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Diver's Lung Function: Influence of Smoking Habit

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Abstract: Diver's Lung Function: Influence of Smoking Habit: Shinya SUZUKI. Japan Maritime Self-Defense Force Undersea Medical Center—To assess the influence of smoking habit on divers' lung function, we measured static lung volumes, dynamic lung volumes and flows and diffusing capacity for carbon monoxide (DLco) on 71 healthy, male, JMSDF active-duty uniformed divers (46 smokers and 25 nonsmokers). All measurements were conducted with an automated system (CHESTAC-25V model; Chest Ltd., Tokyo, Japan). Comparison of lung functions between smokers and nonsmokers was assessed using a Mann-Whitney rank-sum test. Vital capacity in smokers was 120.4 ± 11.3 (mean ± SD)% of the predicted value for age and height, and in nonsmokers was 119.9 ± 15.1%. In the static lung volumes there were no differences between smokers and nonsmokers. Although the forced vital capacity (FVC), the forced expired volume in the 1st second ($FEV_{1.0}$), and the forced expiratory flow rate at 75% of FVC expired ($\dot{V}_{75}$) showed no difference between two groups, the peak expiratory flow rate (PEFR) in smokers was lower than that in nonsmokers ($p<0.005$). The forced expiratory flow rate at 25% of FVC expired ($\dot{V}_{25}$) showed no difference, while the DLco in smokers was worse than in nonsmokers ($p<0.01$). Lung Volumes of the divers in JMSDF were larger than predicted values in the general population. Judging from the ratio of the residual volume to total lung capacity, emphysematous change with aging was negative. PEFR, $FEV_{1.0}$ and $\dot{V}_{75}$ depend on the ventilatory muscle strength and diameter of the large respiratory tract. To investigate the reason why only PEFR was lower in smokers than nonsmokers in this population, more data should be collected. The finding of no difference in $\dot{V}_{25}$ between the two groups could not indicate that smokers had emphysematous change compared to nonsmokers. The decrease in DLco with age in smokers compared to nonsmokers, however, suggested the possibility of emphysema. Considering that emphysema is a contraindication for diving, a diver should not smoke.
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Key words: Diving, Lung function, Smoking habit, Diffusing capacity, Fitness to dive

Divers are affected by certain special conditions such as hyperbarism or underwater exposure[1]. Due to such stress, the regular medical checkup of divers is required to keep their health. Otherwise, they may develop serious disorders. Especially in pulmonary medicine, emphysematous blebs, emphysema and bronchial asthma sometimes become fatal and are considered disqualifying for diving[2,3]. The ventilatory constraint in high density gas breathing is inevitable for divers in deep diving. In the case of a sudden decrease in ambient hydrostatic pressure such as blow-up due to the trouble with the underwater breathing apparatus, lung functions should be in good conditions to avoid the increased risk of arterial gas embolism associated with air trapping. In pulmonary medical checkup physicians must ascertain pulmonary fitness to dive, and have the responsibility of advising a diver to keep his fitness. In Japan the health examination of commercial divers has been formed simple spirometry and pulmonary function test by a physician's recommendation. The medical examination must be performed once every six months and when changing his employer in accordance with medical guidelines established by Safety and Health Regulations for Hyperbaric Work[4]. Divers in Japan Maritime Self-Defense Force are also required to take physical examinations before enrollment in the diving training course and once every six months after finishing the course[5,6]. Since it has been pointed out that the cigarette smoking habit increases the risk of mucous plugs and bronchospasm-induced local air trapping, divers are recommended to refrain from cigarette smoking[1–3,7,8]. In Japan, however, there is little argument against cigarette smoking habit in divers and no description on diver's smoking in any diving textbook[4,9]. In the present study, we examined the effect of cigarette smoking on diver's lung function and discuss the diver's smoking habit.

Subjects and Methods

Subjects were 71 healthy, male, active-duty Japan Maritime Self-Defense Forces (JMSDF) divers (46 smokers and 25 nonsmokers). Physical characteristics of these

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Table 1. Subjects' physical characteristics

	Number of subjects	Age yr	Height cm	Weight kg
Smokers	46	33.5 ± 8.1	169.4 ± 4.8	72.9 ± 10.4
Nonsmokers	25	34.6 ± 5.3	171.4 ± 6.3	68.3 ± 8.8

Values are means ± SD.

smokers and nonsmokers are given in Table 1. There were no significant differences between the two smoking-status groups in age, height or weight.

The history of cigarette smoking in each diver was obtained by interviewing at lung function test. The average number of cigarettes smoked per day was 22.5 ± 8.5 (means ± SD), the period of smoking habit was 15 ± 6.9 years, and the smoking index (Brinkman Index) calculated by multiplying cigarettes per day and years of smoking was 322.7 ± 171.0. Ex-smokers were excluded from this study.

Lung functions were measured with an automated system (CHESTAC-25V model; Chest Ltd., Tokyo, Japan). All tests were performed in the upright position by the same investigator. Lung volumes, including vital capacity (VC), functional residual capacity (FRC), total lung capacity (TLC), residual volume (RV), and RV/TLC were measured by the helium closed circuit method. Forced vital capacity (FVC), forced expiratory volume in the 1st second ($FEV_{1.0}$) and indices of the flow-volume and volume-time curves were obtained from the dry-sealed spirometer method. The flow rate indices were peak expiratory flow rate (PEFR), maximal midexpiratory flow rate (MMF) and expiratory flow rates at 75%, 50% and 25% of VC (respectively $\dot{V}_{75}$, $\dot{V}_{50}$ and $\dot{V}_{25}$). Pulmonary diffusing capacity for carbon monoxide (DLco) was measured by a single-breath technique. Alveolar volume (V_A) was calculated by adding the inspiratory volume to the RV that was measured just before the inspiratory volume measurement. DLco measurement was repeated until three values whose intervariation was within 5% were obtained, and the median value was used for analysis. The unit of lung volumes was converted into body temperature, ambient pressure and saturated with water vapor, BTPS.

Predicted values were calculated for VC, RV, and DLco, utilizing equations adjusted for age, sex, height and weight, as described below:

Baldwin's equation[10)]

Predicted VC [m*l*] = (27.63 − 0.112 × Age) × Ht (Age: years, Ht: cm)

Boren's equation[11)]

Predicted RV [*l*] =1.9 × Ht + 0.012 × Age − 2.24 (Age: years, Ht: m)

Burrows' equation[12)]

Predicted DLco [m*l*/min/mmHg] = 15.5 × BSA − 0.238 × Age + 6.8 (BSA: m^2, Age: years)

Data are expressed as percentages of the predicted value: %VC, %RV and %DLco.

Comparison of values between smokers and nonsmokers was assessed using a Mann-Whitney rank-sum test. The limit of statistical significance was set at $p<0.05$. Regressions were calculated by the least-squares method.

Results

In the static lung volumes there were no differences between smokers and nonsmokers (Table 2). %VC was larger than that of the predicted value in both groups. There was a similar finding in %RV. RV/TLC in smokers and nonsmokers' groups were within a normal limit.

Although FVC and $FEV_{1.0}$ showed no difference between the two groups, PEFR in smokers was significantly lower than that in nonsmokers ($p<0.005$) and tended to show higher values in all ages plotted on the abscissa (Fig. 1). $\dot{V}_{75}$ in smokers was lower by 0.72 [*l*/sec] in average but not significantly different from nonsmokers. $\dot{V}_{25}$ did not differ between both groups.

Smokers had lower values in DLco/V_A than that of nonsmokers. %DLco in nonsmokers and smokers were 105.4 ± 8.5% versus 98.6 ± 12.9%. DLco/V_A in smokers showed a decreasing tendency with aging compared to smokers (Fig. 2).

Discussion

It has been reported that VC in divers was larger than predicted[13,14)]. We observed the similar finding that JMSDF divers of both nonsmokers and smokers had 120% (mean) of predicted VC. Although our data also showed the large mean predicted RV of 115% in both groups, the mean RV/TLC were within a normal limit because VC and/or TLC were large in both groups. These findings indicate that in JMSDF divers not only nonsmokers but also smokers may not have emphysematous change.

In the capacity of mechanical ventilation, Dembert *et al.* reported that smokers had lower FVC and $FEV_{1.0}$ than nonsmokers[7)]. But we did observe no difference between the two groups in JMSDF divers. We think that there may be no differences in the strength of ventilating muscle, diameter of respiratory duct, and/or air trapping tendency in forced expiration.

Although smokers had lower PEFR compared with nonsmokers in the present study, there were no significant

Table 2. Lung functions

	Smokers	Nonsmokers
VC, liters	4.87 ± 0.56	4.89 ± 0.74
%VC, %	120.4 ± 11.3	119.9 ± 15.1
FRC, liters	3.26 ± 0.67	3.25 ± 0.57
TLC, liters	6.51 ± 0.82	6.55 ± 0.91
RV, liters	1.58 ± 0.40	1.63 ± 0.32
%RV, %	115.3 ± 25.9	115.3 ± 22.5
RV/TLC, %	24.3 ± 5.1	24.8 ± 3.7
FVC, liters	4.73 ± 0.58	4.75 ± 0.72
$FEV_{1.0}$, liters	3.92 ± 0.49	4.00 ± 0.64
MMF, *l*/s	4.12 ± 1.05	4.33 ± 1.13
PEFR, *l*/s	11.57 ± 1.61	12.78 ± 1.48**
$\dot{V}_{75}$, *l*/s	9.38 ± 1.85	10.10 ± 1.69
$\dot{V}_{50}$, *l*/s	5.64 ± 1.47	5.75 ± 1.32
$\dot{V}_{25}$, *l*/s	2.10 ± 0.68	2.25 ± 0.84
$\dot{V}_{50}/\dot{V}_{25}$	2.78 ± 0.59	2.69 ± 0.58
$\dot{V}_{25}$/height, *l*/s/m	1.24 ± 0.39	1.31 ± 0.48
DLco/V_A, m*l*/min/mmHg/*l*	4.92 ± 0.75	5.44 ± 0.60**
%DLco, %	98.6 ± 12.9	105.4 ± 8.5*

Values are means ± SD; Diffusing capacity for carbon monoxide values are corrected to hemoglobin concentration of 14.6 g/d*l*. *p<0.01, **p<0.005.

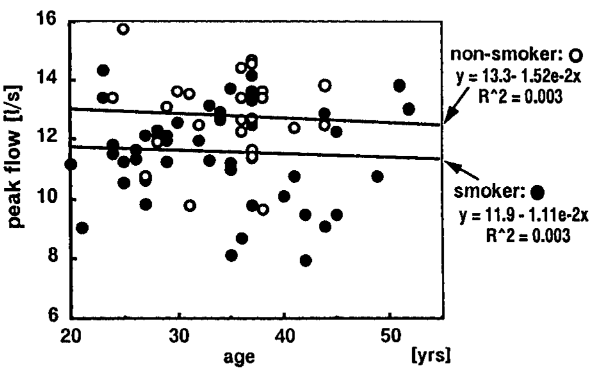

Fig. 1. Correlation of peak flow with age.

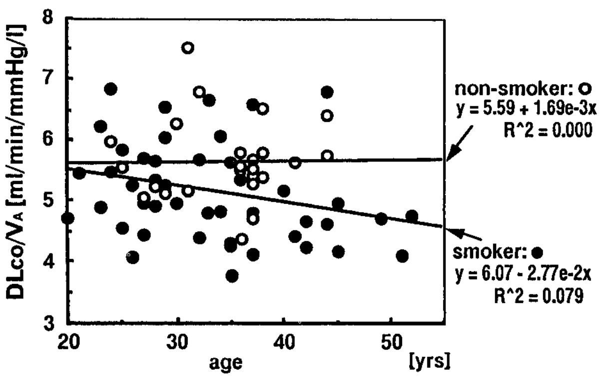

Fig. 2. Correlation of DLco/V_A with age.

differences in both $FEV_{1.0}$ and $\dot{V}_{75}$ that reflect the strength of the ventilating muscle and diameter of the respiratory duct. It was therefore not clear about the reason of smokers' decrease in PEFR. Since there has been no report regarding the relationships between smoking habit and PEFR, further data collection is needed to investigate the reason why only PEFR was lower in smokers in our study.

It was indicated that there was no difference of the obstructive finding at small airways in both smoking-status groups, for $\dot{V}_{25}$ showed no difference between the two groups. Nakamura *et al.*, however, reported that the reduction rate of $FEV_{1.0}$ and $\dot{V}_{25}$ in the old age group became large, i.e., the disturbance of small airways could obviously be present with aging by the effect of smoking[15]. Since all subjects in the present study were active-duty JMSDF divers, there were a few data obtained from over 50 years old. It may be necessary to add more data from the older age group over 50 years old to show the aging effect in our study.

On the other hand, DLco was decreased in smokers and got worse with aging. This finding suggests that the reduced DLco might indicate such a low level of small airway disturbance as unseen in $\dot{V}_{25}$ yet.

While there was a report indicating that a fall in DLco could be explained by the increasing carboxyhemoglobin (COHb) level in smokers[16], Frans *et al.* said that the decreased DLco was apparently not due to COHb but to anatomical lesions, probably of an emphysematous nature, altering the pulmonary membrane[17]. Although the COHb level in smokers may contribute somewhat to the fall in DLco, we consider that the decreased DLco with aging in our study could indicate the emphysematous change of the lungs, i.e., smoking promotes the emphysema, because emphysema generally becomes obvious with aging.

It has been pointed that an association was found between smoking and emphysema, but the mechanism of progression in emphysema is not clear. There are reports that oxides of nitrogen or radicals which possibly damage the lungs are increased in smokers[21,22] and the antioxidants that scavenge the radicals are reduced by smoking[23]. These reports support the idea that smoking can contribute to the development of emphysema, according to the oxidant-antioxidant theory proposed by Taylor *et al.* that explained the cause of emphysema[20].

Centrilobular type of emphysema is more prevalent in smokers than nonsmokers[18]. The lesions of this type tend to be located in the apex of the lungs and are recognized by chest X-rays as blebs when the alveolar space becomes large due to alveolar wall destruction. Should emphysematous blebs be found, the diver would be disqualified. A history of spontaneous pneumothorax, that is related to the amount of cigarette consumption[24], is also considered as one of disqualifying factors for diving because of the known high risk of recurrence even without pressure changes encountered in diving[2,3,25]. Should pneumothorax occur during ascent underwater, the diver might suffer from a tension pneumothorax and arterial gas embolism which would become fatal[26]. Accordingly it is concluded that divers should be strongly recommended to refrain from cigarette smoking to keep their fitness to dive and even more importantly alive.

The divers in JMSDF are selected men and they are basically excellent in lung functions. In this study, however, divers with smoking habit showed the same decrease in lung function with aging as seen in the normal population[27] and the decrement associated with age could hamper the fitness to dive. There are little debates on diver's smoking habit in general in Japan including MSDF. Consequently, many divers carelessly continue their smoking habit. In diving textbooks published in U.S.A. and Europe, there is always a description of forbidding cigarette smoking in divers[1,3,8]. We are hoping that the present study makes divers and physicians in Japan aware of the importance of "stop smoking."

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