEV_1, maximal expiratory flow rates, and Tl_{CO} compared with a non-smoking, age matched control group of policemen. The contrasts within and between groups suggest that diving exposure has contributed to the observed changes.

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REFERENCES

1 **Hlastala MP**, Robertson HT, Ross BK. Gas exchange abnormalities produced by venous gas emboli. *Respir Physiol* 1979;**36**:1–17.
2 **Neuman TS**, Spragg RG, Wagner PD, *et al*. Cardio-pulmonary consequences of decompression stress. *Respir Physiol* 1980;**41**:143–53.
3 **Crosbie WA**, Clarke MB. Physical characteristics and ventilatory function of 404 commercial divers working in the North Sea. *Br J Ind Med* 1977;**34**:19–25.
4 **Crosbie WA**, Reed JW, Clarke MC. Functional characteristics of the large lungs found in commercial divers. *J Appl Physiol* 1979;**46**:639–45.
5 **Davey IS**, Cotes JE, Reed JW. Relationship of ventilatory capacity to hyperbaric exposure in divers. *J Appl Physiol* 1984;**56**:1655–8.
6 **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.
7 **Thorsen E**, Segadal K, Kambestad B, *et al*. Divers' lung function: small airways disease? *Br J Ind Med* 1990;**47**:519–23.
8 **Tetzlaff K**, Friege L, Reuter M, *et al*. Expiratory flow limitation in compressed air divers and oxygen divers. *Eur Respir J* 1998;**12**:895–9.
9 **Thorsen E**, Segadal K, Kambestad BK. Mechanisms of reduced pulmonary function after a saturation dive. *Eur Respir J* 1994;**7**:4–10.
10 **Cotes JE**, Davey IS, Reed JW, *et al*. Respiratory effects of a single saturation dive to 300 m. *Br J Ind Med* 1987;**44**:76–82.
11 **Suzuki S**, Ikeda T, Hashimoto A. Decrease in the single-breath diffusing capacity after saturation dives. *Undersea Biomed Res* 1991;**18**:103–9.
12 **Bermon S**, Magnie MN, Dolisi C, *et al*. Decreased pulmonary diffusing capacity of divers over a 6-year period. *Eur J Appl Physiol Occup Physiol* 1997;**76**:170–3.
13 **Hope A**, Lund T, Elliott DH, *et al*, eds. *Long term health effects of diving*. Bergen, Norway: Norwegian Underwater Technology Centre a.s, 1994.
14 **Skogstad M**, Thorsen E, Haldorsen T, *et al*. Divers' pulmonary function after open-sea bounce dives to 10 and 50 meters. *Undersea Hyperbar Med* 1996;**23**:71–5.
15 **American Thoracic Society**. Standardization of spirometry—1987 update. *Am Rev Respir Dis* 1987;**136**:1285–98.
16 **American Thoracic Society**. Single breath carbon monoxide diffusing capacity (transfer factor). *Am Rev Respir Dis* 1987;**136**:1299–307.
17 **Matthews JNS**, Altman DG, Campbell MJ, *et al*. Analysis of serial measurements in medical research. *BMJ* 1990;**300**:230–5.
18 **Altman DG**. *Practical statistics for medical research*. London: Chapman & Hall, 1995.
19 **Maio DA**, Farhi LE. Effect of gas density on mechanics of breathing. *J Appl Physiol* 1967;**23**:687–93.
20 **Clanton TL**, Dixon GF, Drake J, *et al*. Effects of swim training on lung volumes and inspiratory muscle conditioning. *J Appl Physiol* 1987;**62**:39–46.
21 **Watt SJ**. Effect of commercial diving on ventilatory function. *Br J Ind Med* 1985;**42**:59–62.
22 **Burrows B**, Lebowitz MD, Camilli AE, *et al*. Longitudinal changes in forced expiratory volume in one second in adults. *Am Rev Respir Dis* 1986;**133**:974–80.
23 **Gulsvik A**, Tosteson T, Bakke Å, *et al*. Expiratory and inspiratory forced vital capacity and one-second forced volume in asymptomatic never-smokers in Norway. *Clin Physiol* 2001;**21**:648–60.
24 **Tetzlaff K**, Neubauer B, Reuter M, *et al*. Atopy, airway reactivity and compressed air diving in males. *Respiration* 1998;**65**:270–4.
25 **Thorsen E**, Segadal K, Kambestad BK, *et al*. Pulmonary function one and four years after a deep saturation dive. *Scand J Work Environ Health* 1993;**19**:115–20.
26 **Reuter M**, Tetzlaff K, Steffens JC, *et al*. Functional and high-resolution computed tomographic studies of divers' lungs. *Scand J Work Environ Health* 1999;**25**:67–74.
27 **Thorsen E**, Segadal K, Myrseth E, *et al*. Pulmonary mechanical function and diffusion capacity after deep saturation dives. *Br J Ind Med* 1990;**47**:242–7.
28 **Thorsen E**, Skogstad M, Reed JW. Subacute effects of inspiratory resistive loading and head-out water immersion on pulmonary function. *Undersea Hyperbar Med* 1999;**26**:137–41.