Eur J Appl Physiol (1997) 76: 170–173

ORIGINAL ARTICLE

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Decreased pulmonary diffusing capacity of divers over a 6-year period

Accepted: 22 February 1997

Abstract Non-smoking, male, professional firemen divers ($n = 15$) underwent two pulmonary function tests (PFT) separated by 6 years. Measured data were compared to European Coal Steel Community recommended reference values to permit cross-sectional and then longitudinal study. Higher vital capacity (VC; $P < 0.01$) and forced expiratory volume in 1 s (FEV_1; $P < 0.05$), and lower maximal mid-expiratory flow (MMEF) coefficient with VC (MMEF/VC; $P < 0.05$) were observed in both PFT. Diver's pulmonary diffusing capacity (DL_{CO}) and the coefficient with alveolar volume (DL_{CO}/V_A) showed significantly ($P < 0.001$) different evolution profiles than those expected from predicted values. In divers, DL_{CO} and DL_{CO}/V_A decreased from 104.0% to 91.4% and from 106.4% to 91.5% of predicted values respectively. Changes in DL_{CO} and DL_{CO}/V_A correlated positively with the initial measurement of DL_{CO} ($r = 0.67$, $P < 0.01$) and DL_{CO}/V_A ($r = 0.74$, $P < 0.01$) respectively, whereas no correlation between changes in pulmonary gas transfer function and age or diving history parameters was found. Thus, it is suggested from our observations that hyperbaric atmosphere exposure increases the effects of aging on pulmonary diffusing capacity and that pulmonary gas transfer function should be regularly tested in professional and recreational divers.

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Key words Diving · Pulmonary diffusing capacity · Longitudinal study

Introduction

The effects of a single air dive (Dujic et al. 1993) or a single deep saturation dive (Thorsen et al. 1990b) on pulmonary diffusing capacity are well documented. In both conditions, there is a general agreement on pulmonary diffusing capacity for carbon monoxide (DL_{CO}) increasing during the dive, decreasing right after surfacing and finally showing a trend towards normalisation during a period that can last for several hours or days. Although thousands of scuba divers worldwide dive regularly, information concerning effects of chronic exposure to hyperbaric environments on pulmonary diffusing capacity is limited.

For many years, firemen divers (FD) in the City of Nice Fire Brigade have undergone pulmonary function tests (PFT), including DL_{CO} measurements, as part of a systematic medical survey. The data obtained from each PFT have been compared, with each FD as their own control. The reported results show the changes in pulmonary diffusing capacity over a 6-year period.

Methods

Subjects

A group of 15 male professional FD were given two PFTs between January 1990 and June 1996. All were non-smokers with unremarkable previous medical histories. Their anthropometric data are given in Table 1. The length of their weekly sporting activity, primarily endurance training, was 6.2 h (SEM 0.81 h). Of the FD, 12 dived recreationally outside their professional activities. Maximal depths reached, during leisure or professional dives, were between 40 and 70 m, representing inspired oxygen partial pressures of between 106 and 127 kPa (795 and 955 mmHg). All subjects were skilled divers and their 1990 and 1996 diving histories are presented in Table 1. All subjects were given regular pulmonary X-ray examinations. No diving accidents were noted among this population.

Table 1 Anthropometric data and diving experience of the subjects recorded in 1990 and 1996. (*NS* Not significant)

	1st record	1990	2nd record	1996	*P*
	Mean	SEM	Mean	SEM	
Age (years)	33.4	1.9	39.2	2.0	–
Height (cm)	176.2	1.5	175.9	1.7	NS
Mass (kg)	75.9	2.1	76.3	2.3	NS
Duration of diving career (years)	8.3	1.3	14.1	1.3	–
Maximal operating depth (m)	60.8	2.8	59.3	1.5	NS
Mean annual exposure (h · year^{-1})	46.1	4.5	47.6	9.6	NS

Experimental procedures

All PFT were performed in the same laboratory, by the same technicians, during the afternoon, after the digestive period following a 30-min rest and a micturition. The PFT were preceded by a complete clinical examination and the setting-up of a detailed medical, surgical, professional and diving questionnaire. Height was measured with a height gauge, with a precision of 0.5 cm. Mass was assessed, under standard conditions, with a Testu type 286 weighing machine with a precision of 20 g.

Vital capacity (VC), forced expiratory volume in 1 s (FEV_1), maximal midexpiratory flow (MMEF), residual volume (RV), FEV_1/VC and MMEF/VC were measured and calculated with a body plethysmograph (Bodyscreen II, Erich Jaeger, Würzburg, Germany). Volumes and flows were corrected to BTPS.

Single-breath pulmonary diffusing capacity for carbon monoxide (DL_{CO}) and the coefficient with alveolar volume (V_A), hereafter expressed as DL_{CO}/V_A were studied with a transfertest model C (PK Morgan, Chatham, Kent, UK) according to the manufacturer's instructions. Values were not corrected for possible haematological anomalies. DL_{CO} is expressed in STPD whereas V_A is expressed in BTPS conditions. The recommended reference values of the European Coal Steel Community (ECSC) gave predictions (Quanjer et al. 1993) for all lung variables in the present study, except for DL_{CO} and DL_{CO}/V_A (Cotes et al. 1993).

Statistical analysis

For each parameter, FD data were compared to ECSC and Cotes et al. (1993) theoretical-matched controls. After testing for normal distribution, all data were subjected to ANOVA with repeated measures. Differences between groups were tested using paired *t*-tests (two tailed). Differences of the measured means were calculated for all lung variables, subtracting values of the second record from those of the first, and the relationship between the two parameters determined by linear regression. Statistical significance was established at $P < 0.05$. Results in text and figures are expressed as mean (SEM).

Results

No clinical or radiological anomalies were noted. Height and body mass were homogeneous, considering 1990 and 1996 records respectively. These two records were separated by a 5.8-year interval.

First record

Compared with those predicted, higher ($P < 0.001$) values for VC, FEV_1, and lower values of MMEF/VC ($P < 0.05$), were observed.

Table 2 Pulmonary function data recorded in 1990 and 1996 from divers and their matched controls. Data are expressed as mean (SEM) (*D* Divers, *C* matched controls, *VC* vital capacity, FEV_1 forced expiratory volume in 1 s, *MMEF* maximal midexpiratory flow, *RV* residual volume, DL_{CO} pulmonary diffusing capacity for carbon monoxide, V_A alveolar volume. $F_{time \times gr}$ interaction between time and group).

		Record no.				$F_{time \times gr}$
		1990		1996		
VC (l)	D	5.86^{***}	(0.17)	5.73^{**}	(0.21)	0.21
	C	5.16	(0.10)	4.99	(0.12)	
FEV_1 (l)	D	4.61^{**}	(0.15)	4.48^{**}	(0.16)	0.25
	C	4.13	(0.10)	3.95	(0.10)	
FEV_1/VC (%)	D	78.75	(1.61)	78.46	(1.48)	0.09
	C	80.00	(0.46)	79.27	(0.51)	
MMEF/VC (%)	D	76.81^{*}	(5.24)	73.67^{*}	(5.66)	0.32
	C	91.07	(1.45)	89.27	(1.69)	
RV (l)	D	1.56	(0.13)	1.90	(0.11)	2.89
	C	1.82	(0.05)	1.94	(0.06)	
DL_{CO} (ml · min^{-1} · mmHg^{-1})	D	35.13	(1.35)	29.83^{*}	(1.02)	$25.51^{\dagger}$
	C	33.77	(0.06)	32.63	(0.63)	
DL_{CO}/V_A (ml · min^{-1} · mmHg^{-1} · l^{-1})	D	5.17	(0.21)	4.28^{*}	(0.15)	$30.59^{\dagger}$
	C	4.86	(0.06)	4.68	(0.06)	

* Significantly different from predicted values $P < 0.05$, ** significantly different from predicted values $P < 0.01$, *** significantly different from predicted values $P < 0.001$, † significant interaction $P < 0.001$

Second record

Compared with predicted values, the higher ($P < 0.01$) VC, FEV_1 and the lower MMEF/VC ($P < 0.05$) confirmed the 1990 pattern.

Results from the longitudinal analysis

FD'S DL_{CO} and DL_{CO}/V_A showed significantly ($P < 0.001$; Fig. 1) different evolution profiles than those expected from predicted values, while V_A remained constant over this 6-year period. Compared to predicted values, DL_{CO} decreased 5.30 (1.14) ml · min^{-1} · $mmHg^{-1}$, and DL_{CO}/V_A decreased 0.89 (0.18) ml · min^{-1} · $mmHg^{-1}$ · l^{-1}. The importance of the duration of the diving career, maximal operating depth and mean annual exposure was examined by correlating the variables with the changes in pulmonary diffusing capacity data; no significant correlation was found. The change in DL_{CO} correlated positively with the initial measurement of DL_{CO} ($r = 0.67$, $P < 0.01$; Fig. 2); the change in DL_{CO}/V_A correlated positively with the initial measurement of DL_{CO}/V_A ($r = 0.74$, $P < 0.01$; Fig. 2).

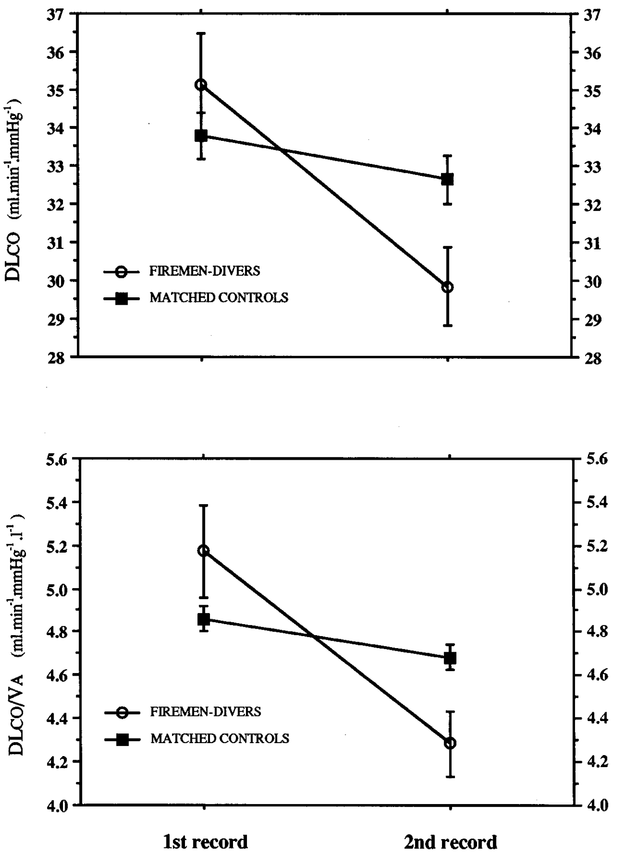

Fig. 1 The *upper* and *lower panels* illustrate the changes in pulmonary diffusing capacity for carbon monoxide (DL_{CO}) and DL_{CO}/V_A, where V_A is alveolar volume, respectively over the 6-year interval. Values are mean (SEM)

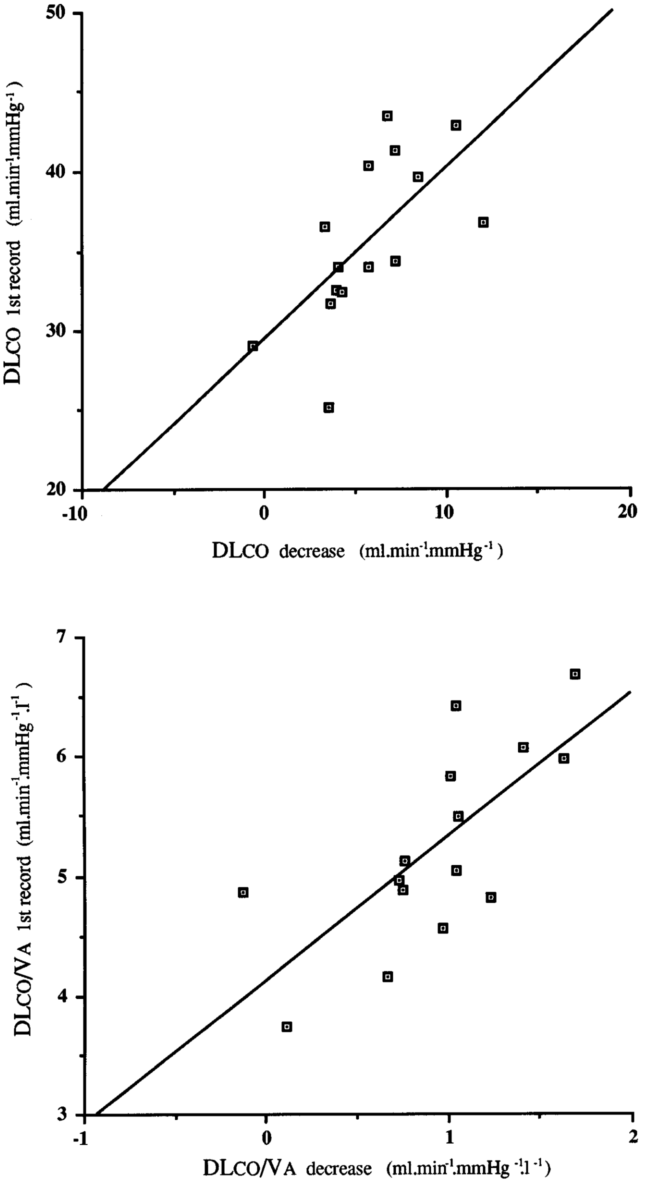

Fig. 2 The *upper panel* illustrates the initial DL_{CO} measure as a function of the DL_{CO} decrease over the 6-year interval. The *lower panel* illustrates the initial DL_{CO}/V_A measure as a function of the DL_{CO}/V_A decrease over the 6-year interval ($n = 15$ firemen divers)

Discussion

Since 1989, new regulations regarding FD professional activities have been in existence. FD are now exclusively detailed to naval and underwater security and rescue. Thus, chronic exposure to pollutants, fumes and toxic substances (Barthélémy et al. 1990) is unlikely and the present population can be considered as an experienced air diving population.

In this study, body plethysmographic data showed high VC values (113.6% and 114.8% of predicted values on the first and second records respectively) and low MMEF/VC values (84.3% and 82.5% of predicted values on the first and second records respectively). These results confirm, like other studies (Bouhuys and Beck 1979; Thorsen et al. 1990a; Bermon et al. 1994), that divers have large lung capacities and a tendency towards small-airways disease. Nevertheless, the obstructive disease observed in our study is moderate and is not associated with high RV values.

The major finding of this study is the large decrease in pulmonary diffusing capacity in FD observed over a 6-year period. This reduction is much more significant than that expected from the ECSC standard (from 104.0% to 91.4% and from 106.4% to 91.5% of predicted values for DL_{CO} and DL_{CO}/V_A respectively). No correlation between pulmonary diffusing capacity reduction and flow reduction in the small airways was found. Thus, it appears that this moderate obstructive disease is not involved in the diffusing capacity reduction observed in our population and that these two phenomena could be explained by distinct physiological mechanisms. Pulmonary diffusing capacity alteration would seem to be a late phenomenon since FD still had higher DL_{CO} and DL_{CO}/V_A values than those predicted after their first 8 years of diving experience. Initial DL_{CO}/V_A values explained 55% of the variance in the DL_{CO}/V_A changes. From a physiological point of view, this interesting finding remains unexplained. Moreover, the change in DL_{CO}/V_A was not linked to the subject's age or diving history parameters. These results suggest that the rate of decrease in diffusing capacity differs with the individual.

A hyperoxic atmosphere may contribute to the transient reduction in pulmonary gas transfer function especially after deep saturation dives (Thorsen et al. 1993). Nevertheless, in our FD, deleterious effects of chronic exposure to hyperoxia remain unlikely since Hyacinthe and Broussole (1979) showed no long-term effects on lung diffusing capacity in frogmen who were exposed to inspired oxygen partial pressure of 1292 mmHg (172 kP) for 2–3 h a day, for 200–300 days a year over a period of several years. Venous gas micro-embolism (VGM) has occured during air dives to a pressure of 0.49 MPa for 40 min without causing any symptoms or discomfort (Thorsen et al. 1995). Using Doppler bubble detection after a single air dive to pressure of 0.55 MPa, Dujic et al. (1993) also reported a reduction in pulmonary diffusing capacity which was correlated to VGM grade. Animal studies demonstrated that micro-embolisations encountered during the decompression phase may cause an inflammatory response (Flick et al. 1981) and capillary endothelial damage (Ohkuda et al. 1981) in the pulmonary micro-circulation. In our divers, it can be hypothesised that these repetitive inflammatory responses and damage may cause changes in the physico-chemical properties of the respiratory membrane leading to irreversible diffusion impairment.

In conclusion, the results of the present longitudinal study showed a decrease in diver's pulmonary diffusing capacity which is more than that expected from the ECSC standard. Repetitive micro-embolisations within the pulmonary capillaries causing repetitive inflammatory reactions and irreversible gas exchange abnormalities may occur after several years. Further longitudinal animal and human studies are needed to explore the relevance of this hypothesis regarding the pulmonary diffusing capacity impairment observed among divers.

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