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Evolution of the respiratory function of professional divers over 15 years

Richard Pougnet[1, 2], Laurence Pougnet[1, 3], Anne Henckes[1, 4], David Lucas[1], Jean-Dominique Dewitte[1, 2], Philippe Mialon[4], Brice Loddé[1, 2]

[1]Société Française de Médecine Maritime (SFMM), French Society of Maritime Medicine, Brest, France
[2]Université de Bretagne Occidentale, Brest, France
[3]Hôpital d'Instruction des Armées, Clermont-Tonnerre, Brest, France
[4]CHRU Brest, Hyperbaric Medicine Unit, Brest, France

ABSTRACT

Background: *The study was aimed at assessing changes in respiratory function after 15 years of professional diving, among scientific divers.*

Materials and methods: *A retrospective study was performed on divers who underwent an initial visit and a visit 15 years later at the same medical centre, among divers who had a scientific activity (monitoring the coastline, fauna and flora). Pulmonary function tests were performed in the same laboratory with the same operating standards and using a Jaeger MasterBody plethysmograph. Each subject acted as his or her own control. The data were analysed by Student's t-test and Spearman's correlation coefficient.*

Results: *Twenty-six divers were included. Changes over 15 years included: a decrease in the forced expired volume in 1 second/functional vital capacity (FEV1/FVC) ratio (–6 for absolute value, $p < 0.01$; and –5% for theoretical value, $p = 0.02$); a decrease in forced expiratory flow $(FEF)_{25\%}$ (–1.1 for absolute value, $p < 0.01$; and –21% for theoretical value, $p < 0.01$); a decrease in transfer factor for carbon monoxide (TLCO) (–0.7 for absolute value, $p = 0.04$); and an increase in vital capacity (VC) (+8% for theoretical value, $p = 0.03$). A significant correlation was found between the consumption of tobacco in packs per year (PY) and the variations in VC ($r = 0.89$; $p < 0.01$) and the variations in the theoretical FEV1 ($r = 0.76$; $p = 0.03$). There was a significant relationship between the number of dives and the variations in the percentage of the theoretical FEV1/FVC ratio ($r = –0.42$; $p = 0.04$). The same relationship was found for the average of dive duration ($r = –0.59$; $p < 0.01$)*

Conclusions: *With increasing length of diving activities service, the pulmonary function displays a trend toward both a decrease in TLCO and a decrease in $FEF_{25\%}$.*

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Key words: diving/physiology, pulmonary ventilation/physiology, occupational exposure, retrospective study

INTRODUCTION

The impact of professional diving on respiratory function has been studied for several decades. The data are often contradictory from one study to another. The populations do not always have a homogeneous exposure, or some articles relate to selected populations (like military divers) which produces a healthy workers effect. This article brings a new light because the population is not selected for its particular physiological capacities. These are scientists who dive for their studies. This highlights the effects of this occupational exposure.

The exercise of professional diving involves a variety of different activities [1]. Some divers are scientists, diving to collect information on fauna, flora, the chemical environment, etc. Other divers are responsible for monitoring human activities, such as coast guards or the gendarmerie. Still others are military and do demining or combat missions. The physical constraints are not the same, and gas mixtures

Richard Pougnet, MD, PhD, Centre de Pathologies Professionnelles et Environnementales, CHRU Morvan, 2 av Foch, 29200 Brest, France, e-mail: richard.pougnet@live.fr

can vary according to dive profiles. All these divers, however, are exposed to factors that may influence their lung function, such as hyperoxia, compression and decompression phenomena [2, 3].

These constraints could lead to deleterious effects on lung function. On this hypothesis, existing studies propose divergent results [1, 4]. For some authors, the long-term effects could be the appearance of a small airway disease [5, 6]. Other studies have shown variations in bronchial flow [7–9]. In contrast, other studies have shown a lack of effect of long-term professional diving on respiratory function [10]. However, studies for which there were no long-term effects often involved populations of military divers. Tetzlaff et al. [10] showed in 2005 that there was no significant effect, which was confirmed by Voortman et al. [11] in 2016. According to these authors, variations in lung capacity are due not to diving, but rather to age.

In France, previous studies have shown a decrease in diffusion lung capacity for carbon monoxide (DLCO) after 5 years of diving and peripheral bronchial discharges (DEM25 and DEM50) after 10 years, taking into account variations due to age and weight [12, 13]. These were studies of professional civilian divers, often scientists. The dive profiles and professional skill requirements were not comparable with the data from the military studies. The purpose of our study was therefore to evaluate the evolution of the respiratory function of scientifically-oriented civil divers over 15 years, taking into account changes related to age and weight variations.

MATERIALS AND METHODS

A retrospective study was carried out based on the files of 339 professional divers being followed at the Consulting Centre for Environmental, Maritime and Professional Pathologies at the Brest (France) University Hospital. We included those divers who had had an initial examination (i.e. before starting the training for professional diving) or at least the first-year examination and the 15-year examination at our Centre, and who dived for scientifically-oriented dives. So exclusion criteria were: been a military or no scientifically divers; and been a diver, who hadn't been followed in this centre for 15 years.

Biometric data, age, past medical history, medications, lifestyle (physical activities, smoking), and diving characteristics (average annual number of dives, mean and maximum depths, mean and maximum dive times, other professional exposure if any) were collected. Smoking consumption was calculated in number of packs per year (PY).

The pulmonary function data at 0 and 15 years were collected. The pulmonary function tests (PFTs) were all collected in the morning, at the same laboratory of the University Hospital. The equipment was a Jaeger Master-Body plethysmograph, calibrated every day and operated by well-trained technicians, with the same procedures over the duration of the study. The PFT included a complete plethysmography and a measurement of transfer factor for carbon monoxide (TLCO), using the breath-holding method. Functional vital capacity (FVC), forced expired volume in 1 second (FEV1), and forced expiratory flows (FEF) at 25% and 50% and 75% of FVC expired (respectively FEF25 and FEF50 and FEF75) were collected; static volumes, in particular total lung capacity (TLC) and vital capacity (VC), were measured by plethysmography, and the FEV1/FVC ratio was then calculated. The values of these parameters were expressed as a percentage of the theoretical value.

STATISTICAL ANALYSIS

The data were collected using Excel® software. Averages and extreme values were determined for each of them. The values at 0 and 15 years were compared to each other and then with the theoretical values in accordance with the values of the European Respiratory Society (ERS) [14–16]. Then Biostatgv® software was used to calculate medians, Student's t-test, and Spearman correlation coefficient.

RESULTS

Twenty-six divers were included in the cohort: 1 (4%) woman and 25 (96%) men. Median age after 15 years of diving was 48.5 years (full range was 39–65 years). Eleven (42%) had medical history at the end of the follow-up: 3 had traumatologic history, 2 had allergies, 1 had gastroesophageal reflux (GOR), 1 had sinusitis, 1 had high blood pressure (HBP) and 1 had anxiety. Only 3 divers had treatments: 1 for anxiety, 1 for HBP, and 1 for GOR.

Ten (38%) divers were current smokers during the 15 years of the follow-up; median consumption was 6 PY (full range was 5–26 PY). Nineteen (73%) divers practiced sport at least once a week: 17 (65%) practiced ground endurance sport (cycling, jogging, etc.) and 2 (8%) did water sports (swimming, windsurfing, etc.). Half (50%) of the divers had been recreational divers before turning professional, but only 8 (31%) practiced recreational diving after becoming a professional diver. Dive profiles were variable (Table 1).

Pulmonary function test carried out at 0 and 15 years showed a progressive decrease in FEF25 in absolute value and compared to theoretical values (Table 2). At the time of the initial examination, 8 (31%) and 10 (35%) divers, respectively, had a FEF25 lower than 70% and 80% of the theoretical value. These numbers were 17 (65%) and 21 (81%) at 15 years. The FEV1/FVC ratio expressed as a percentage of the theoretical value changed at 15 years ($p = 0.02$), but no diver had a FEV1/FVC ratio lower than 80% of the theoretical value over the period of study.

Plethysmography showed a significant increase in VC compared to the theoretical value after 15 years of diving (Table 3). TLC scores were all higher than 80%. They were higher than 120% initially for 6 (23%) divers at 15 years. Absolute values of TLCO decreased significantly after 15 years, but not in comparison with theoretical values (Table 3).

Table 1. Professional dive profiles

Parameters	Mean	Limit values
Number of professional dives per year	68	5–250
Total number of dives over 15 years	1,003	30–3,250
Mean depth [m]	14	4–25
Maximum depth [m]	29	8–60
Mean dive time [min]	60	15–180
Maximum dive time [min]	90	20–180
Total time [min]	79,625	600–585,000

A significant correlation was found between the consumption of tobacco in PY and the variations in VC (B = 0.89; p < 0.01) and also between the consumption of tobacco in PY and the variations in the theoretical FEV1 (B = 0.76; p = 0.03). However, there was no correlation between smoking and the variations in the other data, particularly the decreases in TLCO (p = 0.30), FEF25 (p = 0.79) and FEF50 (p = 0.72).

There was a significant relationship between the number of dives and the variations in the percentage of the theoretical FEV1/FVC ratio: the higher the number of dives, the greater the reduction in the percentage of the theoretical FEV1/FVC ratio (B = –0.42; p = 0.04). The same relationship was found for the average of dive duration (B = –0.59; p < 0.01). Conversely, the maximum duration of the dives did not influence the variations in the PFT.

DISCUSSION

This study of the respiratory function of professional divers employed in the civilian research field showed that

Table 2. Evolution of the various expiratory parameters

Parameters	Initial value Mean (extreme values)	After 15 years Mean (extreme values)	15-year evolution Mean (extreme values)	P
FVC [L]	5.7 (3.2–7.6)	5.4 (3.4–6.8)	–0.3 (–0.8, +0.2)	0.20
Theoretical FVC [%]	116% (82–142)	120% (93–142)	+3.7 (–11, +20)	0.30
FEV1 [L]	4.5 (2.9–5.8)	4.1 (2.7–5.2)	–0.4 (–1.1, +0.2)	0.03
Theoretical FEV1 [%]	112% (82–129)	113% (91–141)	+1.2% (–16, +21)	0.69
Theoretical FEV1/FVC ratio	81 (73–94)	76 (62–87)	–6 (–22, +8)	< 0.001
Theoretical FEV1/FVC ratio [%]	101% (92–119)	96% (82–109)	–5% (–15, +8)	0.02
FEF25 [L/s]	2.3 (1.6–2.9)	1.4 (0.4–3.0)	–1.1 (–1.6,+0.3)	< 0.001
Theoretical FEF25 [%]	88% (40–152)	67% (37–144)	–21% (–98, +54)	< 0.001
FEF50 [L/s]	5.1 (2.6–7.8)	4.4 (1.9–8.5)	–1.0 (–2.2, +0.44)	0.07
Theoretical FEF50 [%]	102% (61–185)	92% (57–175)	–11% (–49, +15)	0.12
FEF75 [L/s]	9.1 (6.5–12.5)	8.6 (4.8–12.8)	–0.9 (–4, +2.5)	0.26
Theoretical FEF75 [%]	114% (90–157)	111% (73–165)	–7% (–45, +20)	0.62

Abbreviations — see text

Table 3. Evolution of the different parameters of static volumes (plethysmography) and of transfer factor for carbon monoxide (TLCO)

Parameters	Initial value Mean (extreme values)	After 15 years Mean (extreme values)	15-year evolution Mean (extreme values)	p
VC [L]	5.6 (3.2–7.6)	5.5 (3.5–7.1)	–0.1 (–0.8, +0.4)	0.60
Theoretical VC [%]	111% (82–134)	118% (97–142)	+8% (–10, +22)	0.03
TLC [L]	7.5 (4.3–10)	7.5 (5.1–10)	0 (–1.0, +1.5)	0.96
Theoretical TLC [%]	106% (80–123)	108% (86–125)	–0.3% (–25, +20)	0.83
TLCO [mmol/min/kPa]	10.1 (6.7–12.5)	9.1 (6.5–11.9)	–0.7 (–1.7, +1.1)	0.04
Theoretical TLCO [%]	94% (74–120)	88% (66–115)	–6% (–28, +14)	0.08

TLC — total lung capacity; VC — vital capacity after 15 years of evolution, PFT are relatively stable and normal. There were significant variations in the degree of deviation from the theoretical values: decrease in FEV1/FVC and FEF25, increase in VC.

Some parameters influence lung volumes, including sex, age, and weight. But in this study, divers could have had changes in weight over a 15-year period. To evaluate the impact of diving and not those of weight or age, a decision was made to compare the results with an unexposed population having the same characteristics of sex, age, weight and sex. Hence the comparison with the reference values of the European Respiratory Society (ERS), which take into account these three parameters. These apply well to Caucasians, between 18 and 70 years old, of average height (between 155 and 195 cm for men and 145 to 180 cm for women). The group studied here corresponded perfectly to these criteria [17]. Theoretical values are often criticised as averages. For certain parameters, subjects might be considered normal or abnormal, whereas in reality they are simply people with larger or smaller sizes. For example, people of small size may have flows that are considered abnormally low. In this study, this problem was avoided: subjects were the same size at baseline and 15 years later; only deviations from theoretical values were compared. It can therefore be concluded that the variations in the differences with the theoretical values, initially and at 15 years, were not due to one of these three parameters. In particular, when a value decreased significantly from the theoretical values, age was not the cause.

However, dive causality cannot be concluded based solely on this data. Other parameters influence variations in lung volumes or bronchial flow, such as diet or physical activity, or environmental pollution. In this study, divers were not exposed professionally to chemical or physical harm to the lungs and bronchi. There was no connection with whether subjects participated in sports or not. It would seem, therefore, that diving is the causal parameter of these variations in relation to the reference values. It is appropriate to moderate the hypothesis because of the weakness of this study, namely co-exposures. There was no investigation of environmental exposure outside of work. Some divers may have been in contact with environmental pollutants. Another shortcoming is related to physical activity, which was tracked over 15 years in medical records, avoiding memory bias. However, the physical activity items were only declarative; classification bias may have occurred in the quantification of physical activity. This study may have underestimated the effects of physical activity or environmental impact other than diving. The choice of divers whose profession was both civilian and scientific in nature should have made it possible to have comparable dive profiles. However, divers had very different activities depending on their studies or their tasks on fauna and flora. This did not make homogeneous exposure groups possible.

In addition, the number of divers monitored over 15 years is relatively low. Other studies have collected data from larger populations. For example, Voortman et al. [11] studied 1,260 Dutch military divers, 103 of whom had been diving for 15 years. Similarly, Sames *et al.* [18] studied the evolution of spirometry in 232 divers for 10 to 25 years. The weakness of our sample did not allow for powerful statistical tests. There could also be a cluster effect on such a small population. Therefore, these results should be confirmed on a larger sample. Our centre follows a large number of divers, but only divers who have done all of their follow-up in this centre were included in this study. This made it possible to have PFT results done in the same laboratory. The purpose of the study was indeed to evaluate the evolution of respiratory function. For this, it was necessary to integrate the spirometry, plethysmography and alveolar-capillary diffusion data, unlike many studies that have only taken spirometry into account. Since these tests required special skills, the choice of a follow-up in the same centre made it possible to collect reliable and comparable data. A future study could include divers who have been followed in our centre for more than 15 years and recover the PFT done in their careers in other centres. Although less relevant from the point of view of the PFT technique, such an approach would make it possible to analyse the evolution of a larger population and to reduce the risk of cluster effects.

These results supported those of previous studies with respect to increasing lung volumes. In the most recent studies, FCV has been shown to increase significantly after 3 or more years of professional diving [7, 11, 19]. Although the oldest studies showed a reduction, it is generally accepted that VC and FVC increase due to the divers' training [1, 18]. For this study, there was no connection with physical activity in general or with diving. The effect of training could be put forward in a future study if data about the type of training were included.

Similarly, the decrease in peripheral bronchial flow rates had already been described in other studies. The significant decrease in FEF25 at 5 years confirms the results of many studies [6, 9, 12, 13, 20, 21]. No significant relation between the decrease in FEF25 and smoking habits was found. Since our subjects had no other professional toxic exposure, we may conclude that this flow reduction derives from the diving experience, suggesting an effect on first the bronchioles and then the larger bronchi. The hypothesis of small airways disease in professional divers has been discussed for several decades [1]. Some studies have shown the appearance of small airways disease among recreational divers [22], but these results have not been systematically shown in all studies for professional divers. There is really no evidence in basic biology to explain these results. One study using high computed tomography of the chest showed minor lobular air trapping, but there was no difference between divers and non-divers. Peripheral flows are rarely studied. Skogstad and Skare [7] showed a decrease in FEF25–75 after 12 years of evolution. In their more homogeneous group, this reduction was correlated with the total number of dives. It is difficult to conclude whether this decrease is relevant. This data has little effect on the clinical condition of the divers. But it seems that it is useful to follow this parameter. Tezlaff et al. [23] showed that expiratory flows at low pulmonary volumes are one of risk factors of pulmonary barotraumas [1, 23–25].

Unlike the most recent data in the literature, there were significant variations in peripheral flows and VC in this study. It is not possible to compare with studies that are simply based on spirometry, because they have no data on plethysmography and FEF25 [11, 18]. The populations were not comparable with that of Voortman et al. [11], for which no variation was found. Their military population included the healthy work bias, well described by the authors. It must also be emphasized that the military has professional aptitude criteria that are not comparable with the civilian population. The divers in this study were all civilians. There was therefore some tolerance for variations in their state of health and compatibility with their occupation. This study therefore had the advantage of showing the evolution of PFT in a dive population subject to a less drastic medical selection. Moreover, unlike data on recreational diving, the subjects of this study were not necessarily interested in diving for the sake of diving. Their dives were based on professional requirements. This difference with the data on recreational diving is considerable: in recreational diving there is a selection effect based on pleasure. Civilian professional divers did not correspond with these other two population types. The data from this study may have shown changes in lung function that were masked by these selections in military and recreational diving studies.

CONCLUSIONS

This study of civilian professional divers showed an evolution in PFT over 15 years. The analyses were done by comparing the deviations from the European theoretical values. There was a significant decrease in FEV1/FVC, FEF25, and an increase in VC. These data are to be weighted against the small size of the population, which included only 26 divers. A complementary study should make it possible to better identify the effects of diving on this particular population. The exposure and selection of these divers was indeed special in that, being scientists, their professional activity included other tasks. Medical selection was thus less drastic than in studies focusing on military divers.

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