[Original]

Influence of Moderate Smoking on Physical Fitness and Local Muscle Oxygenation Profile during Incremental Exercise

Yoshiko KIMURA¹, Yohko NAKAMOTO¹, Hideo SHITAMA¹, Saburo OHMINE¹,
Makoto IDE² and Kenji HACHISUKA³

¹ *Department of Rehabilitation Medicine, University Hospital of Occupational and Environmental Health, Japan. Yahatanishi-ku, Kitakyushu 807-8555, Japan*

² *Saint Mary's Hospital, Rehabilitation Center, Japan. Tsubukuhonmachi, Kurume 830-8543, Japan*

³ *Department of Rehabilitation Medicine, School of Medicine, University of Occupational and Environmental Health, Japan. Yahatanishi-ku, Kitakyushu 807-8555, Japan*

Abstract : To reveal the influence of chronic moderate smoking on physical fitness and local muscle oxygenation profile, we compared the oxygen uptake ($\dot{V}O_2$), CO_2 output, respiratory rate, minute ventilation and blood lactate accumulation between six moderate smokers and ten non-smokers during incremental exercise. In order to know the difference of the peripheral oxygen supply to the muscles between the two groups, oxygenation profiles based on the changes of oxygenated hemoglobin (O_2Hb) in the right vastus lateralis muscles were observed using near-infrared spectroscopy (NIRS). The intensity of incremental exercise using a bicycle ergometer was from 10 W to 80% of the maximum heart rate ($80\%HR_{max}$) of each subject. There were no significant differences between the two groups in $\dot{V}O_2$ and work rate at the level of 2 mmol/ ℓ lactate or $80\%HR_{max}$ ($P < 0.05$). However, as to the local muscle oxygenation profile during exercise, 5 out of the 6 smokers showed a decrease of O_2Hb throughout the incremental exercise, but 8 out of the 10 non-smokers showed a gradual increase of O_2Hb throughout the exercise. In conclusion, our results suggest that chronic moderate smoking might cause a change of local muscle oxygenation profile during incremental exercise, even if the smokers have shown no decrease in physical fitness.

Key words: near-infrared spectroscopy, smoking, physical fitness, oxygenated hemoglobin.

(Received 23 February 2007, accepted 18 April 2007)

Introduction

The negative effects of cigarette smoking on health are well known, and the population attributable fraction between smoking habit and death from all causes, which is an index of death prevention in the community when habitual smokers abstain from cigarette smoking, is 9.0% for males and 1.6% for females, according to NIPPON DATA 80 [1].

Cigarette smoking also affects exercise performance. Maksud *et al.* [2] reported that the mean minute ventilation and perceived exertion were higher in cigarette smokers than in non-smokers, but that aerobic power and the physical work capacity did not differ. Huerta *et al.* [3] found that smoking was associated with lower $\dot{V}O_{2\max}$ in 18–25 years-old persons who had been discharged from military service in the Israeli Defense Forces. Sidney *et al.* [4] revealed that the mean exercise duration in smokers was shorter than that in non-smokers, but the mean time to a heart rate of 130 beats/min was increased. Decreased O_2 delivery to the working muscles due to increased carboxyhemoglobin(COHb) caused a significant reduction in $\dot{V}O_{2\max}$ and in the anaerobic threshold(AT) in smokers [5]. At the 11%COHb level (typical of a heavy cigarette smoker), exercise duration, $\dot{V}O_{2\max}$ and AT were 645 ± 24 s, 45.5 ± 3.5 ml/kg $\cdot$ min and 28.3 ± 2.7 ml/kg $\cdot$ min, respectively, whereas, at the 20%COHb level, exercise duration, $\dot{V}O_{2\max}$ and AT were 599 ± 20 s, 41.4 ± 2.9 ml/kg $\cdot$ min and 25.2 ± 1.9 ml/kg $\cdot$ min, respectively.

It remains unclear, however, whether the physical work capacity of moderate smokers is lower than that of non-smokers, and whether muscle oxygenation in moderate smokers is lower during submaximal exercise. In this study, we planned to assess the contribution of muscle oxygenation to the aerobic exercise tolerance of moderate smokers using near-infrared spectroscopy (NIRS). The NIRS is a non-invasive and continuous method to determine oxygenation and hemodynamics in tissue. Regarding its reliability and validity, NIRS proved to be an appropriate tool to provide information about local muscle O_2 consumption and local blood flow [6].

Methods

The subjects were 16 middle-aged office workers in our university hospital, who voluntarily answered an advertisement displayed on posters seeking study subjects. The inclusion criteria for the subjects in this study were the following: 1) each subject had to be male, 2-a) he had to be smoking from 10–20 cigarettes a day over the last 10 years, smoker group, or 2-b) he had to be a complete non-smoker for the last 10 years, non-smoker group, 3) he had to be aged between 40 and 55 years old, 4) he must never have had abnormal findings at his annual regular medical check-up, which included a physical examination, a biochemical blood test, urinalysis, electrocardiography and a chest X-ray, 5) he must not be participating regularly in sports activities, and 6) he must give informed consent as regards the purpose and procedure of the experiment. According to the inclusion criteria, 16 out of 19 applicants were taken on as subjects: 6 were approved as smoker group subjects, and 10 as non-smoker group subjects.

Height and body weight were measured before the experiment, and the body mass index (kg/m^2) of each subject was calculated based on the formula: body weight (kg)/height (m) $\times$ height (m). Total serum cholesterol was obtained from the data of the last annual regular medical check-up. The subjects were interviewed about smoking and physical activity before the experiment, and their approximate amounts of smoking and daily physical activity were expressed using both the Brinkman index[7] and the short questionnaire for the habitual physical activity index (HPAI)[8], respectively. The Brinkman index is a simple scale, defined as the average number of cigarettes smoked per day multiplied by the number of years of smoking. The HPAI is a self-administered scale to assess physical activity at work, sports during leisure time, and physical activity during leisure time excluding sport, and its construct validity and test-retest reliability have been established. It consists of 16 items, and each item is rated from 1 to 5. Based on the formula, these scores are calculated and are added together, to give the work, sport and leisure-time indexes. The total HPAI score is obtained by adding the three indexes, which gives a result within a range between 3 (sedentary) and 15 (active) for each subject.

Before the experiment, which was carried out at least 2 hrs after lunch in both groups, the smokers were ordered to abstain from smoking for at least 5 hrs. A subject sat on an electrically braked bicycle ergometer (Isopower TTK 1251, Takei Scientific Inc., Niigata, Japan), and its saddle height was adjusted to obtain a slightly flexed knee position when the pedal was at the bottom position. After a 4-min rest period, each subject was asked to pedal the bicycle ergometer (at 10 W resistance) at a rate of 60 rpm, and another 10 W resistance was added every minute up to 80% of the maximal heart rate ($80\%HR_{\max}$). Pulmonary ventilation ($\dot{V}_E$, in BTPS), O_2 uptake ($\dot{V}O_2$, in STPD), CO_2 output ($\dot{V}CO_2$, in STPD) and respiratory rate (RR) were measured breath-by-breath using a Westron Mass Spectrometer (WSMR-1400A, Arcosystem Inc., Chiba, Japan). Heart rate was also monitored using an electrocardiogram (Bioview1000, NEC, Tochigi Japan). Tidal volume (V_T), ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) and oxygen pulse (O_2 pulse), reflecting the O_2 extracted from the blood delivered to the tissues by each heart beat[9], were calculated from these measurements. At rest and during the last 45–60 s of every workload, a sample of forearm venous blood was taken through a catheter fixed in the right median forearm vein, and the blood lactate concentration was determined enzymatically. VO_2 at 2 mmol/ ℓ lactate accumulation in the blood was detected using the V-slope method, and 2 mmol/ ℓ lactate accumulation, which is conventionally employed to determine the lactate threshold[10], was compared between the smoker and non-smoker groups.

NIRS (OM 200, Shimadzu Co., Kyoto, Japan) was used to monitor continuous muscle (or, more precisely, capillary-venular) oxygenation changes. The probe was fixed by a Velcro strap and biadhesive tape at the lower one-third of the right vastus lateralis muscle parallel to the major axis of the right thigh. The sampling frequency was set at 1 Hz.

NIRS is used to evaluate the changes in muscle oxygenation profile, that is to say, if blood supply to peripheral muscles is enough or more during exercise, O_2Hb remains at a constant level (type 2), or continues to increase (type 1), once it decreases immediately at the onset of incremental exercise. If blood supply is not enough, O_2Hb continues to decline throughout the

exercise (type 3).

The ankle-brachial systolic pressure index (ABPI) at rest was measured before the experiment, using PWV/ABI VP1000 (Colin, Aichi, Japan). ABPI is an index of blood flow in the lower extremities, and a value below 0.9 is considered as abnormal.

All the subjects were thoroughly informed about the purpose of the experiment and its practical details before they gave their written consent to participate. This experiment was approved by the Ethics Committee of the University of Occupational and Environmental Health.

Data analysis

Results were presented as the means $\pm$ standard deviation. Differences in ABPI, HPAI, $\dot{V}_E$, RR, V_T , $\dot{V}_E/\dot{V}O_2$ and O_2 pulse between the smoker and non-smoker groups were analyzed by unpaired Student's *t* test. Because the predicted values of 5 cells of muscle oxygenation profiles were less than 5, the differences in muscle oxygenation profiles between the smoker and non-smoker groups were determined by Fisher's exact test, after cells classified as being of the type 2 and type 3 were combined together. A probability of $P < 0.05$ was considered statistically significant.

Results

There were no significant differences in age, height, body mass index, total serum cholesterol and ankle-brachial systolic pressure between the smoker and non-smoker groups (Table 1: $P > 0.05$). The smoker group smoked 15–20 cigarettes a day for more than 20 years, and its Brinkman index (446.5 ± 122.6) was significantly different from that of the non-smoker group ($P < 0.05$). The non-smoker group had never smoked at all, except one subject, who had smoked 10 cigarettes a day 15 years ago for less than one year. No significant differences in physical activities at work, home and during leisure time were found between the smoker and non-smoker groups ($P < 0.05$).

At rest time of the incremental ergometric exercise, no significant differences in the heart rate and $\dot{V}O_2$ were found between the smoker and non-smoker groups (Table 2: $P < 0.05$). At 80%HR_{max} and 2 mmol/l lactate accumulation, there were no significant differences in heart rate, $\dot{V}O_2$, work rate and rating of perceived exertion (RPE) between the smoker and non-smoker groups ($P < 0.05$).

Respiratory responses during incremental exercise were plotted against work rate. $\dot{V}_E$ (Fig. 1A) showed no significant difference between the groups except at rest time. RR (Fig. 1B) was slightly higher in the smoker group, and a significant difference was found only at 10, 70 and 80 W. There was no significant difference in V_T (Fig. 1C) between the two groups. The ventilatory equivalent for oxygen in the smoker group (Fig. 1D) was significantly higher at from 10 to 70 W. There was no significant difference in O_2 pulse between the two groups.

NIRS revealed that 1 of the smoker group had a type 2 muscle oxygenation profile during the incremental exercise, and 5 of the smoking group had a type 3, whereas 8 of the non-smoker group had a type 1, 1 had a type 2 and 1 had a type 3 profile (Fig. 2). More of the

smoker group had a type 2 or a type 3 muscle oxygenation profile than the non-smoker group (Fisher's exact test, $P < 0.05$).

Table 1. Comparison of general characteristics between smoker and non-smoker group

	Smoker group (N=6)	Non-smoker group (N=10)	<i>P</i> -value
Age (years old)	50.3 $\pm$ 4.0	48.7 $\pm$ 4.4	
Height (cm)	169.0 $\pm$ 5.1	167.9 $\pm$ 7.2	
Weight (kg)	65.7 $\pm$ 6.3	69.9 $\pm$ 6.9	
Body mass index (kg/m ²)	23.0 $\pm$ 2.2	24.8 $\pm$ 2.6	
Total cholesterol (mg/dl)	215.0 $\pm$ 14.0	204.1 $\pm$ 26.2	
Ankle-brachial systolic pressure index	1.03 $\pm$ 0.15	1.19 $\pm$ 0.13	
Brinkman index	446.5 $\pm$ 122.6	0.8 $\pm$ 1.8	$P < 0.05$
Habitual physical activity index	8.1 $\pm$ 0.8	7.8 $\pm$ 1.1	

means $\pm$ SD

Brinkman index: the average number of cigarettes smoked per day multiplied by the number of years of smoking, Habitual physical activity index: the total score falls between 3 (sedentary) and 15 (active)

Table 2. Comparison of physical measurements between smoker and non-smoker group

	Smoker group (N=6)	Non-smoker group (N=10)
At rest		
Heart rate (beats/min)	80.2 $\pm$ 11.7	74.8 $\pm$ 9.1
$\dot{V}O_2$ (ml/kg $\cdot$ min)	4.2 $\pm$ 0.7	3.8 $\pm$ 0.7
At 80%HR _{max}		
Heart rate	136.0 $\pm$ 3.3	137.1 $\pm$ 3.6
$\dot{V}O_2$	17.4 $\pm$ 2.5	18.0 $\pm$ 2.4
Work rate (W)	100.0 $\pm$ 8.3	111.0 $\pm$ 20.8
RPE (Borg scale)	14.7 $\pm$ 2.4	14.2 $\pm$ 2.4
At 2 mmol/l lactate accumulation		
Heart rate	122.8 $\pm$ 8.8	128.6 $\pm$ 11.4
$\dot{V}O_2$	15.9 $\pm$ 2.6	16.6 $\pm$ 2.1
Work rate	81.7 $\pm$ 23.4	96.0 $\pm$ 21.2

means $\pm$ SD

Fig. 1. Pulmonary responses during incremental exercise. Because maximum intensity of the incremental exercise was $80\%HR_{\max}$, each final work rate was different, and the values up to 110 W are shown in the figures. 1A: V_E (ℓ/min), 1B: RR (breaths/min), 1C: V_T (ℓ), 1D: V_E/VO_2 , *: $P < 0.05$, $\diamond$: non-smokers, $\blacksquare$: smokers.

Discussion

The main finding of this study was that the muscle oxygenation profile obtained with NIRS showed a significant difference between the smoker and non-smoker groups, although there were no significant differences in heart rates, $\dot{V}O_2$, work rate, RPE at the levels of 2 mmol/ ℓ lactate accumulation in blood nor $80\%HR_{\max}$. The subjects in this study were appropriately selected from applicants based on the inclusion criteria, and the subjects' profiles, including their physical characteristics and activity level, indicate that they were average middle-aged sedentary office workers without any disease. The smoker group, whose Brinkman index was 446.5 ± 122.6 , is regarded as moderate smokers[11], and they seem to have no change in small airway dysfunction or emphysematous destruction of lung parenchyma according to the annual regular medical check-up. However, we should be wary about extrapolating the results of this study to all smokers, because this study has limitations, i.e. the number of subjects is small, and we did not monitor venous carboxyhemoglobin.

Fig. 2. NIRS profiles during incremental exercise. NIRS profiles were classified into three types: in type 1, O₂Hb dropped immediately after the onset of the exercise and gradually increased until the end of the exercise; in type 2, O₂Hb was stable, once it dropped immediately after the onset of the exercise; and in type 3, O₂Hb continued to decline throughout the incremental exercise. Eight out of 10 non-smokers had a type 1 profile, but none of the smokers had a type 1 profile. Five out of 6 smokers belonged to a type 3, but only 1 of the smokers had a type 2 profile.

□: type 1, ▨: type 2, ■: type 3, —: oxygenated (O₂Hb), - - : deoxygenated Hb.

NIRS has been used to evaluate the changes in muscle oxygenation during exercise non-invasively and continuously. Muscle oxygenation measured with NIRS indicates capillary and venular O₂Hb saturation around the muscle and O₂Mb saturation in tissues, but approximately 75% of the total tissue optical signal during exercise arises from O₂Hb, with the remainder associated with tissue O₂Mb. Therefore, the change in O₂Hb and deoxygenated hemoglobin (HHb) is related to the balance of blood flow in the local muscle and O₂ extraction by the exercising muscle.

During low intensity exercise, the influence of increased blood flow on activated muscles is greater than that of O₂ extraction [12]. In the present study, O₂Hb decreased immediately at the onset of the incremental exercise and continued to decrease gradually during exercise (type 3) in 1 out of the 10 non-smokers and in 5 out of the 6 smokers. This fact may mean that chronic moderate smoking gives rise to changes in the muscle oxygenation profile, even

if the smoker has no decrease in physical fitness. O_2 kinetics similar to those of the smokers is also found in patients with arteriosclerosis obliterans (Ohmine, unpublished data), that is, O_2Hb in the calf muscle measured with NIRS began to decrease immediately after the beginning of exercise on a treadmill, and continued to decrease to the end of the exercise. In ASO patients, blood flow to the exercising muscle is disturbed due to peripheral vascular dysfunction [13].

$\dot{V}O_2$ at 2 mmol/ ℓ lactate accumulation and work rates at 80%HR_{max} were the same in the smoker and non-smoker groups in the present study. Cooper *et al.* [14] evaluated a 12-min endurance run for distance in smokers and non-smokers, where smokers showed a reduced performance compared to non-smokers. They reported that in the smoker group, endurance was negatively proportional to the number of cigarettes per day and the duration of smoking. So, the difference between our results and theirs may be due to the number of cigarettes smoked per day or the smoking history.

Krumholz *et al.* [15] studied the factors influencing work capacity in middle-aged, long-term smokers, and found that the pulmonary diffusing capacity and the diffusing capacity/total lung capacity ratio were significantly lower in smokers. Impaired diffusion capacity with a fixed amount of oxygen would require a larger $\dot{V}_E$ [2]. In our data, there was no difference in the $\dot{V}_E$ between the smoker and non-smoker groups, however, the $\dot{V}_E/O_2$ ratio was significantly higher in the smoker group for up to 70 W. Chronic moderate smoking may have caused a subtle change in the pulmonary diffusing capacity.

In the present study, we didn't examine the level of blood CO. CO is known to displace O_2 from hemoglobin and to reduce the O_2 carrying capacity of blood [16]. Gowa *et al.* [17] studied the effect of stopping smoking for 4 weeks using five well-trained habitual smokers, and found that the ventilation threshold (V_T) elevated significantly after only 2 weeks of stopping smoking. They attributed the result to lowered COHb and COMb densities due to stopping smoking, since the O_2 pulse increased remarkably, which means that the O_2 supply to the exercising muscles was improved. Koike *et al.* [5] reported that 20%COHb decreased exercise duration, $\dot{V}O_{2max}$ and AT more than 11%COHb. Horvath *et al.* [18] studied the precise level of COHb at which $\dot{V}O_{2max}$ was impaired and found that $\dot{V}O_{2max}$ was not significantly decreased until COHb levels reached 4.3%. In our data, $\dot{V}O_2$ at 2 mmol/ ℓ lactate accumulation and 80%HR_{max} was the same in the smoker and non-smoker groups. Because our smokers were moderate smokers [11], this might have had less of an affect on their O_2 carrying capacity due to the low rate of COHb.

In conclusion, the chronic moderate smokers in this study had the same aerobic exercise performance as the non-smokers. NIRS could detect subtle changes in local muscle oxygenation of the chronic moderate smokers even if smoking did not diminish physical fitness. The precise pathophysiology of the disturbance of local muscle oxygenation in the chronic moderate smokers still remains unclear, but the pulmonary diffusing capacity and local circulation in muscles may have an influence on this phenomenon. Further study is needed to focus on the pathophysiology of this physical response of chronic moderate smokers during exercise.

Acknowledgement

We thank Dr. Futoshi Wada (Department of Rehabilitation Medicine, School of Medicine, University of Occupational and Environmental Health, Japan), for his assistance with the study design and data analysis.

References

1. Kawaminami T, Minowa M, Okayama A, Hayakawa T & Ueshima H (2003): NIPPON DATA 80 Research Group. An association (population attributable fraction) between smoking habit and mortality from all causes, cancer and lung cancer: NIPPON DATA 80, 1980-1999. National integrated projects for prospective observation of non-communicable diseases and its trend in the aged. *Jpn J Hyg* 57: 669–673
2. Maksud MG & Baron A (1980): Physiological responses to exercise in chronic cigarette and marijuana users. *Eur J Appl Physiol* 43: 127–134
3. Huerta M, Grotto I, Shemla S, Ashkenazi I, Shpilberg O & Kark JD (2004): Ergometry estimation of physical fitness among Israeli soldiers. *Mil Med* 169: 217–220
4. Sidney S, Sternfeld B & Gidding SS (1993): Cigarette smoking and submaximal exercise test duration in a biracial population of young adults: the CARDIA study. *Med Sci Sports Exerc* 25: 911–916
5. Koike A & Wasserman K (1992): Effects of acute reduction in oxygen transport on parameters of aerobic function during exercise. *Ann Acad Med* 21: 14–22
6. Beekvelt MC, Colier WN, Wevers RA & Engelen GM (2001): Performance of near-infrared spectroscopy in measuring local O₂ consumption and blood flow in skeletal muscle. *J Appl Physiol* 90: 511–519
7. Brinkman GL & Coates O (1963): The effect of bronchitis, smoking and occupation on ventilation. *Ann Rev Respir Dis* 87: 68–93
8. Baecke JA, Burema J & Frijters JE (1982): A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr* 36: 936–942
9. Grassi B, Quaresima V, Marconi C, Ferrari M & Cerretelli P (1999): Blood lactate accumulation and muscle deoxygenation during incremental exercise. *J Appl Physiol* 87: 348–355
10. Hirsch GL, Sue DY, Wasserman K, Robinson TE & Hansen JA (1985): Immediate effects of cigarette smoking on cardiorespiratory response to exercise. *J Appl Physiol* 58: 1975–1981
11. McDonough P & Moffatt RJ (1999): Smoking-induced elevations in blood carboxyhaemoglobin levels: effect on maximal oxygen uptake. *Sports Med* 27: 275–283
12. Homma S, Fukuoka Y, Fuji N & Eda H (1992): Study of human muscle circulation during bicycle exercise using near-infrared spectroscopy. *Jpn J Phys Fitness Sports Med* 41: 586–594
13. Komiyama T, Shigematsu H, Yasuhara H & Muto T (2000): Near-infrared spectroscopy grades the severity of intermittent claudication in diabetics more accurately than ankle pressure measurement. *Br J Surg* 87: 459–466
14. Cooper KH, Gey GO & Bottenberg RA (1968): Effects of cigarette smoking on endurance performance. *J Am Med Assoc* 203: 123–126
15. Krumholz RA & Hedrick EC (1972): Exercise response of smoking and non-smoking middle-aged business executives. *J Lab Clin Med* 80: 79–87
16. Vogel JA & Gleser MA (1972): Effect of carbon monoxide on oxygen transport during exercise. *J Appl Physiol* 32: 234–239
17. Gowa Y, Yoshioka T, Watanabe K & Shiraishi T (1989): The effects of stop-smoking on aerobic

- capacity. Department of Health Science. Osaka Kyoiku University 38: 183–189
18. Horvath SM, Raven PB, Dahms TE & Gray DJ (1975): Maximal aerobic capacity at different levels of carboxyhemoglobin. J Appl Physiol 38: 300–303

中等度の喫煙が体力や漸増運動時の局所筋の酸素動態におよぼす影響

木村 美子¹, 中元 洋子¹, 舌間 秀雄¹, 大峯 三郎¹, 井手 睦², 蜂須賀 研二³

¹産業医科大学病院 リハビリテーション部

²聖マリア病院 リハビリテーションセンター

³産業医科大学 医学部 リハビリテーション医学講座

要 旨： 6名の喫煙者と10名の非喫煙者を対象として、漸増運動が体力や末梢循環(酸素動態)におよぼす影響について調べた。酸素動態の計測には近赤外線分光装置を用いて右外側広筋の酸素化ヘモグロビン濃度(O_2Hb)の変化量を測定した。その結果80%HR_{max}到達時や血中乳酸濃度 2 mmol/l 時の仕事量, $\dot{V}O_2$ やHRには2群間で有意差はなかったが、運動強度によってはRRや酸素当量が喫煙者において著明に高い傾向がみられた。 O_2Hb は喫煙者の内5名では運動の強度が上がるにつれて減少し続ける傾向がみられたが、非喫煙者では8名で運動中を通じて増加し続けた。喫煙者では中等度の運動強度でも筋の酸素需要に供給が追いついていない可能性がある。喫煙者が運動を行う際には中等度の強度であっても末梢循環動態に十分な配慮が必要であることが示唆された。

キーワード： 近赤外線分光法, 喫煙, 体力, 酸素化ヘモグロビン.

J UOEH (産業医大誌) 29 (2) : 149–158 (2007)