ORIGINAL ARTICLES

Changes in Pulmonary Diffusing Capacity at Rest under Various Ambient Temperatures in Normal Young Adults

Akira YASUKOUCHI*, Koichi IWANAGA** and Yukihiro KOYA**

* *Department of Industrial Physiology, National Institute of Industrial Health, 21-1, Nagao 6-chome, Tama-ku, Kawasaki 214, Japan*

** *Department of Ergonomics, Kyushu University of Design Sciences, 9-1, Shiobaru 4-chome, Minami-ku, Fukuoka 815, Japan*

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Abstract : Change in pulmonary diffusing capacity for carbon monoxide (D_L) with ambient temperature was investigated to compare the relation between D_L and pulmonary capillary blood volume (V_c) with that occurring during exercise in the previous study and to examine the possibility of evaluating the potential capacity for increase in V_c . Five subjects were exposed to ambient temperatures of 12, 20, 28 and 36°C for about 100 min. The average D_L increased by about 30% from 27.2 at 36°C to 34.9 ml/min/Torr at 12°C. D_L was primarily determined by acute change in V_c which might be well related to determinants of change in stroke volume rather than cardiac output. It was implied that the mechanism of change in D_L at rest might be different that during exercise. The best parameter matching for change in D_L was mean skin temperature, which was considered to make possible the detection of changes in V_c . Comparison with the previous study revealed that the magnitude and pattern of change in D_L with V_c was uniform whether V_c was altered either by change in ambient temperature or by performing exercise. This means that it is not always necessary to have a patient perform exercise in order to examine the potential increase in V_c . On the other hand, change in D_L in this study seemed to depend mainly on the characteristics of the pulmonary arterial system while change in D_L during exercise seemed to depend on the total number of the pulmonary capillaries in the previous study. Therefore, it was implied that selection of stimulation, which could either be change in thermal condition at rest or an exercise regime, could assist in the differentiation of various characteristics of pulmonary diseases.

Key words : Pulmonary diffusing capacity—Pulmonary capillary blood volume—At rest—Ambient temperature—Pulmonary disease

INTRODUCTION

In a previous study,¹⁾ it was suggested that a unit increase in pulmonary diffusing capacity for carbon monoxide (D_L) per unit increase in energy expenditure could be a basis for evaluating the potential increase in pulmonary capillary blood volume (V_c). In this study, it was examined whether the potential increase in V_c could be evaluated by change in D_L even at rest instead of during exercise because patients cannot always perform exercise. For this purpose, D_L was altered by thermal stimulation at rest and the relation between D_L and V_c obtained in this study was compared with that obtained during exercise in the previous study. The mechanism of D_L change was also discussed in an attempt to qualitatively evaluate pulmonary disease.

SUBJECTS AND METHODS

Five male subjects for this study were volunteers ranging in age from 21 to 25 with no significant history of cardiopulmonary complaints. Their physical characteristics appear in Table 1. Thermal conditions were ambient temperatures of 12, 20, 28 and 36°C, each with a respective relative humidity of about 50%, maintained in a climatic chamber. Each of the subjects, wearing a thin running shirt and shorts, was exposed to each temperature condition in the recumbent position on a reclining bed for about 70 min and then in the sitting position on a chair for about a further 40 min. Before entering the chamber, all subjects rested in the recumbent position for 30 min in an ambient temperature of 28°C with a relative humidity of about 50%.

Expired gas was collected in Douglas bags for three min in each case after the 8th, 28th and 58th min of exposure during the recumbent rest and after the 10th min during the sitting rest and for the last three min of exposure. The ventilation volume was measured with a wet gas meter. Oxygen and carbon

Table 1. Physical characteristics of the subjects

Subjects	Age (years)	Height (cm)	Weight (kg)	BSA (m ²)	LBM (kg)	B. Fat (%)
OH	22	175.5	53.2	1.60	47.6	11.0
IW	23	170.1	55.2	1.58	50.3	7.4
KI	24	164.0	62.3	1.62	53.2	12.9
TA	21	175.2	89.9	2.02	65.6	27.6
WA	25	160.8	54.0	1.52	47.6	11.9
Mean	23.0	169.1	62.9	1.67	52.9	14.2
S.D.	1.6	6.6	15.5	0.20	7.5	7.8

BSA, body surface area calculated from the equation of Fujimoto *et al.*²⁾; LBM, lean body mass obtained by subtracting body fat weight from total body weight; B. Fat, a percent weight of fat in the body calculated from the formula of Brožek *et al.*³⁾

dioxide concentrations of the mixed expired gas were analyzed by an electromagnetic gas analyzer (Fukuda Sangyo) calibrated by the micro-Scholander method.⁴⁾ ECG was recorded to determine heart rate during collection of the expired gas. Skin temperatures of the chest, upper arm, thigh and lower leg were taken using copper-constantan thermocouples and rectal temperature was determined by thermister thermometer during the period of expired gas collection. Mean skin temperature was calculated from the equation of Ramanathan.⁵⁾

Four determinations of D_L were made in a sitting posture after the 80 min of exposure. The mean of two measurements obtained by inhalation of the room-air mixture was considered as the value of D_L . Details of the methods used to measure D_L and V_c were described in the previous study.¹⁾ Cardiac output was determined in three of five subjects using a CO_2 rebreathing method⁶⁾ after the last D_L measurement during the sitting position had been taken.

RESULTS AND DISCUSSION

The end-inspiratory lung volume on measurement of D_L was not affected by change in ambient temperature ($F=0.84$, d.f.=3,12). All measurements of oxygen intake, heart rate, rectal temperature and mean skin temperature changed significantly with thermal conditions before D_L was measured after the 80th min of exposure (Table 2). However, these measurements were almost constant during measurement of D_L . Figs. 1 and 2 show the changes in D_L and V_c with ambient temperature. The average D_L increased by about 30% from 27.2 ml/min/Torr at 36°C to 34.9 ml/min/Torr at 12°C.

It has been suggested by Gibson *et al.*⁷⁾ and Otis and Jude⁸⁾ that the chemical characteristics of carbon monoxide and hemoglobin change with body temperature. Although there was a significant change in rectal temperature (Table 2) in this study, its range appeared to be too small to affect D_L . D_L would be largely influenced by changes in V_c as a result of various physiological factors being affected by changes in ambient temperature rather than changes in body temperature *per se*. Glaser *et al.*⁹⁾ have demonstrated that, when the body surface is

Table 2. Ranges of mean values of oxygen intake, heart rate, rectal temperature and mean skin temperatures of 12, 20, 28 and 36°C at the 60th min of exposure and F values as the results of analysis of variance for these parameters

	d.f.	Oxygen intake (ml/min)	Heart rate (beats/min)	Rectal temperature (°C)	Mean skin temperature (°C)
Range		210-287	52.0-71.8	36.8-37.4	27.2-35.7
F-value					
Temperature	3,12	20.94**	31.20**	3.91*	89.64**
Subject	4,12	20.48**	14.75**	2.58	1.44

* and ** show the significance at at least 5% and 1% level, respectively.

Fig. 1. Changes in D_L at ambient temperatures of 12, 20, 28 and 36°C for each subject: ○-OH, △-IW, □-KI, ●-TA, ▲-WA.

Fig. 2. Changes in V_c at ambient temperatures of 12, 20, 28 and 36°C for each subject: ○-OH, △-IW, □-KI, ●-TA, ▲-WA.

heated, the effectively ventilated pulmonary capillary volume is diminished and D_L reduced.¹⁰⁾ In addition, Frayser *et al.*¹¹⁾ have shown that D_L and V_c decrease even during exercise with increases in ambient temperature and that this is related to increased cutaneous vasodilatation. In this study, the mean value of V_c was 9.4% smaller at 36°C than at 28°C. Contrary to this observation of body heating, it is expected that V_c would increase in relation to decreases in skin blood flow in the case of body cooling.¹²⁾ In this study, V_c was shown as a power function of the heat conductance index, calculated from oxygen intake, rectal temperature and mean skin temperature, fit by the method of least squares. Accordingly, it is suggested that any thermal effect on D_L , or V_c would be mainly associated with a significant shift of blood between the surface and the inside of the body in this study. This observation was consistent with the observations of Ross *et al.*¹³⁾ and Bondurant *et al.*¹⁴⁾ that pulmonary vascular engorgement was produced by pressure suit inflation and that this was accompanied by increase in D_L .

Since change in V_c would be dependent on a blood shift in the body, V_c is likely to have a close correlation with altered venous blood return. There was a significant correlation between V_c and cardiac output ($r=0.76$, $P<0.01$) in this study. However, computation of the second order partial correlation between V_c and cardiac output, holding stroke volume statistically constant, resulted in a correlation of -0.1 . Conversely, the relation of V_c to stroke volume, holding cardiac output constant, showed a significant coefficient of 0.73 ($P<0.05$). It has been suggested that, in a resting condition, V_c is determined by how effectively pulmonary arterial pressure can provide blood to the upper regions of the lungs against a hydrostatic gradient.¹⁵⁾ Therefore, it is reasonable to assume that V_c is closely related to stroke volume if the determinants of stroke volume are associated with pulmonary arterial pressure as described by Astrand and Rodahl, and Tajimi *et al.*^{16,17)} Thus, V_c seems to depend on the pulmonary arterial system, which means that pulmonary capillary recruitment is mainly responsible for regulating V_c , particularly in an upright position.

The relation between D_L and V_c was very close, producing a high correlation coefficient of 0.93 , as was also observed in the previous study,¹⁾ when D_L was increased during exercise (Fig. 3). The regression of D_L on V_c was compared with that in the previous study as follows:

$D_L = 15.3 + 0.245 V_c$ $r=0.93$ $n=20$ $Sy.x = 1.5$ ml/min/Torr
in this study and

$D_L = 14.2 + 0.272 V_c$ $r=0.89$ $n=39$ $Sy.x = 2.9$ ml/min/Torr
in the previous study. Where r is the correlation coefficient, n is the number of data and $Sy.x$ is the standard deviation for the errors in estimating the regression equation. It was disclosed that these two regression lines were statistically identical, *i.e.*, $F=0.38$ (d.f.=1,55) for slopes and $F=0.74$ (d.f.=1,56) for elevations according to analysis of covariance. Consequently, the total regression

Fig. 3. Relation between D_L and V_c at rest and during exercise. Closed circles show data obtained in this study.

Open circles show data obtained at rest and during exercise at 25°C in the previous study.

equation resulted in:

$$D_L = 14.1 + 0.271 V_c \quad r = 0.90 \quad n = 59 \quad Sy.x = 2.5 \text{ ml/min/Torr}$$

This demonstrates that a unit change in D_L always reflects the same change in V_c whether D_L is changed by exercise or by ambient temperature without exercise.

It was suggested by the previous study that the slope of D_L against energy expenditure was valid for evaluating the potential capacity for V_c increase. For the purpose of detecting the potential increase in V_c under resting conditions, it is necessary to find a significant dependent variable which can be a good match for changes in D_L , as was the case for oxygen intake in the previous study. However, change in D_L in this study was thought to be controlled by the pulmonary arterial system with changes in blood shift within the body. Thus, the mechanisms of change in D_L at rest would be thought to differ from those during exercise.¹⁸⁾ Additionally, physical characteristics may affect D_L in such a thermal condition at rest.^{19,20)} These make it difficult to find the appropriate variable. If a variable should be selected among the parameters available in this study from the viewpoint of reflecting changes in skin blood flow and simplicity of measurement, mean skin temperature would seem to be most suitable. The regression equations of D_L on mean skin temperature for each subject are listed in Table 3 which shows a high correlation coefficient ranging from 0.96 to 0.99. The slope of D_L on mean skin temperature was statistically constant ($F = 0.31$, d.f. = 3,7) except for subject WA

Table 3. Regression equations D_L on mean skin temperature ($\bar{T}_s$) for each subject

Subject	Regression equation	r	N
OH	$D_L = 50.7 - 0.76\bar{T}_s$	0.98	3
IW	$D_L = 55.5 - 0.75\bar{T}_s$	0.96	4
KI	$D_L = 53.2 - 0.67\bar{T}_s$	0.99	4
TA	$D_L = 59.7 - 0.86\bar{T}_s$	0.97	4
WA	$D_L = 79.6 - 1.55\bar{T}_s$	0.76	4

and the average slope for four subjects was -0.77 . As far as the lower limit of the slope necessary for detecting lack of increase in V_c is concerned, mean skin temperature seems to be worthy note. Mean skin temperature indicates a relatively immediate response to acute change in thermal stress, which means that long exposure is not necessary to change D_L . In fact, there were significant changes in oxygen pulse, correlated with stroke volume ($r=0.94$), and changes in heat conductance even at the 10th min of exposure. Although more extensive studies on the relation between D_L and mean skin temperature may be necessary, it is thought that determination of the potential increase in V_c will be possible if the way of thermal stimulation to the body surface is well taken into consideration.

A knowledge of the characteristics of change in D_L at rest and during exercise might contribute to the diagnosis of pulmonary capillary bed diseases and the monitoring of the state of recovery from these diseases. For example, the changes in D_L at rest determined in this study, depending mainly on pulmonary capillary recruitment, would probably help with diagnosing impairments of the pulmonary arterial system while increases in D_L during exercise, depending mainly on pulmonary capillary dilation, would likely assist in determining the distensibility of pulmonary capillaries.

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