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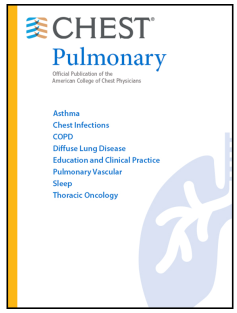

Impact of SCUBA diving on French military divers' lung function: a retrospective cohort

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Ethical considerations
We used routinely collected anonymised data, which are not publicly available. As the study was conducted in a military setting, the project was presented to and approved by the French Armed Forces Health Service (SSA). A detailed data management plan was developed with the SSA's data controller representative, and the research was conducted according to the principles of the World Medical Association Declaration of Helsinki.
Institutional review board approval not required for this retrospective cohort study.

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Conflict of interest
All authors declare that there is no financial nor personal interest or belief that could affect their objectivity.

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Impact of SCUBA diving on French military divers' lung function: a retrospective cohort

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Impact of SCUBA diving on male French military divers' lung function: a retrospective cohort

Key words list:
Diving, Lung function, Military, Long term impact

Abbreviations

BMI Body Mass Index: kg·m^{-2}
COPD Chronic obstructive lung disease
$FEF_{25-75\%}$ Forced mid-expiratory flow: l·s^{-1}
$FEF_{75\%}$ Forced expiratory flow when 75% of forced expiratory vital capacity has been exhaled: l·s^{-1}
FEV_1 Forced Expiratory Volume in one second: l
FVC Forced expiratory vital capacity: l
ICC Intraclass Correlation Coefficient
NITROX, gas mix containing nitrogen and enriched oxygen (making up to 60% of the mix)
SCUBA Self-Contained Underwater Breathing Apparatus
SMHEP Service de Médecine Hyperbare et d'Expertise Plongée, Medical center responsible for the medical follow-up of military divers
T_{Lco} Carbon monoxide transfer factor for the lung: mmol·min^{-1}·kPa^{-1}

Abstract

Background: While acute risks concerning underwater divers are well-documented, the literature regarding the long-term impacts on pulmonary function remains inconclusive. Although oxygen toxicity at high partial pressures is established for patients in intensive care, the impact of diving seems limited.

Research Question: What are the long-term effects of SCUBA diving on pulmonary function in military divers?

Study design and Methods: This longitudinal study used routinely collected data from the Military Hospital of Sainte-Anne, Toulon, over a 20-year follow-up period. We expressed spirometric measures as a percentage of predicted values to account for age, height, and ethnicity, and analysed it using mixed-effects models. The impact of diving is assessed for different gas and diving apparatus. Other included variables were atopy, smoking history, and body mass index.

Results: 331 divers were included (2685 spirometric measurements), with an average follow-up of 23.9 years and 2491 dives. Only male divers met inclusion criteria. Baseline FEV_1 matched predicted values (100.00%, SD=11.98). Every 1000 dives, FEV_1 increased by 3.21% (95% CI [2.73–3.68], $p < 0.001$), regardless of gas or apparatus. FVC (3.02%, [2.52–3.53], $p < 0.001$) and $FEF_{75\%}$ (10.12%, [8.29–11.95], $p<0.001$) increased, while FEV_1/FVC remained stable. Each BMI point increase was associated with a 0.51% rise in FVC ($p=0.010$) and 0.38% rise in FEV1 ($p = 0.032$), while each pack-year was associated with a 1.12% decline in $FEF_{75\%}$ ($p=0.005$).

Interpretation: SCUBA diving is associated with increased pulmonary flows and volumes in this population of military divers. Prospective studies could explore the role of unmeasured confounding factors and could significantly contribute to health policies for both military and civilian divers.

To breathe underwater, divers use scuba equipment. In most cases, air is used, which contains about 20% oxygen (O_2). According to Dalton's law, as the depth of immersion increases, the partial pressure of O_2 increases. Therefore, even when the diver breathes air, their pulmonary system is exposed to hyperoxia. During certain technical dives, whether civilian or military, divers use oxygen-enriched mixtures containing up to 60% O_2 (NITROX), or even pure oxygen (100%) [1]. In these cases, exposure to hyperoxia is even more significant. The toxicity of prolonged exposure to high concentrations or partial pressures of oxygen has been demonstrated in patients hospitalised in intensive care units, where it can lead to potentially fatal pulmonary fibrosis [2]. The consequences include impaired gas exchange at the alveolar level, measured by the carbon monoxide transfer factor (T_{Lco}), and a decrease of FEV_1/FVC [2,3].

Furthermore, military and professional divers use specific breathing equipment that increases the mechanical strain on the lungs [4,5]. For example, the use of dorsal rebreathers can cause pulmonary oedema due to differences in hydrostatic pressure between the lungs of the divers, and the apparatus. However, the impact of prolonged and repeated exposure to a hyperbaric environment, as imposed by underwater diving, remains to be clarified [3,6]. A literature review from 2014 aiming to highlight the impact of underwater diving on ventilatory function found 15 articles with a longitudinal design [7]: sample sizes were small, follow-up durations were short, and results were contradictory. Overall, it suggests a small deterioration in ventilatory function with a decrease in Forced Expiratory Volume in 1 second (FEV_1) [8–11], peripheral flows ($FEF_{50\%}$, $FEF_{75\%}$) [8,9,12], Forced Vital Capacity (FVC) [9–11], and T_{Lco} [12–15]. Among these studies, only three found a significant decrease in FEV_1 after age-standardisation [8,10,12]. Thus, this literature review does not allow us to conclude whether the variations in spirometric parameters are caused by diving exposure or ageing [7]., and whether these minimal variations may have clinical consequences. Finally, these studies did not consider the gas and type of diving apparatus used. More recently, two wider retrospective studies with 232 and 1,260 divers concluded that diving had no clinically significant impact on lung function [16,17].

Considering the data demonstrating the toxicity of high partial pressure oxygen on lung function and given the varying conclusions of previous studies on the long-term impacts among professional divers, we aimed to determine whether the professional practice of underwater diving could permanently affect the ventilatory function of French military divers. More precisely, we wonder whether practising professional military diving for over 20 years permanently alters the ventilatory function of military divers. If so, are there identifiable risk factors, individual or related to diving practice and the gas mixtures used?

Methods

Study design and setting

We conducted a retrospective monocentric study using routinely collected hospital data on a cohort of military SCUBA divers who were followed up at Sainte-Anne military hospital (Toulon, France), where they attend fitness-to-dive assessments every four years. This fitness-to-dive assessments include spirometric measurements.

Participants

All French military divers are followed up at Saint-Anne military hospital with spirometry data currently available in the database. Depending on their speciality, these divers may use mainly: open circuit diving apparatus with air, open circuit diving apparatus with NITROX, semi-closed circuit diving apparatus with NITROX, or closed-circuit diving apparatus with pure oxygen.

We have included all divers with a follow-up beginning before January 1st, 2002, to assess the long-term impact of diving on lung function with a manageable sample. Divers are excluded if spirometric measures at baseline (free of exposure to military diving) are missing, no spirometric measurement has been conducted at 20 years of follow-up or after, or data on birthdate, height at admission, or history of SCUBA diving in civilian structures before admission are missing.

As the study was conducted in a military setting, the project was presented to and approved (n° 2022HJ29/EPSMPP) by the French Armed Forces Health Service (SSA). A detailed data management plan was developed with the SSA data controller representative, and the research was conducted according to the principles of the World Medical Association Declaration of Helsinki. Patient consent was not required, but they were informed of their right to withdraw.

Dataset, variables, and measurements

The available data include spirometric measurements (FEV_1, FVC, $FEF_{75\%}$, $FEF_{25\text{-}75\%}$), diving exposure such as the type of apparatus and mixture used (Air, NITROX, oxygen, open-circuit, semi-closed or closed-circuit-rebreather) and the number of dives for each of these apparatuses and mixtures. Also collected are age, sex, height, weight, diver's professional speciality, military branch, comorbidities such as atopic history, diving accident history and smoking pack-years. Spirometry tests are conducted by nursing staff. The measurement tools vary throughout the follow-up period, with changes in the spirometer model and brand, software, and calibration protocol. We calculated predicted values for all spirometric values included, using the GLI-2012 equations [18,19]. New variables, expressed as percentages of predicted values, allowed us to account for the natural evolution of lung function over time by comparing our measured data to a control population.

Study size

Previous longitudinal studies mainly included small samples of less than 30 patients, except for one study, which included 1260 patients with a mean follow-up time of 5 years [20]. These studies have conflicting results and do not allow us to safely estimate the effect of diving on spirometric parameters. Thus, we were not able to calculate a minimal sample size for our own study.

Analysis

All analyses were performed in R software (version 4.2.2) and RStudio (2022.07.2+576) [21,22]. The primary outcome chosen is the change in FEV1 (as a percentage of predicted value) per 1,000 dives, calculated separately for each dive type (compressed air open circuit, Nitrox open circuit, Nitrox semi-closed circuit, and oxygen closed circuit). The model adjusts these coefficients for clinical characteristics such as atopic history, smoking history, and BMI, resulting in four distinct coefficients representing the change in FEV1 for each type of dive. Secondary outcomes include 1. Changes in

FVC, $FEF_{75\%}$, and FEV_1/FVC (as a percentage of predicted value) per 1,000 dives. Parametric t-tests, paired and unpaired, were used after controlling for normality to assess differences between quantitative variables. For qualitative variables, the Chi-squared test was employed. Before any quantitative analysis, a test for equality of variances (Fisher's test) was conducted. If this test indicated significantly different variances, the Welch test was used to compare means; otherwise, the Student's t-test was applied. Results are reported as mean and standard deviation for normally distributed data or as median and interquartile range for non-normally distributed data, with a 95% confidence interval. The chosen significance threshold was $p < 0.05$.

A multiple linear model with mixed effects was used to evaluate the impact of diving on pulmonary function. Fixed effects included duration of diving exposure in years, presence of atopic history, smoking status expressed in pack-years, and diving characteristics. Random effects were considered at the diver level to account for individual differences among divers. This model allows for considering unmeasured parameters and estimating the ventilatory function evolution for each group and an average slope based on all divers. Each diver could dive with more than one apparatus. In the model, the number of dive for each apparatus was accounted (i.e., diver "a" may have dived 100 times with a closed circuit and 500 times with an open circuit at the time of a fitness-too-dive assessment. Both values were included in the model. Missing data, representing less than 10% of the sample, were disregarded. Otherwise, Multiple Imputation would have been considered.

Results

Participants

Among approximately 3,500 divers currently followed-up, 367 were followed-up for more than 20 years and were screened for inclusion. 36 were excluded for reasons presented in Figure 1. 331 divers were finally included in the statistical analysis, representing 2685 spirometric evaluations. All were male. Five different army branches are represented, each corresponding to different operational diving constraints.

Descriptive data

The sociodemographic characteristics are presented in Table 1. The divers had an average age of 24.1 ± 2.8 years at the beginning of their career. Previous experience in recreational diving before their professional career was reported by 119 (37.7%) divers, with 37 (11.7%) divers having experience of more than 100 dives. For 15 divers, no information on dives before their professional career was available. The average duration of follow-up was 23.9 ± 5.5 years, with a maximum of 42.9 years. At the end of the follow-up, 70 divers (20.7%) were reservists. The total number of dives averaged 2469 ± 1201, with a maximum of 7060. 170 (52.6%) primarily dived with compressed air, 45 (13.9%) used closed-circuit rebreathers, 47 (14.6%) used open-circuit with NITROX, and 60 (18.2%) regularly used semi-closed-circuit rebreathers.

The average weight of the subjects at baseline was 73.3 ± 7.3 kg (95% CI [72.5-74.1]) and 80.1 ± 9.4 kg (95% CI [79.1-81.1]) at the end of the follow-up period, the difference being significant ($p < 0.001$). Their Body Mass Index (BMI) was 23.2 ± 1.7 kg/m2 (95% CI [23.0-23.4]) at baseline and 25.4 ± 2.3 kg/m2 (95% CI [25.2-25.7]) at the end of the follow-up ($p < 0.001$). Smoking status, atopy, respiratory comorbidities and spirometric values are summarised in Table 2. 24 diving accidents were reported, including 5 decompression sickness, 5 pulmonary oedema, 4 barotrauma, and 10 biochemical accidents (hypoxia, hyperoxia, hypercapnia, narcosis).

Main results

Models' conception

The regression models' intra-class correlation coefficients (ICC) are all between 0.40 and 0.70, confirming a cluster effect and justifying the use of mixed-effects models. Diagnostic tests for each mixed-effects regression model presented below showed that the models satisfy the necessary conditions for validation. Tables 3 to 6 present detailed results of each model, while Figure 2 summarises association between the number of dives and FVC, $FEF_{75\%}$,and FEV_1 as a percentage of predicted values.

FEV_1: FEV_1 significantly increases with the number of dives, with an average of 3.21% of predicted values each 1000 dives ([2.73–3.68], $p < 0.001$). There is no significant difference in using one gas mixture over another or using different apparatuses. FEV1 increases with BMI (0.38% [0.03–0.72], $p = 0.032$).

$FEF_{75\%}$: $FEF_{75\%}$ increases with the number of dives, with an average of 10.12% [8.29–11.95] of predicted values per 1000 dives ($p<0.001$). There is no significant difference in using one gas mixture over another or using different apparatuses.

FVC: FVC significantly increases with the number of dives, with an average increase of 3.02% of predicted values per 1000 dives ([2.52–3.53], $p < 0.001$). There is no significant difference in using one gas mixture over another or using different apparatuses. A higher BMI is associated with a larger FVC (+0.51% per $kg \cdot m^{-2}$, $p=0.010$).

FEV_1/FVC: FEV_1/FVC is not influenced by the number of dives performed ($p=0.434$). There is no significant difference in using one gas mixture over another, with widely overlapping confidence intervals.

Discussion

Key results

Mean FEV_1 value at baseline perfectly fits predicted values (100.00%), indicating that our sample is comparable to the population used to create the equations for these predicted values. The multivariate analysis performed in this study shows a change of 3.21% in predicted values for 1000 dives, after correcting for the effects of BMI, atopic history, and smoking on FEV_1. This same association is found for other spirometric parameters used to assess ventilatory flows such as $FEF_{75\%}$ (+10.12%), as well as for assessing lung volumes with FVC (+3.02%). These variations are not greater than expected variability in the general population [23], but the whole cohort is impacted. Only the FEV_1/FVC ratio is not influenced by diving, as it is the ratio of two variables rising at the same pace. The increase in FEF75 must be interpreted while keeping in mind that these values are measured at higher volumes when FVC is greater. The observed increase in FVC, FEV1, and FEF75, expressed as percentages of predicted values, should be interpreted with caution. In absolute values (without accounting for age, as presented in Table 2) and over the course of their career, FVC remains stable (95% CI: [5.32–5.48 L] at baseline and [5.30–5.50 L] at the end of follow-up), while flow rates decrease, with a reduction in FEV1 (95% CI: [4.54–4.66 L] at baseline and [4.24–4.36 L] at the end of follow-up) and FEF75 (95% CI: [2.60–2.80 L] at baseline and [1.80–2.00 L] at the end of follow-up). The distinct types of gas and devices used do not significantly influence the evolution of FEV_1 or other spirometric values. Thus, we cannot demonstrate a link between the oxygen concentration in the breathed mixture and lung function (dose-effect). However, as the depth limits for diving are calculated based on the partial pressure of gases and not on their concentration in the breathed mixture, the dose-effect of oxygen measured in partial pressure could be evaluated by studies with data collection allowing precise knowledge of the duration of each dive, their depth, and the mixture used. The discrepancy in our results compared to previous studies can be explained by adjusting the measured values for the age of the divers using predicted values. Indeed, we observe a decrease in ventilatory flows over time when using the raw spirometric values measured in litres during consultations. Using predicted values ensures this decrease is smaller than expected due to ageing alone.

Tobacco consumption is known to affect lung function. We do not show any alteration of FEV_1 associated with smoking in our study, but $FEF_{75\%}$ decreases with the extent of smoking history (-1.12% per pack-year), indicating that our cohort may just be insufficient to demonstrate the impact of smoking on FEV_1 (low power, which could have been improved by including more patients). A second hypothesis is that smoking impact may be reduced in our cohort compared to the general population due to physical training intensity [24]. BMI is associated with a moderate FEV_1 increase of 0.38% and a FVC increase of 0.51% of predicted values per BMI point. This minimal, though significant, relationship between BMI and volume is to be expected given the minimal changes in BMI over time. Interestingly, the direction of change is typically lower not higher and it may be that the BMI increase in this particular population is a reflection of greater muscle mass as opposed to sedentary behaviour. Atopic status does not significantly modify spirometric values measured in our cohort. The exclusion of symptomatic asthmatic patients from the cohort due to their inability to engage could explain the weak and nonsignificant impact of atopy on lung function in our cohort. Among the patients included, despite their atopic status or even asthma, the hidden use of ß2-mimetics in anticipation of fitness visits could also explain the lack of significance. Finally, a lack of power (too few included subjects) may also be responsible for the lack of significant effect of atopy on FEV_1 and $FEF_{75\%}$.

Limitations

Despite its strengths, this study has some important limitations to consider. Firstly, the use of predicted value can not completely replace an adequate control group. The studied sample consists exclusively of military personnel, meaning the results may not be generalisable to a broader population of professional divers, as military diving practices are specific and distinct from those of civilian professional divers. Military diving equipment, protocols and physical training differ significantly from civilian divers, which could uniquely influence the outcomes. There is currently no database to track civilian professional divers, so the comparability of results is limited. Additionally, the absence of women in the sample limits the scope of the conclusions. Furthermore, we cannot establish a dose-response relationship between oxygen exposure and its effects on FEV_1, as the various gas mixtures used similarly impact this measure. Dive characteristics such as duration, depth, and temperature could not be evaluated due to their strong interdependence with the types of gases and equipment used and due to the quality of collected data. For instance, closed-circuit oxygen divers undertake longer but shallower dives than others. Including duration and depth in the analysis model in addition to the gas mixture could have led us to mistakenly conclude either the absence of an effect of these three parameters or attribute the effects of one parameter to the others. It is essential to note that these results do not allow for the affirmation of a causal relationship between diving and the increase in FEV_1. There is merely a correlation between these two variables, indicating that the FEV_1 of divers tends to increase compared to the general population as they undertake more dives. It would be premature to attribute this increase directly to diving. More in-depth analyses of this database are necessary to understand better the long-term effects of diving on pulmonary function. A better interpretation of spirometric values evolution could have been made with Z-scores instead of percentages of predicted values. Our initial analysis plan did not consider this opportunity of using Z-scores but preferred comparability of results with previous studies using percentages of predicted values.

Although these limitations must be considered, the methodology of this study demonstrates considerable improvements over earlier retrospective studies, particularly through the inclusion of more spirometric measurements and longer follow-up [7,26]. Predicted values account for age, height, sex, and ethnicity, while the model adjusts for variables known to impact lung function (BMI, atopic history, smoking history, socio-professional category) and accounts for different dive characteristics [27,28]. Thus, this is the first study to evaluate differences between air, NITROX, and pure oxygen [7]. However, military divers are offered diverse career paths, leading them to specialities requiring various intensities of physical training and levels of adverse occupational and environmental exposures, such as moisture or asbestos in navy ships, leptospirosis or other infectious diseases met during missions and training [5]. Water and inhaled gas temperature, depth and length of dives could not be evaluated due to the collinearity with the type of gas and apparatus used.

While this study aimed to explore the impact of diving on lung function in French military divers, these other factors may also influence lung function evolution. The predicted values offer the possibility of accounting for normal ageing but do not account for these factors, and the retrospective design of this study does not allow for adequate collection of these factors [29]. These factors may influence FEV_1 on a more important scale than SCUBA diving. The sample of divers included in the study may not sufficiently represent the overall population used to create the equations for predicted values. Still, this hypothesis is not supported by the average value of FEV_1 at baseline (100.00% of predicted value), when the subjects were already enrolled in the military and physically fit and trained**.** Another hypothesis is that diving may strengthen respiratory muscles due to the higher airflow resistances met when breathing with SCUBA equipment and the higher respiratory effort needed. This is supported by the positive effect that respiratory muscle training has on lung function. [30–32] However, the studies focused on the impact on lung function of patients with neurological diseases, asthma, or COPD. Thus, the impact of respiratory muscle training on healthy subjects is unclear. Finally, the spirometric test instructions may be better understood by subjects at the end of the follow-up than at the first lung function assessment, artificially increasing the values over time. [33]

Conclusion

SCUBA diving is associated with a slower decline of pulmonary flows and volumes over time in this population of military divers. However, this association should not be interpreted as evidence that diving is directly responsible for these changes, as it contrasts with findings from previous studies and many potential confounders were not explored. Our findings emphasise the importance of further investigating the long-term effects of underwater diving on pulmonary function among military personnel. Prospective studies incorporating non-diving controls could more precisely explore the unmeasured confounding factors in our study. These studies could significantly contribute to health policies for both military and civilian divers by enhancing our understanding of the impact of diving on their respiratory health. As a result, the modalities of pulmonary function monitoring could be adapted, including improving the quality of spirometry tests through better explanations and instructions for performance, and extending follow-up beyond the professional career.

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Fig 1. Flow chart of inclusion for eligible patients

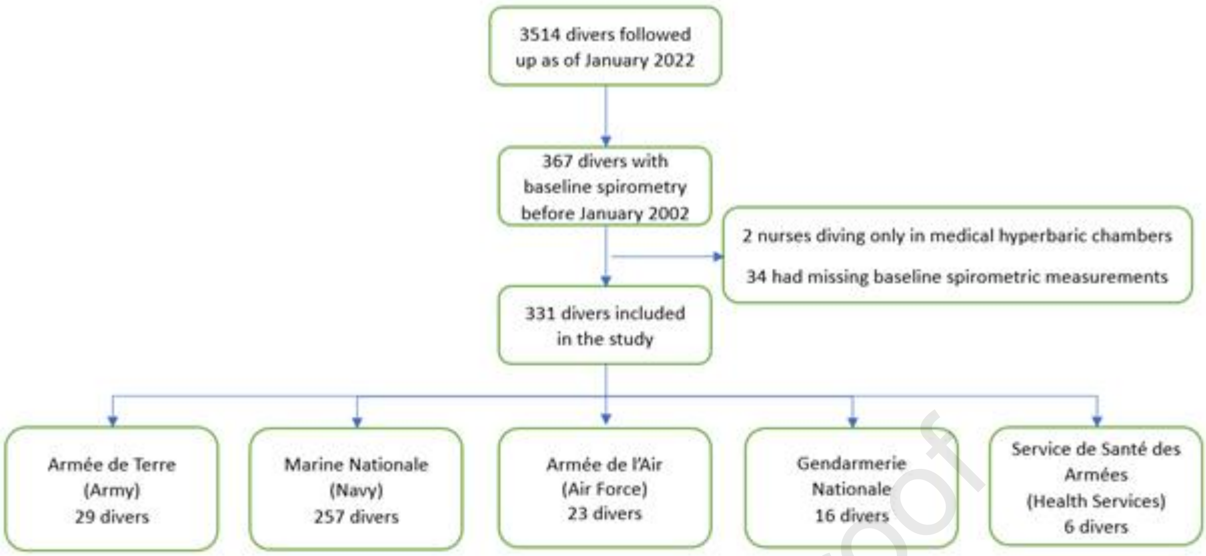


Fig 2. Evolution of spirometric values according to the number of dives and age at the time of data collection. Abbreviations: FEF75% Forced expiratory flow when 75% of forced expiratory vital capacity has been exhaled, FEV1 Forced Expiratory Volume in one second, FVC Forced expiratory vital capacity

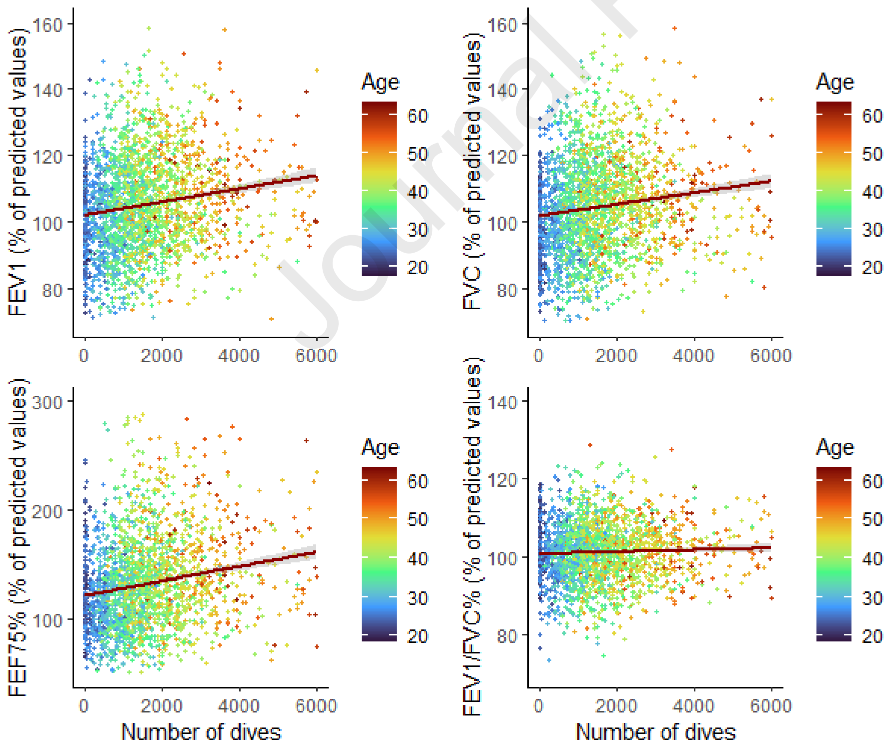


Table 1. Sociodemographic Characteristics of Participants at Baseline and End of Follow-up

Characteristic	n (%)	{range}
Age at baseline, mean ± SD	24.1 ± 2.8	{17 - 35}
Rank category		

Officer	34 (10.7)	
Warrant Officer	285 (89.3)	
Number of dives preceding military training, mean ± SD	68 ± 186	{0 – 1500}
0	197 (62.3)	
1 – 100	82 (25.9)	
More than 100	37 (11.7)	
Number of dives at end of follow-up, mean ± SD	2469 ± 1201	{450 – 7060}
Less than 1001	14 (4.5)	
1001 – 2000	123 (39.5)	
2001 – 3000	92 (29.6)	
More than 3000	82 (26.4)	
Main apparatus and gas mixture used during follow-up		
Air open circuit	170 (52.6)	
NITROX open circuit	47 (14.6)	
NITROX semi-closed-circuit rebreather	61 (18.9)	
Oxygen closed-circuit rebreather	45 (13.9)	
Number of dives with Air open circuit, mean ± SD	1273 ± 1505	{200 - 6000}
Number of dives with NITROX open circuit	237 ± 505	{0 - 3200}
Number of dives with NITROX semi-closed-circuit rebreather	564 ± 1112	{0 - 6000}
Number of dives with Oxygen closed-circuit rebreather	420 ± 979	{0 - 6050}

Table 2. Clinical Characteristics of Participants at Baseline and End of Follow-up

Characteristic	Baseline	End of follow up	p-value
Smoking status			**< 0.001**
Non-smoker	261 (79.1)	235 (71.2)	
Current smoker	61 (18.5)	43 (13.0)	
Former smoker	8 (2.4)	52 (15.8)	
Smoking consumption (pack-years), mean ± SD	2.2 ± 1.3	10.2 ± 7.2	**< 0.001**
Body Mass Index (kg/m^2), mean ± SD	23.2 ± 1.7	25.4 ± 2.3	**< 0.001**
Body Mass Index < 25 kg/m^2	259 (85.2)	138 (45.1)	
Body Mass Index ≥ 25 kg/m^2	45 (14.8)	168 (54.9)	
Atopic/allergic history	53 (16.6)	53 (16.6)	1
Known respiratory comorbidities	5 (1.6)	17 (5.3)	**0.009**
Any other known medical condition	5 (1.6)	40 (12.5)	**< 0.001**
Currently on daily medication	1 (0.3)	13 (4.1)	**0.001**
FVC (litres)	5.4 ± 0.7	5.4 ± 0.9	0.703
FVC (% of predicted value)	98.6 ± 11.5	108.4 ± 15.2	**< 0.001**
FEV1 (litres)	4.6 ± 0.6	4.3 ± 0.6	**< 0.001**
FEV1 (% of predicted value)	100.0 ± 11.9	109.2 ± 14.9	**< 0.001**
FEV1/FVC (%)	85.3 ± 6.6	80.0 ± 6.1	**< 0.001**
FEV1/FVC (% of predicted values)	101.7 ± 7.7	101.1 ± 7.7	0.358
FEF75% (litres)	2.7 ± 0.9	1.9 ± 0.6	**< 0.001**
FEF75% (% of predicted values)	122.1 ± 39.7	148.7 ± 50.5	**< 0.001**
FEF25-75% (litres)	5.2 ± 1.1	4.2 ± 1.0	**< 0.001**
FEF25-75% (% of predicted values)	107.3 ± 22.4	115.7 ± 28.5	**< 0.001**

Table 3. Multivariate analysis of FEV1 (% of predicted values)

	Univariate			Multivariate			Complete model		
Characteristic	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**
Total No. of dives[2]	2.21	1.70 – 2.71	**<0.001**	3.21	2.73 – 3.68	**<0.001**			
No. Air open circuit[2]	2.62	2.06 – 3.19	**<0.001**				3.42	2.80 – 4.04	**<0.001**
No. Nitrox open circuit[2]	1.15	-0.51 – 2.81	0.175				3.83	2.14 – 5.53	**<0.001**
No. Nitrox semi closed circuit[2]	-0.27	-0.98 – 0.43	0.443				2.98	2.10 – 3.86	**<0.001**
No. Oxygen closed circuit[2]	0.52	-0.31 – 1.36	0.220				2.42	1.38 – 3.47	**<0.001**
Rank category[3]			0.795			0.197			0.165
Officer	-0.21	-1.82 – 1.39		1.41	-0.73 – 3.55		1.52	-0.63 – 3.67	
Body Mass Index	0.93	0.66 – 1.20	**<0.001**	0.36	0.02 – 0.70	**0.039**	0.38	0.03 – 0.72	**0.032**
Pack-year	-0.22	-0.39 – -0.05	**0.010**	-0.07	-0.30 – 0.16	0.546	-0.07	-0.30 – 0.16	0.526
Atopic history	2.67	1.22 – 4.13	**<0.001**	1.78	-1.58 – 5.15	0.297	1.65	-1.72 – 5.01	0.336

[1] CI = Confidence Interval.
[2] Estimates for the number of dives (total and per gas/apparatus) represent the evolution of FEV1 per 1000 dives.
[3] Baseline category = Warrant Officer
No. Patients = 309; No. Obs. = 2386; Sigma = 8.85; ICC = 0.60; Log-likelihood = -8 965;
AIC = 17 951; BIC = 18 015; REMLcrit = 17 929; conditional R^2 = 0.627

Table 4. Multivariate analysis of $FEF_{75\%}$ *(% of predicted values)*

	Univariate			Multivariate			Complete model		
Characteristic	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**
Total No. of dives[2]	7.39	5.78 – 9.00	**<0.001**	10.12	8.29 – 11.95	**<0.001**			
No. Air open circuit[2]	6.83	5.04 – 8.62	**<0.001**				11.49	9.21 – 13.78	**<0.001**
No. Nitrox open circuit[2]	4.80	-0.40 – 10.00	0.070				14.41	7.97 – 20.86	**<0.001**
No. Nitrox semi closed circuit[2]	1.47	-0.76 – 3.69	0.195				6.83	3.55 – 10.11	**<0.001**
No. Oxygen closed circuit[2]	1.46	-1.18 – 4.11	0.227				7.93	3.95 – 11.91	**<0.001**
Rank category[3]			0.644			0.746			0.515
Officer	-1.22	-6.38 – 3.94		1.16	-5.88 – 8.20		2.35	-4.73 – 9.44	
Body Mass Index	1.48	0.59 – 2.38	**0.001**	0.64	-0.55 – 1.84	0.290	0.56	-0.64 – 1.77	0.357
Pack-year	-0.99	-1.52 – -0.46	**<0.001**	-1.13	-1.91 – -0.35	**0.004**	-1.12	-1.90 – -0.34	**0.005**
Atopic history	4.56	-0.15 – 9.28	0.058	0.51	-8.47 – 9.50	0.911	-0.16	-9.17 – 8.84	0.972

[1] CI = Confidence Interval.
[2] Estimates for the number of dives (total and per gas/apparatus) represent the evolution of FEV1 per 1000 dives.
[3] Baseline category = Warrant Officer
No. Patients = 308; No. Obs. = 2162; Sigma = 32.6; ICC = 0.41; Log-likelihood = -8 965;
AIC = 21 731; BIC = 21 777; REMLcrit = 21 715; conditional R^2 = 0.457

Table 5. Multivariate analysis of FVC (% of predicted values)

	Univariate			Multivariate			Complete model		
Characteristic	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**
Total No. of dives[2]	1.98	1.48 – 2.48	**<0.001**	3.02	2.52 – 3.53	**<0.001**			
No. Air open circuit[2]	2.07	1.50 – 2.63	**<0.001**				3.65	2.94 – 4.36	**<0.001**
No. Nitrox open circuit[2]	3.15	1.50 – 4.80	**<0.001**				3.57	1.55 – 5.58	**<0.001**
No. Nitrox semi closed circuit[2]	-0.36	-1.06 – 0.34	0.310				3.85	2.80 – 4.90	**<0.001**
No. Oxygen closed circuit[2]	0.70	-0.13 – 1.53	0.098				2.99	1.70 – 4.28	**<0.001**
Rank category[3]			0.792			0.548			0.677
Officer	0.22	-1.38 – 1.81		0.68	-1.54 – 2.90		0.48	-1.80 – 2.77	0.22
Body Mass Index	0.97	0.70 – 1.24	**<0.001**	0.48	0.12 – 0.84	**0.009**	0.51	0.12 – 0.89	**0.010**
Pack-year	-0.07	-0.24 – 0.09	0.391	-0.08	-0.31 – 0.16	0.527	-0.09	-0.35 – 0.16	0.479
Atopic history	2.42	0.97 – 3.87	**0.001**	1.38	-1.79 – 4.54	0.392	1.50	-1.79 – 4.79	0.369

[1] CI = Confidence Interval.
[2] Estimates for the number of dives (total and per gas/apparatus) represent the evolution of FEV1 per 1000 dives.
[3] Baseline category = Warrant Officer
No. Patients = 309; No. Obs. = 2386; Sigma = 9.61; ICC = 0.54; Log-likelihood = -9 120.
AIC = 18 256; BIC = 18 302; REMLcrit = 18 240; conditional R^2 = 0.577.

Table 6. Multivariate analysis of FEV1/FVC (% of predicted values)

	Univariate			Multivariate			Complete model		
Characteristic	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**	**ß**	**95% CI[1]**	**p-value**
Total No. of dives[2]	0.19	-0.07 – 0.46	0.158	0.11	-0.17 – 0.40	0.434			
No. Air open circuit[2]	0.46	0.16 – 0.76	**0.003**				0.16	-0.23 – 0.56	0.417
No. Nitrox open circuit[2]	-1.99	-2.85 – -1.12	**<0.001**				0.23	-0.88 – 1.34	0.686
No. Nitrox semi closed circuit[2]	0.14	-0.22 – 0.51	0.440				-0.32	-0.89 – 0.25	0.266
No. Oxygen closed circuit[2]	-0.16	-0.60 – 0.27	0.461				0.05	-0.64 – 0.75	0.883
Rank category[3]			0.393			0.520			0.279
Officer	-0.37	-1.20 – 0.47		0.39	-0.83 – 1.60		0.68	-0.55 – 1.91	
Body Mass Index	-0.06	-0.20 – 0.09	0.443	-0.08	-0.27 – 0.12	0.444	-0.12	-0.33 – 0.09	0.271
Pack-year	-0.14	-0.23 – -0.05	**0.002**	-0.04	-0.16 – 0.09	0.591	-0.05	-0.19 – 0.08	0.433
Atopic history	0.09	-0.68 – 0.85	0.825	0.24	-1.35 – 1.83	0.763	0.19	-1.44 – 1.83	0.815

[1] CI = Confidence Interval.
[2] Estimates for the number of dives (total and per gas/apparatus) represent the evolution of FEV1 per 1000 dives.
[3] Baseline category = Warrant Officer
No. Patients = 309; No. Obs. = 2386; Sigma = 5.49; ICC = 0.45; Log-likelihood = -7 750;
AIC = 15 517; BIC = 15 563; REMLcrit = 17 929; conditional R^2 = 0.454

Take home points

Study question: What are the long-term effects of SCUBA diving on pulmonary function in military divers?

Results: Diving history is associated with higher pulmonary flows and volumes in this population of military divers.

Interpretation: Our findings emphasise the importance of further investigating the long-term effects of underwater diving on pulmonary function among military personnel.

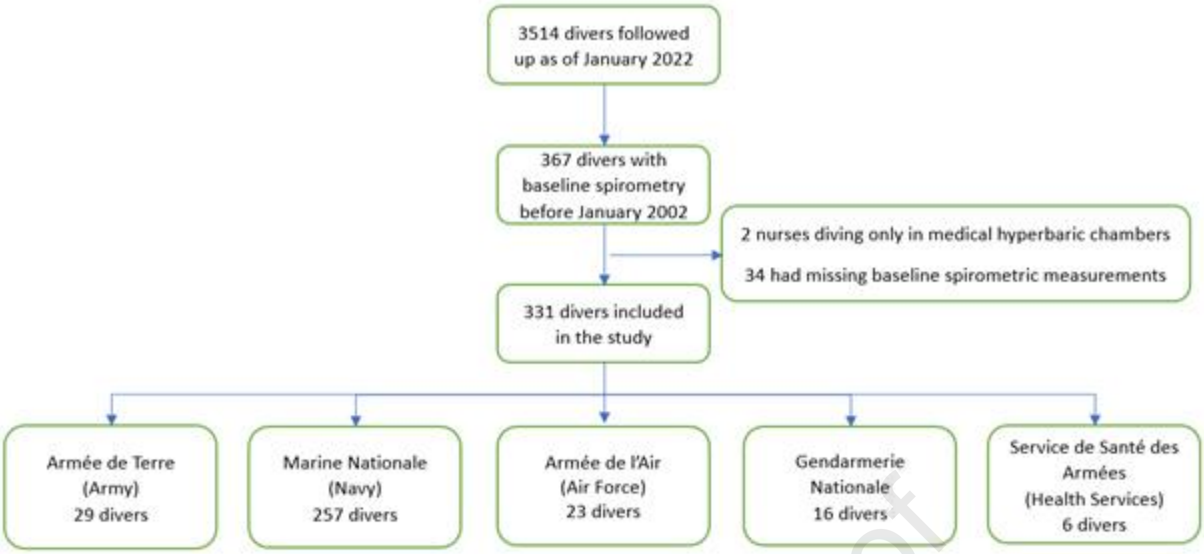


Fig 1. Flow chart of inclusion for eligible patients

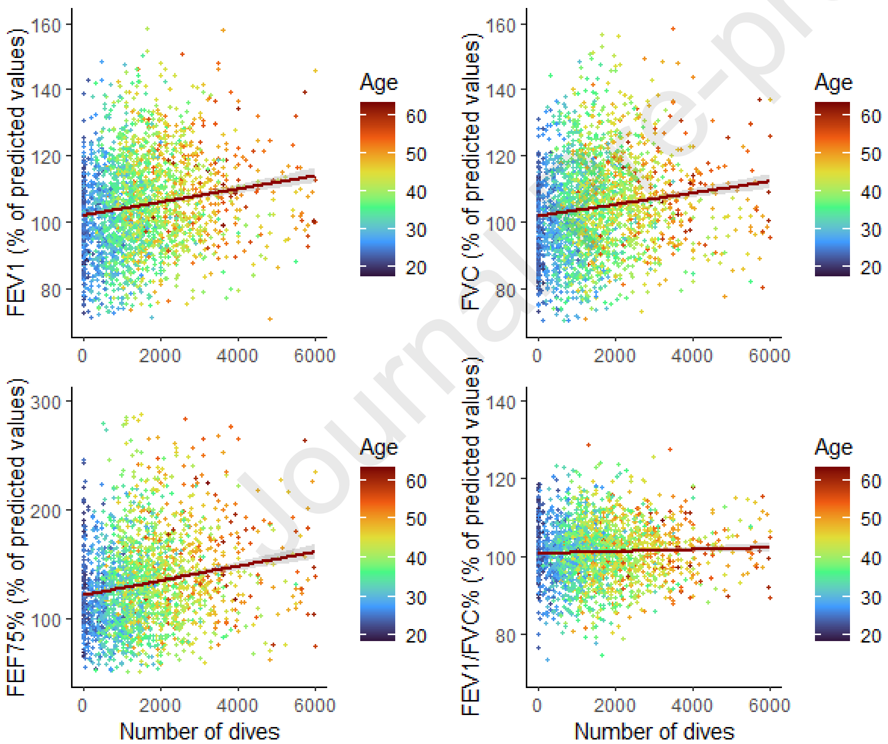
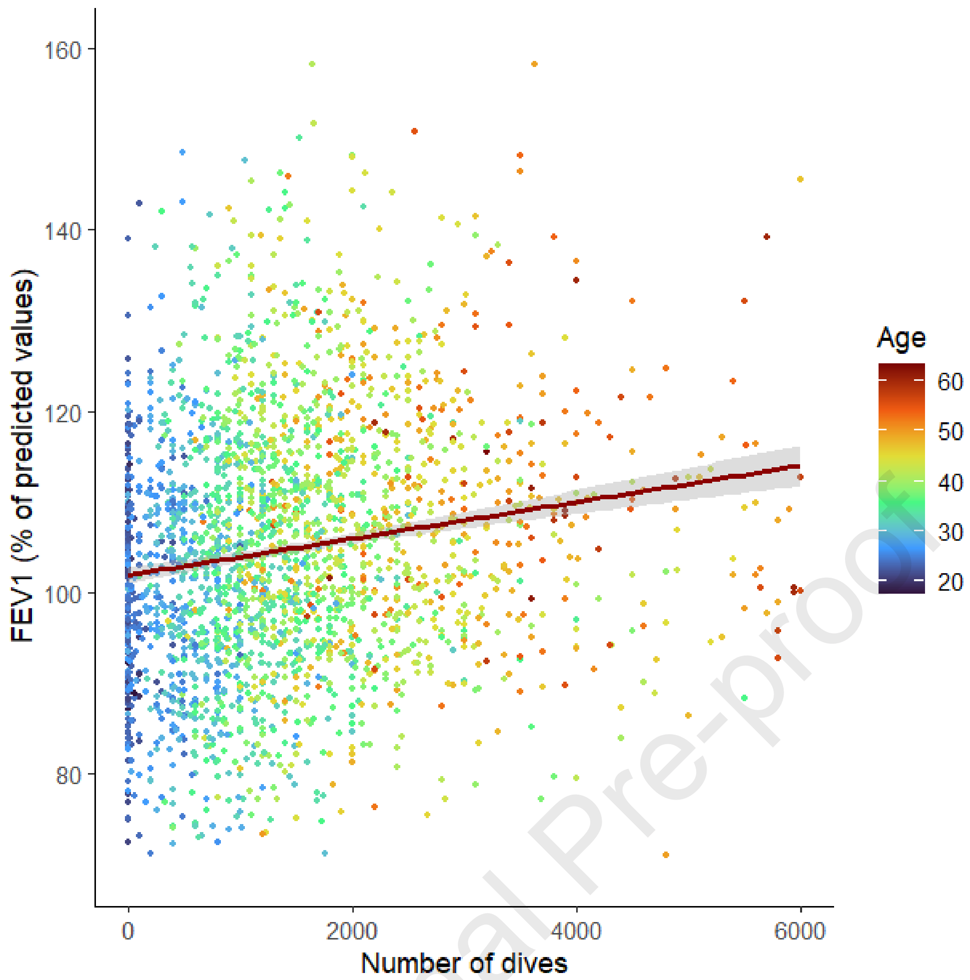
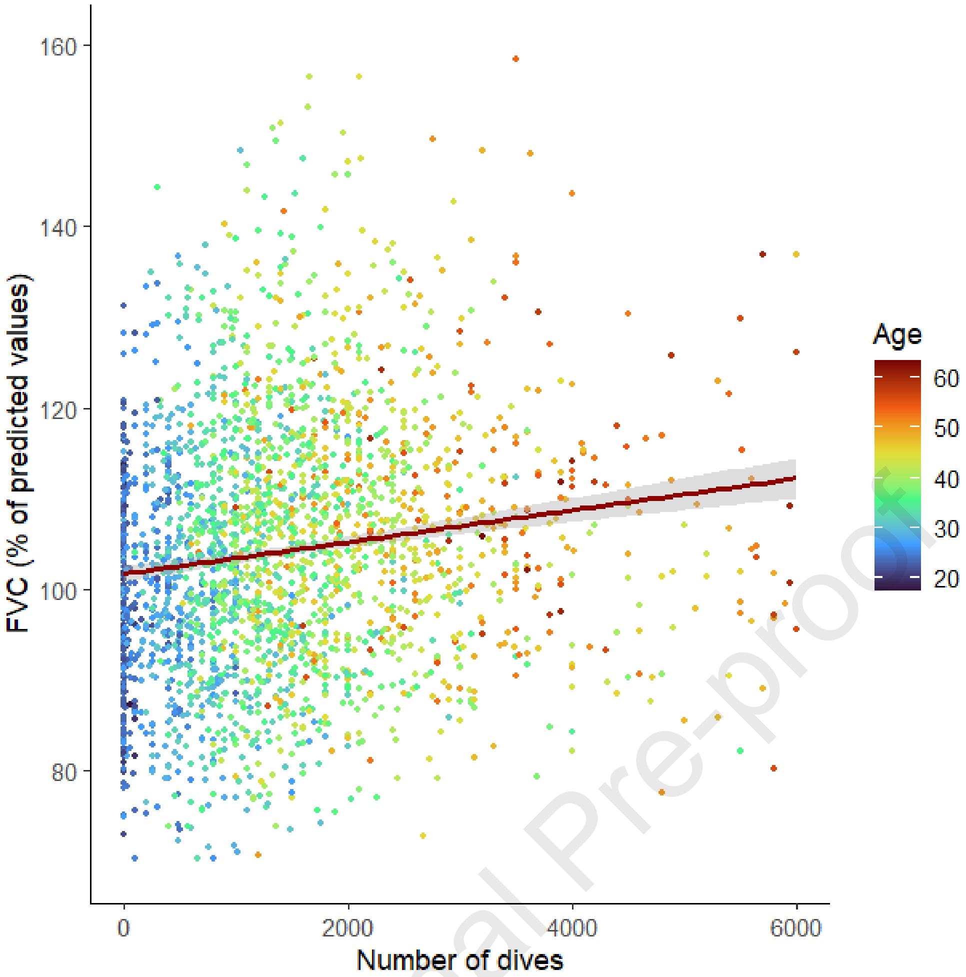
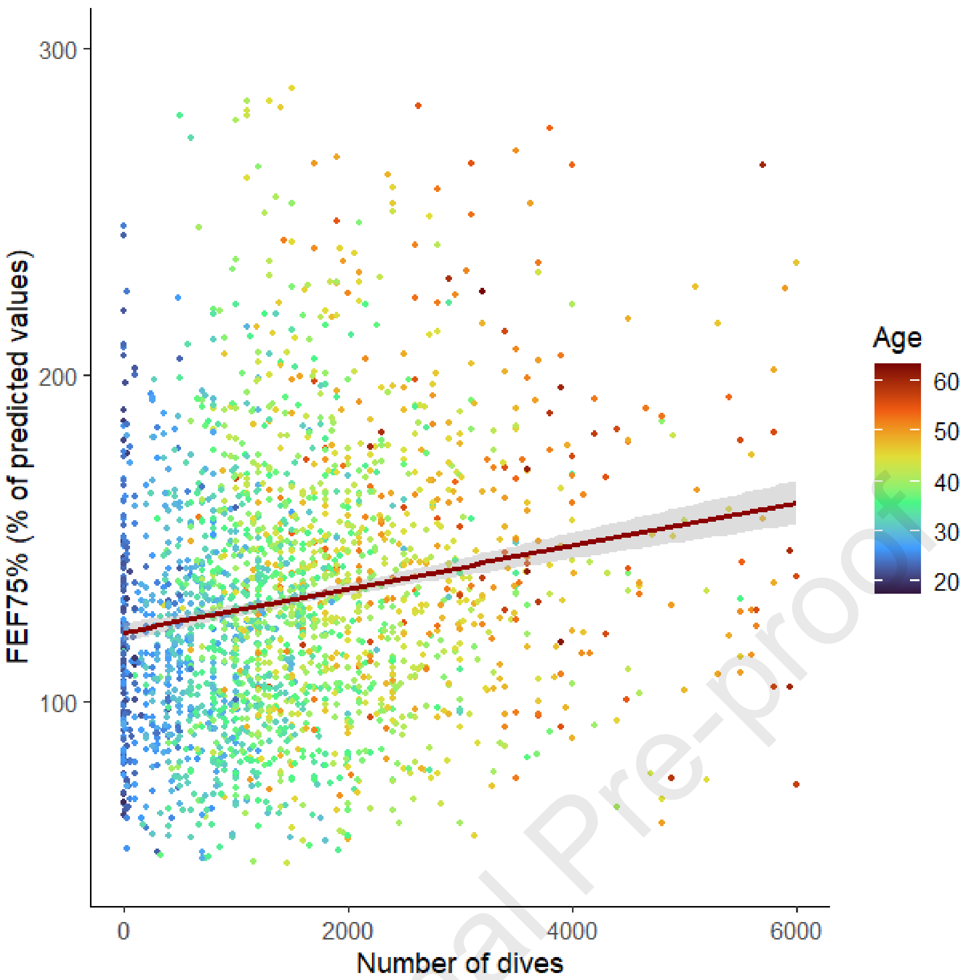


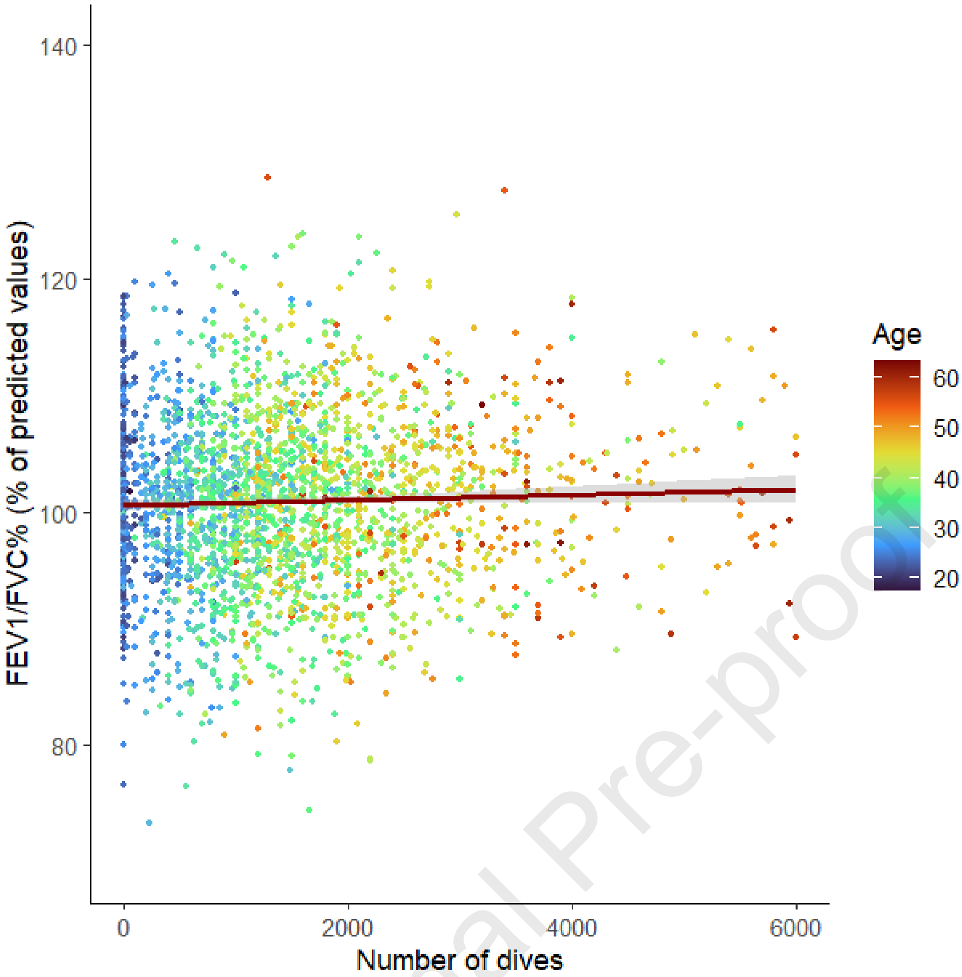
Fig 2. Evolution of spirometric values according to the number of dives and age at the time of data collection. Abbreviations: FEF75% Forced expiratory flow when 75% of forced expiratory vital capacity has been exhaled, FEV1 Forced Expiratory Volume in one second, FVC Forced expiratory vital capacity


FEV1 (% of predicted values)
160
140
120
100
80
0
2000
4000
6000
Number of dives
Age
60
50
40
30
20


FVC (% of predicted values)
160
140
120
100
80
0
2000
4000
6000
Number of dives
Age
60
50
40
30
20



FEF75% (% of predicted values)
300
200
100
0
2000
4000
6000
Number of dives
Age
60
50
40
30
20


FEV1/FVC% (% of predicted values)
140
120
100
80
0
2000
4000
6000
Number of dives
Age
60
50
40
30
20

Take home points

Study question: What are the long-term effects of SCUBA diving on pulmonary function in military divers?

Results: Diving history is associated with higher pulmonary flows and volumes in this population of military divers.

Interpretation: Our findings emphasise the importance of further investigating the long-term effects of underwater diving on pulmonary function among military personnel.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: