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Pulmonary function of a firemen-diver population: a longitudinal study

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Abstract. Non smoking, male professional firemen-divers ($n = 20$) underwent two pulmonary function tests (PFT) separated by 8–9 years. Measured data were compared to European Coal Steel Community recommended reference values to permit cross-sectional and then longitudinal studies. Higher vital capacity (VC) and forced expiratory volume in 1 s (FEV_1; both $P < 0.001$), and lower residual volume ($P < 0.01$) were observed in both PFT. Longitudinal analysis showed a smaller VC reduction than FEV_1 reduction, leading to a FEV_1/VC percentage decrease with time. Maximal mid expiratory flow (MMEF) and MMEF/VC changes during this 9-year period showed an unusually pronounced decrease, suggesting possible chronic effects of diving on small airways. Thus, it is suggested from our observations that a hyperbaric stimulus compensates in part for the effects of aging on VC and that obstructive disease could occur in subjects with long diving experience.

Key words: Diving – Pulmonary function – Obstructive disease – Longitudinal study

Introduction

Numerous cross-sectional studies (Crosbie et al. 1977; Bouhuys and Beck 1979; Crosbie et al. 1979a; Giry et al. 1983; Thorsen et al. 1990) have described the medical supervision of populations exposed to hyperbaric environments. Categorization of these populations, according to age or diving history, has made possible the first steps to be taken towards an understanding of the particular changes in pulmonary function. These studies have provided evidence for higher values of vital capacity (VC) forced expiratory volume in 1 s (FEV_1), and lower values of maximal midexpiratory flow (MMEF) forced expiratory flow at 75% and 50% of VC (FEF_{75}, FEF_{50}) respectively. Unfortunately no explanations have been unanimously agreed concerning these changes, and the diving ability question still remains unsolved.

Longitudinal studies have been rare and usually have focused on a 1-year period (Carey et al. 1988) or on a 5-year period (Davey et al 1984; Watt 1985). Nevertheless, they have allowed a better understanding of the risks to which divers are exposed, enabling a more logical approach to be made when assessing the diving ability of subjects with long diving experience.

Furthermore, any controversy regarding reference values which have been used in divers' pulmonary function surveys (Cimsit and Flook 1981; King and Trowbridge 1981) could be avoided by using longitudinal analysis.

For many years, firemen-divers (FD) belonging to the City of Nice Fire Brigade have undergone pulmonary function tests (PFT) as part of a systematic medical survey. The data obtained from each PFT have been compared using each FD as his own control. The results reported here show the changes in pulmonary function over a 9-year period.

Methods

Subjects. A group of 20 male professional FD were given PFT between January 1983 and June 1992. All were nonsmokers with unremarkable previous medical histories. Their anthropometric data are given in Table 1. The length of their weekly sporting activity, mainly endurance training, was 6 h (SEM 1.5) h. Of the FD 18 practised diving outside their professional activities. Maximal depths reached, during leisure or professional dives, were between 40 and 70 m representing inspired oxygen partial pressures between 106 and 127 kPa (795 and 955 mmHg). Diving history, recorded in 1992, is presented in Table 2. All these subjects were given regular pulmonary X-rays. No diving accidents were noted among this population.

Experimental procedures. All PFT were performed in the same laboratory, by the same technicians, during the afternoon, after

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Table 1. Anthropometric data of the subjects, recorded in 1983 and 1992

	1st Record 1983		2nd Record 1992		P
	mean	SEM	mean	SEM	
Age (years)	33.10	1.28	41.95	1.37	—
Height (cm)	174.60	1.52	174.40	1.55	NS
Mass (kg)	74.55	1.65	75.20	2.25	NS

NS, Not significant

Table 2. Diving experience at the second record

	2nd Record 1992	
	mean	SEM
Duration of diving career (years)	22.50	1.76
Maximal operating depth (m)	64.80	2.76
Mean annual exposure ($h \cdot year^{-1}$)	45.85	4.46

the digestive period, following a 30-min rest and 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, in standard condition, with a Testut type 286 weighing machine with a precision of 20 g.

Spirography was recorded on a 9-l spirometer (Godart Expirograph), from the comfortably-seated subject. The forced vital capacity manoeuvre (FVC) was repeated until the FVC was the same as slow VC, or as near as possible to VC. Inspiratory capacity (IC) and expiratory reserve volume (ERV) were also obtained using spirometry. The IC/VC percentage was calculated.

Combined with the measurement of functional residual capacity (FRC), residual volume (RV), total lung capacity (TLC) and RV/TLC percentage were calculated. The FRC was obtained on a Godart FRC Computer using a closed circuit helium dilution method. At the end of PFT, maximum voluntary ventilation (MVV) was performed for 20 s (best of three trials). Volume and

Table 3. Pulmonary function data recorded in 1983 and 1992. Predicted values and the results of their comparison are in brackets

	1st Record 1983				2nd Record 1992				P	
	Actual		Predicted		Actual		Predicted			
	mean	SEM	mean	SEM	mean	SEM	mean	SEM		
VC (l)	5.85	0.16	(5.07	0.09)	5.69	0.17	(4.81	0.09)	**	(***)
		└ *** ┘				└ *** ┘				
FEV$_1$ (l)	4.60	0.13	(4.05	0.06)	4.29	0.13	(3.79	0.06)	***	(***)
		└ *** ┘				└ *** ┘				
FEV$_1$/VC (%)	78.78	1.26	(81.09	0.21)	75.57	1.41	(79.58	0.22)	***	(***)
		└ NS ┘				└ ** ┘				
MMEF ($l \cdot s^{-1}$)	4.75	0.33	(4.66	0.05)	3.96	0.24	(4.28	0.05)	***	(***)
		└ NS ┘				└ NS ┘				
MMEF/VC (%)	81.55	5.40	(92.33	1.25)	70.66	3.99	(89.30	1.31)	**	(***)
		└ NS ┘				└ *** ┘				
FRC (l)	3.58	0.20	(3.28	0.04)	3.69	0.16	(3.36	0.04)	NS	(***)
		└ NS ┘				└ * ┘				
RV (l)	1.43	0.11	(1.78	0.03)	1.60	0.08	(1.97	0.04)	NS	(***)
		└ ** ┘				└ *** ┘				
MVV ($l \cdot min^{-1}$)	146.33	4.72	(133.76	2.14)	132.92	3.94	(125.16	2.23)	***	(***)
		└ ** ┘				└ ** ┘				
TLC (l)	7.29	0.24	(6.86	0.12)	7.28	0.18	(6.84	0.12)	NS	(NS)
		└ * ┘				└ ** ┘				
ERV (l)	2.14	0.11	(1.50	0.01)	2.08	0.13	(1.39	0.02)	NS	(***)
		└ *** ┘				└ *** ┘				
IC (l)	3.88	0.12	(3.57	0.08)	3.66	0.12	(3.48	0.08)	*	(***)
		└ * ┘				└ NS ┘				
IC/VC (%)	66.55	1.65	(70.44	0.51)	64.60	2.22	(72.28	0.56)	NS	(***)
		└ NS ┘				└ ** ┘				
MVC/IC ($l \cdot l^{-1}$)	36.10	1.68	(37.52	0.39)	36.69	1.17	(36.07	0.40)	NS	(***)
		└ NS ┘				└ NS ┘				
RV/TLC (%)	19.37	1.13	(25.97	0.39)	22.07	1.06	(28.90	0.42)	*	(***)
		└ *** ┘				└ *** ┘				
R$_L$ ($cm\ H_2O \cdot l^{-1} \cdot s$)	3.10	0.20	—		2.88	0.22	—		NS	—

NS, Not significant; VC, vital capacity; FEV$_1$, forced expiratory volume in 1 s; MMEF, maximal midexpiratory flow; FRC, functional residual capacity; RV, residual volume; MVV, maximal voluntary ventilation; TLC, total lung capacity; ERV, expiratory reserve volume; IC, inspiratory capacity; R$_L$, total pulmonary resistance

$^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$

test gas calibrations were carried out before each test and volumes were corrected to body temperature and pressure, saturated.

Pulmonary resistance, excluding the nose, was measured by the forced oscillations method (Siemens, Siregnost FD5).

The 1992 PFT was completed with a body plethysmographic (Bodyscreen II, Erich Jaeger, Würzburg, Germany) flow-volume loop including FEF_{75} and FEF_{50}.

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, England) according to Cotes (1979). Values were not corrected for possible haematological anomalies. The DL_{CO} is expressed in standard temperature and pressure, dry conditions. The recommanded reference values of the European Coal Steel Community (ECSC) gave predictions (Quanjer 1983) for all lung function variables in the present study, except for DL_{CO} and DL_{CO}/V_A (Cotes 1979).

Statistical analysis.. For each subject, mean values were compared using paired Student's *t*-test. The relationship between two parameters was examined by correlation analysis. Statistical significance was chosen as $P<0.05$.

Results

No clinical or radiological anomalies have been noticed. Anthropometric data were homogeneous, considering 1983 and 1992 records (Table 1).

First record

Compared with those predicted, higher values for VC ($P<0.001$), FEV_1 ($P<0.001$), MVV ($P<0.01$), TLC ($P<0.05$), ERV ($P<0.001$), and IC ($P<0.05$), and lower values of RV ($P<0.01$) and RV/TLC ($P<0.001$), were observed (Table 3).

Second record

Compared with predicted values, higher VC ($P<0.00\ 1$), FEV_1 ($P<0.001$), MVV ($P<0.01$), TLC ($P<0.01$), and ERV ($P<0.001$), and lower RV ($P<0.001$), and RV/TLC ($P<0.001$) confirmed the 1983 pattern. This transversal analysis also showed up high FRC ($P<0.05$) and low FEV_1/VC ($P<0.01$), MMEF/VC ($P<0.001$), and IC/VC ($P<0.01$; Table 3).

Results from the longitudinal analysis

Results from the comparison of measured values over 9 years showed significant changes regarding VC, FEV_1, FEV_1/VC, MMEF, MMEF/VC, MVV, IC while other parameters remained constant over this period. These results and those obtained from a similar longitudinal study of theoretical values are given in Table 3.

It was thus possible to compare the difference of the means (Table 4). It is noteworthy that the VC reduction of FD was smaller ($P<0.05$) than that calculated from the ECSC standard, whereas a greater decrease ($P<0.05$) for FEV_1/VC, MMEF, MMEF/VC, MVV, IC/VC was observed.

Table 4. Differences of the measured and predicted means (and SEM). Values of 1992 are subtracted from 1983 values

	Differences of the means: 1983–1992				P
	Actual		Predicted		
	mean	SEM	mean	SEM	
VC (l)	0.16	0.04	(0.26	0.00)	*
FEV_1 (l)	0.31	0.06	(0.26	0.00)	NS
FEV_1/VC (%)	3.21	0.82	(1.51	0.07)	*
MMEF ($l \cdot s^{-1}$)	0.79	0.19	(0.38	0.00)	*
MMEF/VC (%)	10.88	3.14	(3.03	0.16)	*
FRC (l)	−0.10	0.12	(−0.08	0.01)	NS
RV (l)	−0.17	0.10	(−0.19	0.01)	NS
MVV (l)	13.41	2.31	(8.60	0.31)	*
TLC (l)	0.01	0.11	(0.02	0.01)	NS
ERV (l)	0.06	0.09	(0.11	0.00)	NS
IC (l)	0.22	0.09	(0.09	0.01)	NS
IC/VC (%)	1.95	1.6	(−1.84	0.1)	*
MVV/IC ($l \cdot l^{-1}$)	−0.59	1.86	(1.45	0.09)	NS
RV/TLC (%)	−2.70	1.17	(−2.93	0.08)	NS

NS, Not significant. For definitions see Table 3. * $P<0.05$

Table 5. Body plethysmograph data and diffusion capacity recorded in 1992

	Actual (1992)		Predicted (1992)		P
	mean	SEM	mean	SEM	
FEF_{50} ($l \cdot s^{-1}$)	4.63	0.32	4.97	0.06	NS
FEF_{75} ($l \cdot s^{-1}$)	1.65	0.17	2.13	0.05	**
DL_{CO} ($ml \cdot min^{-1} \cdot mmHg^{-1}$)	32.80	1.13	30.80	0.51	NS
DL_{CO}/V_A ($ml \cdot min^{-1} \cdot mmHg^{-1} \cdot l^{-1}$)	4.95	0.17	4.94	0.05	NS

NS, Not significant; FEF_{50}, forced expiratory flow at 50% of vital capacity; FEF_{75}, forced expiratory flow at 75% of vital capacity; DL_{CO}, pulmonary diffusing capacity for carbon monoxide; V_A, alveolar volume
$^{**}P<0.01$

Body plethysmograph data and pulmonary diffusing capacity for carbon monoxide recorded in 1992

Small airway flows appeared significantly reduced ($P<0.01$) with measured FEF_{75}: 1.65 (SEM 0.17) $l \cdot s^{-1}$ [predicted: 2.13 (SEM 0.05) $l \cdot s^{-1}$]; DL_{CO}: 32.80 (SEM 1.13) $ml \cdot min^{-1} \cdot mmHg^{-1}$ and DL_{CO}/V_A: 4.95 (SEM 0.17) $ml \cdot min^{-1} \cdot mmHg^{-1}$ were not significantly different from predicted values (Table 5).

The importance of the duration of the diving career, maximal operating depth, mean annual exposure, age and mass gain was examined by correlating the variables with the changes in pulmonary function data. There was no significant correlation between the change in VC, FEV_1, FEV_1/VC and any of these variables. Change in MMEF correlated positively with the initial measurement of MMEF ($r=0.69$, $P<0.001$); the change in MMEF/VC correlated positively with the initial measure of MMEF/VC ($r=0.68$, $P<0.001$); the change in MVV showed a positive correlation with the initial measurement of MVV ($r=0.56$, $P<0.05$).

Discussion

The two cross-sectional analyses in the present study (1983 and 1992), both pointed out a higher diver's VC than the one predicted using ECSC standard (115% and 118%, respectively). These percentages are close to those that have been found by Davey et al. (1984) and Thorsen et al. (1990). This commonly related fact (Cimsit and Flook 1981; Fisher et al. 1970; Friemel et al. 1983; King and Trowbridge 1981) has suggested various hypotheses. Regular ventilatory training during sports (Armour et al. 1993; Davey et al. 1984; Stuart and Collins 1958), high density of breathed gas (Crosbie et al. 1979a; Maio and Fahri 1967) and additional resistances produced by pressure regulators (Mascret 1986) and wet suits (Crosbie et al. 1977) have been offered as some of the explanations. The same changes observed among skin divers with or without wet suits have pointed to respiratory muscle hypertrophy (Bouhuys and Beck 1979; Song et al. 1963) as the main factor. Different patterns in FEV_1 change and low FEV_1/VC have given rise to controversy concerning barotrauma risks in obstructive or "pseudo-obstructive" divers (Bouhuys and Beck 1979; Cimsit and Flook 1981; Crosbie et al. 1979a, b; Davey et al. 1983). Some of these authors have reported a smaller decrease in VC than in FEV_1, and thus a FEV_1/VC percentage smaller than 70% (4 subjects in 1992 in our study). Nevertheless, the significantly low FEV_1/VC percentage observed in the 1992 cross-sectional study (see Table 3) does not allow us, by itself, to suggest airflow obstruction because measured FEV_1 values were always above predicted values, and FEV_1/VC reduction is mainly the result of changes in VC.

In this longitudinal study, the observed decline in measured VC averaged $17\,\text{ml}\cdot\text{year}^{-1}$. Davey et al. (1984) have related similar results among a professional-divers group. The significant increase in VC relative values, (from 115% to 118% of ECSC reference values) between 1983 and 1992, like that shown in a longitudinal study of competitive-swimmers (Clanton et al. 1987), comes within the framework of the above hypotheses. Nevertheless, this result suggests, unlike others studies (Crosbie et al. 1979a; Watt 1985), that the operating diver's VC does not decline at a faster rate than that calculated from ECSC values. Maximal VC is normally reached around the age of 30 (Burrows et al. 1983), but the changing pattern of the diver's VC was still different than the one from ECSC at 42 years (this study), and indeed at 47 years (Davey et al. 1984). It would seem that only an additional decrease in VC, on cessation of diving, could cancel this difference. Thus, the possibility remains that the hyperbaric gases associated with regular endurance training induce early and especially long-lasting changes in VC (Carey et al. 1988).

Persisting FEV_1 values above those predicted were measured during both PFT (114% and 113%, respectively). This could mean that there was a continuous muscle adaptation to gaseous and mechanical resistances (Mascret 1986).

A significant reduction in small airway flow over this 9-year period, led us to consider the FD exposure to risks. According to Davey et al. (1984), firemen and professional divers both present such a reduction, but the latter have the larger decrease. Barthélémy et al. (1990) have described a similar reduction comparing FD and matched populations of welders, and attributed small airway flow deterioration to specific nuisances (pollutants, fumes, toxic substances) associated with FD activities.

According to the questionnaire results, City of Nice FD are more frequently exposed to hyperbaric gases than to toxic fumes. Thus MMEF and MMEF/VC decreases, in this study, do not seem attributable to smoking habits or toxic fumes. Nevertheless, unlike other authors (Cimsit and Flook 1981; Segadal et al. 1990; Thorsen et al. 1990), no correlation between small airway flow reduction and diving history has been found. The MMEF/VC was normal in 1983 and significantly reduced in 1992 (see Table 3 and FEF_{75} values also). Moreover, between the 13th and 22nd year of practice, the measured decrease rate for MMEF/VC was 1.22% each year versus 0.34% each year for the predicted rate of decrease ($P<0.05$). Thus this abnormal reduction would seem to be a late phenomenon. Chronic exposure to an hyperoxic gases could induce elastase activation, by free radical action on $\alpha_1 p_1$ antiprotease (Corlier 1987), and enhance the effect of increasing age on these airways until cessation of diving. This explanation is supported by the finding of significant positive correlations between the change in MMEF, MMEF/VC and initial MMEF, MMEF/VC, respectively ($P<0.001$). Therefore, the possibility remains that diving induces some structural changes in the fibro-elastic properties of small airways (Watt 1985).

The 20% lower RV seen among this FD population was similar to that expected in other divers (Barthélémy et al. 1990; Friemel et al. 1983), whereas TLC values remained high.

According to Barlett et al. (1984), a low ERV could result from hypertrophy of arms and thorax muscles (including respiratory muscles) leading to an increased cost of breathing. In the present study, higher than predicted ERV values (around 145%) were close to those found among a population of runners (Armour et al. 1993). Thus, it seems that the endurance-type training of FD is a stronger stimulus than the twice-weekly dives, with regard to muscle development and subdivisions of lung volumes. Moreover, when IC is used as an index of elastic recoil of lung and chest wall, and MVV as an index of the dynamic activity of the chest bellows including the function of airways respiratory muscles and chestwall (Bergofsky 1985), no imbalance between respiratory muscle dynamic activity and lung and chest elasticity (MVV/IC percentage) was found in FD. Normal values of DL_{CO} in 1992 are common results (Fisher et al. 1970; Hyacinthe and Broussolle 1979). Barthélémy et al. (1990) have reported decreased DL_{CO}, but the FD population they studied, unlike the one presented here, included many more firemen than divers.

Hyperbaric gases and physical training, probably by respiratory muscle hypertrophy, increased VC relative values and minimized the effect of aging on this parameter. Whereas FEV_1/VC reduction was due to a lesser decrease in VC than in FEV_1, obstructive disease concerning small airways was observed. To understand the mechanism of hyperbaric pathogenesis, further longitudinal studies, performed with divers not exposed to toxic fumes, are required.

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