

Low FEV₁, smoking history, and obesity are factors associated with oxygen saturation decrease in an adult population cohort

Monica Linea Vold^{1,3}

Ulf Aasebø^{1,2}

Hasse Melbye³

¹Department of Respiratory Medicine, University Hospital of North Norway,

²Department of Clinical Medicine,

³Department of Community Medicine, University of Tromsø, Tromsø, Norway

Background: Worsening of pulmonary diseases is associated with a decrease in oxygen saturation (SpO₂). Such a decrease in SpO₂ and associated factors has not been previously evaluated in a general adult population.

Aim: We sought to describe SpO₂ in a sample of adults, at baseline and after 6.3 years, to determine whether factors predicting low SpO₂ in a cross-sectional study were also associated with a decrease in SpO₂ in this cohort.

Methods: As part of the Tromsø Study, 2,822 participants were examined with pulse oximetry in Tromsø 5 (2001/2002) and Tromsø 6 (2007/2008). Low SpO₂ by pulse oximetry was defined as an SpO₂ ≤ 95%, and SpO₂ decrease was defined as a ≥ 2% decrease from baseline to below 96%.

Results: A total of 139 (4.9%) subjects had a decrease in SpO₂. Forced expiratory volume in 1 second (FEV₁) < 50% of the predicted value and current smoking with a history of ≥ 10 pack-years were the baseline characteristics most strongly associated with an SpO₂ decrease in multivariable logistic regression (odds ratio 3.55 [95% confidence interval (CI) 1.60–7.89] and 2.48 [95% CI 1.48–4.15], respectively). Male sex, age, former smoking with a history of ≥ 10 pack-years, body mass index ≥ 30 kg/m², and C-reactive protein ≥ 5 mg/L were also significantly associated with an SpO₂ decrease. A significant decrease in FEV₁ and a new diagnosis of asthma or chronic obstructive pulmonary disease during the observation period most strongly predicted a fall in SpO₂. A lower SpO₂ decrease was observed in those who quit smoking and those who lost weight, but these tendencies were not statistically significant.

Conclusion: A decrease in SpO₂ was most strongly associated with severe airflow limitation and a history of smoking. Smoking cessation and reducing obesity seem to be important measures to target for avoiding SpO₂ decreases in the general population.

Keywords: pulse oximetry, lung function, cohort study, general population

Introduction

Pulse oximetry is an inexpensive, noninvasive method for measuring oxygen saturation (SpO₂). Pulse oximetry has a wide range of use both in primary pulmonary care and critical care medicine. Low SpO₂/hypoxemia have been associated with conditions or diseases causing ventilation–perfusion mismatch in the lungs, hypoventilation, right-to-left shunts, reduced diffusion capacity, and reduced oxygen partial pressure in inspired air. Decrease in SpO₂/desaturation has been associated with the worsening of preexisting pulmonary diseases.^{1–3}

There is no clear cutoff point for abnormal SpO₂, but SpO₂ ≤ 95% is used in most adult studies. In their blood gas reference values for sea level, Crapo et al found mean

Correspondence: Monica Linea Vold
Department of Respiratory Medicine,
University Hospital of North Norway,
9038 Tromsø, Norway
Tel +47 776 26828
Fax +47 776 28261
Email monica.linea.vold@unn.no

arterial oxygen saturation (SaO_2) to be 95.5%–96.9% (standard deviation [SD] 0.4%–1.4%), depending on age.⁴ Resting $\text{SpO}_2 \leq 95\%$ has been found to predict oxygen desaturation during sleep, exercise, and flights, in chronic obstructive pulmonary disease (COPD) patients.^{5–7} $\text{SpO}_2 \leq 95\%$ has also been identified as a risk factor for postoperative pulmonary complications.⁸ The limit of 96% therefore seems a reasonable cutoff value. A cutoff value of $\leq 92\%$ has been used when screening for respiratory failure in COPD.⁹

In a previous cross-sectional study, we have shown that body mass index (BMI) and the forced expiratory volume in 1 second (FEV_1) as a percentage of the predicted value (FEV_1 % predicted) are the most important predictors of low SpO_2 in the general adult population.¹⁰ Other predictors for low SpO_2 are former and current smoking, C-reactive protein (CRP) ≥ 5 mg/L, age, male sex, elevated hemoglobin, and respiratory symptoms.

The role of inflammation in lung function decline is not clearly understood. CRP and other biomarkers have, in COPD, been associated with progression of the disease and decline in lung function.^{11–13} Systemic inflammation in COPD might play a role in the development of extrapulmonary comorbid conditions.^{14,15} Elevated CRP levels have previously been found to be associated with cardiovascular disease (CVD), metabolic syndrome, and obesity. In sleep apnea, elevated CRP has been associated with hypoxemia.^{16,17} Sleep apnea is associated with obesity and metabolic syndrome, both characterized by systemic inflammation and comorbidities.¹⁸ In some studies, elevated CRP has been associated with hypoxemia in COPD patients.^{19,20}

Lung function decline in adult population cohorts has been evaluated by spirometry, but decrease in SpO_2 has not been studied. We wanted to investigate changes in SpO_2 in an adult population cohort to determine whether parameters predicting low SpO_2 in a cross-sectional study were also associated with a decrease in SpO_2 in a cohort study.

Material and methods

Subjects

A cohort of the adult population in Tromsø, Norway has been followed in the Tromsø Study since 1974. Tromsø is a university city in northern Norway, with approximately 70,000 inhabitants. To date, the Tromsø Study has consisted of six cross-sectional studies. Participant selection in Tromsø 4 (1994/1995) has influenced later studies as described in the cohort profile (Figure 1).²¹ In the fourth study, all inhabitants of Tromsø 55–74 years of age, and 5%–10% of the samples in the other cohorts aged 25–84 years were asked to take part in

an extra, more extended medical examination; a total of 7,916 (77%) participated. All participants who had this second visit in Tromsø 4 were invited to the Tromsø 5 Study²¹ and were again eligible for a second, extended, medical examination. As part of the fifth Tromsø Study (2001/2002), 5,152 subjects were examined with pulse oximetry. Of these, 3,453 (67.0%) participants also took part in Tromsø 6 (2007/2008),²¹ and 3,127 (60.7%) attended the extended examination. Figure 2 shows the flow chart of participants from Tromsø 5 to 6.

A total of 9.8% of the participants were not examined with pulse oximetry and spirometry due to absence of staff or drop out related to wait time for lung function testing. SpO_2 values of 2,822 participants were measured in both Tromsø 5 and Tromsø 6. The mean time between measurements was 6.3 years (SD 0.4 years).

Examinations

In both Tromsø 5 and Tromsø 6, a questionnaire including medical history and smoking habits was enclosed in the invitation to participate. Participants who reported suffering from angina pectoris, myocardial infarction, or cerebral stroke were classified as “self-reported CVD”. “Pack-years” of cigarette use was calculated by multiplying the average number of cigarettes smoked daily by the number of years smoked and dividing the product by 20. Subjects who attended the assessment received an additional questionnaire about dyspnea, cough, and sputum. Examinations at the first visit included height and weight, and BMI (kg/m^2) was calculated.

Pulse oximetry and spirometry were included at the second visit for both Tromsø 5 and Tromsø 6. SpO_2 values were measured with a digital handheld pulse oximeter (Onyx II® 9550; Nonin Medical, Inc., Plymouth, MN, USA). Participants rested at least 15 minutes before examination. The best of three measurements was recorded. The manufacturer’s testing has shown that only values between 70% and 100% are accurate to within $\pm 2\%$, and values below 70% are regarded as invalid. None of the participants received supplemental oxygen.

Spirometry was carried out using a SensorMedics Vmax™ Legacy 20® (VIASYS Healthcare Respiratory Technologies, Yorba Linda, CA, USA) in Tromsø 5, and the Vmax Encore 20® (VIASYS Healthcare Respiratory Technologies) in Tromsø 6. American Thoracic Society (ATS)/European Respiratory Society (ERS) criteria for spirometry testing were followed.²² Norwegian reference values for prebronchodilator spirometry were used because reversibility testing was not performed.²³ Three trained technicians conducted the spirometry.

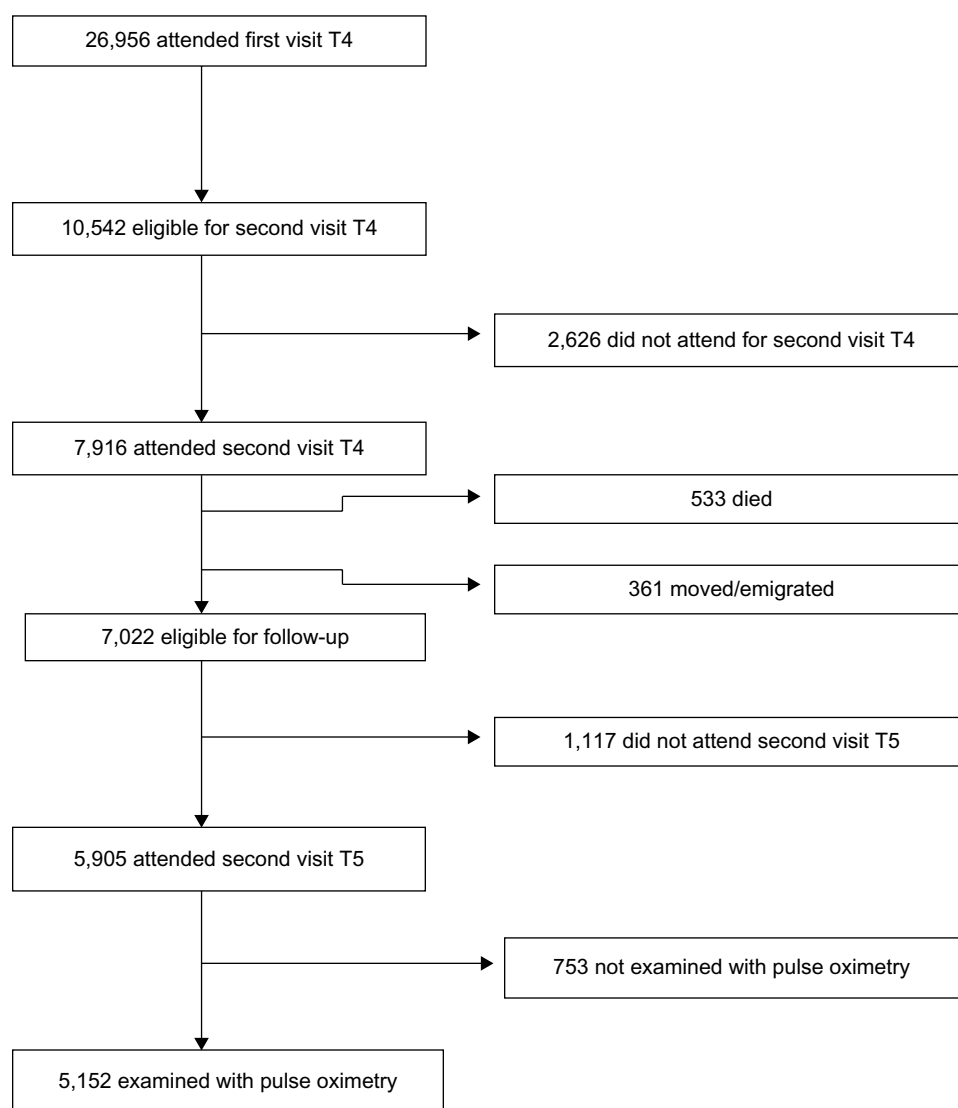


Figure 1 Participation from Tromsø 4 (T4) to Tromsø 5 (T5).

Adjustment of spirometry results

The mean annual FEV_1 decline of 14 mL/year (standard error [SE] 0.8) was lower than expected. The lowest mean decline recorded, in samples of women who never smoked, was 17.6 mL/year, but higher values, depending on sex, age, and history of smoking, are usually found.^{24,25} We therefore considered potential sources of bias. The use of two different spirometers in Tromsø 5 and 6 was a likely source. The Norwegian supplier confirmed that the Vmax Legacy used in Tromsø 5 probably provided values that were too low and that this was not the case for Vmax Encore used in Tromsø 6, but no documentation could be provided. Küenzli et al have demonstrated that using different spirometers in longitudinal studies is a source of bias.²⁶ We therefore tested 48 subjects, 24 patients and 24 voluntary employees using both spirometers. The

mean FEV_1 value found with the Vmax Legacy was 2.5% (66 mL [SE 14 mL]) lower than that measured by the Vmax Encore. We therefore chose to correct the FEV_1 values in Tromsø 5 by adding 2.5%. Likewise, forced vital capacity (FVC), was 5.2% (188 mL [SE 25 mL]) lower when the Vmax Legacy was used compared with the Vmax Encore.

Laboratory samples

Blood was drawn for high-sensitivity CRP, fibrinogen, and uric acid analyses (also biomarkers of inflammation). For 3 consecutive days, albumin and creatinine were measured in urine, and the albumin:creatinine ratio (ACR) was estimated for each day. Mean values were used in the analysis, and an ACR between 3.0 and 30.0 mg/mmol was used as an indication of microalbuminuria.

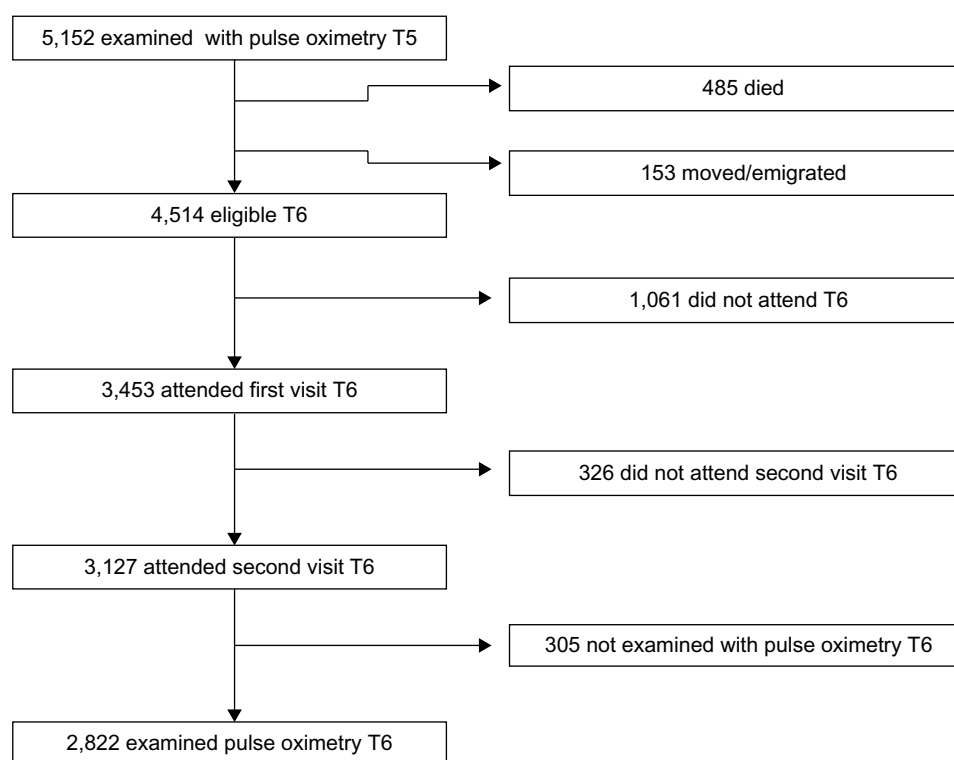


Figure 2 Participation from Tromsø 5 (T5) to Tromsø 6 (T6).

Statistical analysis

Low SpO_2 was defined by $\text{SpO}_2 \leq 95\%$, and SpO_2 decrease was defined by $\geq 2\%$ decrease from baseline to $< 96\%$. Differences in continuous variables between subgroups at baseline (Tromsø 5) were explored using the Mann–Whitney U test, and differences found between baseline and after 6.3 years were explored using the Wilcoxon signed-rank test. Frequency of SpO_2 decrease was analyzed by sex, age, smoking habit, spirometry, BMI, CRP, fibrinogen, uric acid, ACR, self-reported health and diseases, and pulmonary symptoms. Continuous variables (age, BMI, FEV_1 , fibrinogen, uric acid, ACR, and CRP) were categorized, and the statistical significance of differences was analyzed by chi-square test. Predictors of SpO_2 decrease with a statistical significance of $< 5\%$ were entered into a multivariable binary logistic regression and excluded by backward stepwise elimination. Only predictors with $P < 0.05$ were kept in the final model. Changes from baseline variables other than SpO_2 were registered and continuous variables categorized, based on one standard deviation. The associations with SpO_2 decrease were analyzed by chi-square test. IBM SPSS Statistics for Windows, Version 21 (IBM Corp, Armonk, NY, USA) was used.

The Regional Committee for Medical and Health Research Ethics in North Norway approved the Tromsø 5 and 6 surveys. All participants gave written, informed consent.

Results

Among the 2,822 participants who had SpO_2 measured in both studies, 241 (8.5%) and 213 (7.5%) had an $\text{SpO}_2 \leq 95\%$ in Tromsø 5 and Tromsø 6, respectively. Fifty-six (2.0%) had $\text{SpO}_2 \leq 95\%$ in both studies. Sixteen (0.6%) in Tromsø 5 and 25 (0.9%) participants in Tromsø 6 had $\text{SpO}_2 \leq 92\%$. SpO_2 decrease was seen in 139 (4.9%) participants. Mean age at baseline of the 2,822 participants was 63.2 (SD 8.9) years, range 32–81 years. No significant difference was seen between mean SpO_2 at baseline (97.4%) and that found after 6.3 years (97.3%). Self-reported diseases were more frequently reported in Tromsø 6 than in Tromsø 5, but the frequency of current smoking dropped from 23.7 to 15.2 (Table 1). Valid spirometry was found in 2,728 participants, for both baseline and after 6.3 years. Mean FEV_1 % predicted increased significantly, from 88.7% to 90.8% ($P < 0.001$). There was no significant change in mean BMI, but in those with $\text{BMI} \geq 30 \text{ kg/m}^2$ at baseline, the BMI decreased significantly, from 32.8 to 32.4 ($P < 0.001$).

Table 2 displays frequency of SpO_2 decrease by baseline characteristics. Age, male sex, self-reported CVD, obesity ($\text{BMI} \geq 30 \text{ kg/m}^2$), FEV_1 % predicted, chronic cough with sputum, and smoking were all significantly associated with a SpO_2 decrease in univariable analysis, as were the biomarkers CRP, fibrinogen, and uric acid.

Table 1 Characteristics of 2,822 participants in Tromsø 5 (baseline) and Tromsø 6 (6.3 years later)

	Tromsø 5		Tromsø 6	
	n	(%)	n	(%)
Sex				
Female	1,625	(57.6)		
Male	1,197	(42.4)		
Age (years)				
<70	2,162	(76.6)	1,346	(47.7)
≥70	660	(23.4)	1,476	(53.3)
Self-reported diseases				
CVD	348	(12.3)	541	(19.2)
Asthma	218	(7.7)	288	(10.2)
COPD	115	(4.1)	178	(6.3)
Diabetes	87	(3.1)	198	(7.0)
Hypertension	571	(20.2)	1,018	(36.1)
Smoking history				
Never smoked	1,010	(35.8)	1,008	(35.7)
Former smoker	1,143	(40.5)	1,386	(49.1)
≥10 pack-years	630	(22.3)	816	(28.9)
Current smoker	669	(23.7)	428	(15.2)
≥10 pack-years	558	(19.8)	387	(13.7)
Dyspnea ^a				
0	1,557	(55.2)	1,335	(47.3)
I	1,120	(39.7)	1,266	(44.9)
≥2	145	(5.1)	221	(7.8)
Chronic cough with sputum				
No	2,646	(93.8)	2,637	(93.4)
Yes	176	(6.2)	185	(6.6)
BMI (kg/m ²)				
<20	57	(2.0)	75	(2.7)
20–30	2,171	(76.9)	2,163	(76.7)
≥30	585	(20.8)	583	(20.7)
FEV ₁ % predicted				
≥80	2,018	(71.5)	2,089	(74.0)
50–80	708	(25.1)	614	(21.8)
<50	48	(1.7)	65	(2.3)
FEV ₁ /FVC ratio				
<70	631	(23.1)	805	(29.5)
≥70	2,097	(76.9)	1,923	(70.5)
Spirometry pattern				
Normal	1,923	(70.5)	1,775	(65.1)
Obstructive	631	(23.1)	805	(29.5)
Restrictive	174	(6.4)	148	(5.4)
CRP (mg/L)				
<5	2,426	(86.0)	2,438	(86.4)
≥5	357	(12.7)	340	(12.0)
Hemoglobin (g/dL) ^b				
≤Upper limits	2,546	(90.2)	2,741	(97.1)
>Upper limits	8	(0.3)	37	(1.3)
Fibrinogen (g/L)				
<4	2,304	(81.6)	1,943	(68.9)
≥4	312	(11.1)	834	(29.6)
Uric acid (μmol/L) ^c				
≤Upper limits	2,547	(90.3)	2,601	(92.2)
>Upper limits	110	(3.9)	177	(6.3)
Albumin:creatinine ratio (mg/mmol)				
<3	2,606	(92.3)	2,475	(87.7)
≥3	127	(4.5)	231	(8.2)

(Continued)

Table 1 (Continued)

	Tromsø 5		Tromsø 6	
	n	(%)	n	(%)
SpO ₂				
≥96	2,581	(91.5)	2,609	(92.5)
93–95	225	(8.0)	188	(6.7)
≤92	16	(0.6)	25	(0.9)

Notes: "Pack-years" were obtained by multiplying the average number of cigarettes smoked daily by the number of years smoked and dividing the product by 20. ^adyspnea: 0= no dyspnea, 1= dyspnea walking rapidly on level ground or up a moderate slope, and ≥2= dyspnea walking calmly on level ground, washing or dressing, or at rest; ^bupper limits: men 17 g/dL, women 16 g/dL; ^cupper limits: men 480 μmol/L, women 18–49 years 350 μmol/L, women ≥50 years 400 μmol/L.

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; CVD, cardiovascular disease; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; SpO₂, arterial oxygen saturation as measured by pulse oximetry.

Table 3 shows the results of the multivariable logistic regression. In the final multivariable analysis, 2,682 subjects were included. Current smoking with pack-years ≥10 and FEV₁ % predicted <50 had the highest odds ratio (OR), 2.48 (1.48–4.15) and 3.55 (1.60–7.89), respectively. In addition age, male sex, former smoking with pack-years ≥10, increased CRP, and high BMI were significant predictors in the multivariable analysis. We did not find any significant interactions. Assumptions for logistic regression were met, and we did not find any multicollinearity.

When FEV₁/FVC ratio, as a dichotomous (with a threshold of 0.7 or lower) or as a continuous variable, was added to the multivariable model that included FEV₁ % predicted, no significant association with SpO₂ decrease was found; 91.7% of FEV₁ % predicted <50 had FEV₁/FVC ratio <0.7.

Frequency of SpO₂ decrease by changes from baseline of other variables (across Tromsø 5 and Tromsø 6) is shown in Table 4. Participants who had been diagnosed with asthma, COPD, or diabetes between the two time points had a significantly higher incidence of SpO₂ decrease. These participants had significantly decreased FEV₁ % predicted at baseline, of 81.1, 71.5, and 82.8, respectively, ($P<0.001$). In addition, FEV₁ % predicted decrease/year and CRP increase were associated with SpO₂ decrease. As BMI increased, the frequency of decline in SpO₂ increased. The opposite was the case when BMI dropped. This trend was not statistically significant. Smoking cessation between the time points was associated with a lower frequency of SpO₂ decrease than was continued smoking, but this finding was not statistically significant.

Discussion

SpO₂ decrease was associated with smoking history ≥10 pack-years, lung function (by FEV₁ % predicted <50),

Table 2 Frequency of SpO₂ decrease by subjects' characteristics among 2,822 study participants

	SpO ₂ decrease (n)	(%)	P-value ^a
Total numbers	139	(4.9)	
Sex			
Female	59	(3.6)	<0.001
Male	80	(6.7)	
Age (years)			
<70	96	(4.4)	0.031
≥70	43	(6.5)	
Self-reported diseases			
CVD	27	(7.8)	0.009
Asthma	12	(5.5)	
COPD	9	(7.8)	0.1
Diabetes	7	(8.0)	0.2
Hypertension	28	(4.9)	1.0
Smoking history			
Never smoking	30	(3.0)	0.002
Former smoking	65	(5.7)	
<10 pack-years	21	(4.1)	0.2
≥10 pack-years	44	(7.0)	<0.001
Smoking	44	(6.6)	<0.001
<10 pack-years	2	(1.8)	0.8
≥10 pack-years	42	(7.5)	<0.001
Dyspnea ^b			
0	68	(4.4)	0.3
1	62	(5.5)	
≥2	9	(6.2)	
Chronic cough with sputum			
No	122	(4.6)	0.003
Yes	17	(9.7)	
BMI (kg/m ²)			
<20	3	(5.3)	0.033
20–30	95	(4.4)	
≥30	41	(7.0)	
FEV ₁ % predicted			
≥80	84	(4.2)	<0.001
50–80	44	(6.2)	
<50	9	(18.8)	
FEV ₁ /FVC ratio			
<70	39	(6.2)	0.08
≥70	94	(4.5)	
Spirometry pattern			
Normal	78	(4.1)	0.001
Obstructive	39	(6.2)	
Restrictive	16	(9.2)	
CRP (mg/L)			
<5	107	(4.4)	<0.001
≥5	32	(9.0)	
Hemoglobin (g/dL) ^c			
≤Upper limits	126	(4.9)	0.7 ^d
>Upper limits	0	(0.0)	
Fibrinogen (g/L)			
<4	107	(4.6)	0.011
≥4	25	(8.0)	

(Continued)

Table 2 (Continued)

	SpO ₂ decrease (n)	(%)	P-value ^a
Uric acid (μmol/L) ^e			
≤Upper limits	122	(4.8)	0.014
>Upper limits	11	(10.3)	
Albumin:creatinine ratio (mg/mmol)			
<3	127	(4.9)	0.06
≥3	11	(8.7)	

Notes: "Pack-years" were obtained by multiplying the average number of cigarettes smoked daily by the number of years smoked and dividing the product by 20. ^aP-values by chi-square; for smoking compared with never smoking, for others by trend; ^bdyspnea: 0= no dyspnea, 1= dyspnea walking rapidly on level ground or up a moderate slope, and ≥2= dyspnea walking calmly on level ground, washing or dressing, or at rest; ^cupper limits men 17 g/dL, women 16 g/dL; ^dFischer's exact test; ^eupper limits men 480 μmol/L, women 18–49 years 350 μmol/L, women ≥50 years 400 μmol/L.

Abbreviations: BMI, body mass index; CRP, C-reactive protein; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; SpO₂, arterial oxygen saturation as measured by pulse oximetry.

BMI ≥30 kg/m², CRP ≥5 mg/L, male sex, and age, in multivariable logistic regression. Decrease in FEV₁ % predicted was significantly associated with decrease in SpO₂, and a tendency, although not statistically significant, for less frequent SpO₂ decrease with BMI decrease and smoking cessation were also observed.

Table 3 Factors associated with arterial oxygen saturation (SpO₂) decrease in multivariable logistic regression

	OR	95% CI	P-value
Sex			
Male	1.68	1.15–2.45	0.008
Age (years)	1.03	1.01–1.06	0.008
Smoking history			
Never smoking	1		
Former smoking			
<10 pack-years	1.14	0.62–2.09	0.7
≥10 pack-years	1.74	1.04–2.92	0.035
Smoking			
<10 pack-years	0.71	0.17–3.04	0.6
≥10 pack-years	2.48	1.48–4.15	0.001
BMI (kg/m ²)			
<30	1		
≥30	1.72	1.15–2.57	0.008
FEV ₁ % predicted			
≥80	1		
50–80	1.18	0.79–1.75	0.4
<50	3.55	1.60–7.89	0.002
CRP (mg/L)			
≥5	1.74	1.12–2.71	0.013

Notes: N=2,682 subjects. Pack-years were obtained by multiplying the average number of cigarettes smoked daily by the number of years smoked and dividing the product by 20.

Abbreviations: BMI, body mass index; CI, confidence interval; CRP, C-reactive protein; FEV₁, forced expiratory volume in 1 second; OR, odds ratio.

Table 4 Frequency of SpO₂ decrease and associations to changes from baseline characteristics

	Total (n)	SpO ₂ decrease (n)	(%)	P-value
	2,822	139	(4.9)	
Self-reported diseases, new				
CVD	225	7	(3.1)	0.2
Asthma	104	14	(13.5)	<0.001
COPD	117	16	(13.7)	<0.001
Diabetes	113	10	(8.8)	0.049
Hypertension	512	28	(5.5)	0.5
Smoking history T5–T6				0.3
Quit smoking	266	14	(5.3)	
Continued smoking	399	30	(7.5)	
BMI (kg/m ²)				
All				0.09
≥2↑	302	22	(7.3)	
2↑–2↓	2,201	106	(4.8)	
≥2↓	309	11	(3.6)	
≥30				0.1
≥2↑	60	7	(11.5)	
2↑–2↓	407	29	(7.1)	
≥2↓	115	4	(3.5)	
FEV ₁ % predicted/year ^a				
≥2↓	168	18	(10.7)	<0.001
CRP (mg/L)				
≥5↑	142	13	(9.2)	0.020
Fibrinogen (g/L)				
≥1↑	593	33	(5.6)	0.6
Uric acid (μmol/L)				
≥60↑	293	15	(5.1)	0.9
Albumin:creatinine ratio (mg/mmol)				
≥3↑	142	8	(5.6)	0.7

Notes: ^aDecrease divided by years between examinations. Upward arrows indicate an increase, downward arrows indicate a decrease.

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; CVD, cardiovascular disease; FEV₁, forced expiratory volume in 1 second; SpO₂, arterial oxygen saturation as measured by pulse oximetry; T5, Tromsø 5; T6, Tromsø 6.

Comparison with previous studies

This study complements our previous cross-sectional study showing that smoking, FEV₁ % predicted, and obesity are the most important predictors of low SpO₂.¹⁰ The findings from a longitudinal cohort provide stronger indications of a causal relationship than can be determined using a cross-sectional study.²⁷

The association between male sex and a fall in SpO₂ was consistent with our previous findings. More men had previously smoked and had also smoked for more pack-years. CVD was also more common in men.

The impact of age was also consistent with the cross-sectional study. Aging means physiological changes and increasing comorbidity, and the summation of risk factors might accelerate an SpO₂ decrease.

We found a significant association between SpO₂ decrease and self-reported CVD in univariable analysis. CVD contributes to heart failure, which may affect pulmonary function and thus lower SpO₂. This association was not shown in multivariable analysis. One reason for this might be that CVD is strongly associated with both age and male sex.

Low SpO₂ and partial pressure of oxygen in arterial blood (PaO₂) in smokers have been shown in previous studies.^{28,29} Even when correcting for lung function by FEV₁ % predicted, this association was clearly demonstrated.

More than 90% of the group with a FEV₁ % predicted <50 had an FEV₁/FVC ratio <0.7. Even though an FEV₁/FVC ratio <0.7 was not significant in univariate analysis, severe airflow limitation seems to be associated with an SpO₂ decrease.

We found that baseline CRP ≥5 mg/L was associated with an SpO₂ decrease in both uni- and multivariable analysis, and the associations with CVD and other chronic diseases probably contributed to increased OR in the multivariable analysis. Other biomarkers, such as fibrinogen, uric acid, and microalbuminuria (expressed by the albumin:creatinine ratio), were significant in univariable, but not multivariable, analyses. Microalbuminuria has been found to be associated with hypoxia (defined as SpO₂ ≤92%) in COPD.^{30,31} In our study, less than 1% of participants had SpO₂ ≤92%, which may be a reason for not finding this association. CRP might also be a better marker of inflammation associated with SpO₂ decrease than microalbuminuria, fibrinogen, and uric acid.

BMI ≥30 kg/m² was, as expected, associated with SpO₂ decrease. Among other disorders, this group is at risk for sleep apnea and obesity hypoventilation, which is known to lead to low daytime SpO₂.^{32–34}

Baseline hemoglobin above the upper limit was not associated with SpO₂ decrease. This was expected since a high hemoglobin value is usually a consequence of, rather than a reason for, a decrease in SpO₂.

A new diagnosis of asthma or COPD between the time points was associated with a decrease in SpO₂. Subjects with such a new diagnosis had decreased FEV₁ % predicted at baseline. COPD is frequently underdiagnosed, which may be linked to less help-seeking among smokers.³⁵ It is not unexpected that subjects recently diagnosed with COPD or asthma had troubling symptoms and increased risk of decreased SpO₂.

Strength and limitation

The subjects in this study were a subgroup of participants in the cross-sectional study on SpO₂ from the sixth Tromsø Study.¹⁰ This study would have provided stronger supplemental evidence if the subjects had been recruited from a separate population sample. Of the original group examined with lung function tests in Tromsø 5, only 54.8% were reexamined in Tromsø 6. We know that almost 10% died between these time points. Those with severe health problems and increased risk of low SpO₂ probably participated to a lesser degree than others. We found that almost 10% quit smoking, mean FEV₁ % predicted increased, and those in the obese category lost weight. A healthy survivor effect and a decreased representation of those with poor health may have led to a healthier sample. This may explain why aging did not lead to decreased SpO₂.

Smoking may have been a difficult topic for some participants, and thus there may have been some bias in categorizing smokers, former smokers, and never smokers. Yet previous studies have showed that self-reports of smoking are usually accurate.^{36,37} The pack-years calculated might be uncertain, because of recall bias, especially among former smokers. Only seven out of 256 participants who quit smoking between Tromsø 5 and 6 had valid data on the question, "How long has it been since you stopped?" Some participants may have stopped smoking recently, and the effect of smoking cessation on SpO₂ may not have been measurable yet, thereby weakening the associations.

Pulse oximetry has some limitations; among others, high carboxyhemoglobin might have given falsely elevated SpO₂ in smokers and thus, diminished the association between SpO₂ and smoking.³⁸

SpO₂ decrease may be imprecise since the accuracy of the device is within $\pm 2\%$. By using three measurements, categorizing in groups, and excluding values that fell within the normal range (SpO₂ >95%), we tried to decrease this influence.

The FEV₁ % predicted values in Tromsø 6 increased. Reasons for this might be selection bias and a healthier sample. Using two different spirometers may also have contributed to the difference, even though we attempted to correct for this. Using age in whole years as of December 31 in calculating FEV₁ % predicted may have resulted in a systematic bias, since the mean years between analyses were 6.3, not 6.0;³⁹ however, this is likely to have underestimated the increase in predicted values. Due to the high number of subjects aged 75 years or older, a limitation in the validity of

the reference values, when applied in the oldest age groups, might also have played a role.

Clinical implications

This study describes associations between unhealthy lifestyle and decreased SpO₂. Smoking stands out as an important cause, and not only through its deteriorating effect on lung function. Obesity is another modifiable risk factor for decreased SpO₂. It is promising that the findings in this study indicate that subjects who stop smoking or lose weight may have a decreased risk of decreased SpO₂. It may be possible to stabilize SpO₂ with a healthier lifestyle.

Conclusion

A decrease in SpO₂ was most strongly associated with low FEV₁ % predicted and a history of smoking. It was also associated with higher BMI. This is in accordance with the findings of our previous cross-sectional study. Smoking cessation and reducing obesity are important measures that may help avoid SpO₂ decrease in the general population.

Author contributions

All authors participated in concept and design of the study. HM performed data collection, and MLV and HM performed data analysis and interpretation. MLV and HM drafted the manuscript. All authors participated in revision and gave final approval of the manuscript.

Disclosure

The authors report no conflict of interest in this work.

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