APPLIED HUMAN SCIENCE
Journal of Physiological Anthropology

Peak Oxygen Uptake and Respiratory Function in Persons with Spinal Cord Injury

Masahiro Yamasaki[1], Takashi Komura[1], Yasuaki Tahara[2], Kumiko Katsuno[3], Yumiko Fukuyama[3], Ryo Michimuko[4] and Kaoru Fujiie[5]

1) Department of Health Science, Hiroshima University
2) Department of Health and Physical Education, Nagasaki University
3) Department of Nursing, Nagasaki University
4) Department of Physical Education, Kassui Women's College
5) Department of Medical Engineering, Spinal Injuries Center

Abstract. This study investigated the association between peak oxygen uptake (peak $\dot{V}o_2$) during arm cranking exercise and respiratory function in paraplegics. Fourteen male paraplegics were recruited for the present study. The subjects were grouped according to the level of injury into the HL (Th3-Th8) and LL (Th11-L3) group. Prior to the maximal test, pulmonary function, including vital capacity (VC) and residual volume (RV), was measured in the sitting position. Mean peak $\dot{V}o_2$ in the LL group (1662 $ml\cdot min^{-1}$) was significantly greater than that in the HL group (1357 $ml\cdot min^{-1}$), corresponding to 82% of that in the LL group ($P \leq 0.05$). In respiratory function, the HL group showed marked restrictive impairment of ventilatory function. That is, VC and RV were significantly lower in the HL group than in the LL group ($P \leq 0.05$). The reduction in VC and RV is related to the degree of loss of control in respiratory functioning muscle mass. However, there was no clear-cut correlation between respiratory function and peak $\dot{V}o_2$ expressed as a function of body mass ($ml\cdot kg^{-1}\cdot min^{-1}$). In addition, a multiple linear regression analysis revealed that RV and VC were not associated with peak $\dot{V}o_2$ ($ml\cdot min^{-1}$) in contrast to the importance of body mass. It seems reasonable to conclude from these results that respiratory function is not an important factor in determining peak $\dot{V}o_2$ in the paraplegic.

(Appl Human Sci, 15(1): 13-17, 1996)

Keywords: spinal cord injury, respiratory function, arm cranking exercise, peak oxygen uptake

Introduction

In order to investigate physical work capacity and its limitation in the paraplegic, many studies have been undertaken on peak oxygen uptake (peak $\dot{V}o_2$) during maximal arm cranking exercise or wheelchair propulsion (Nilsson et al., 1975; Zwiren and Bar-Or, 1975; Glaser et al., 1980; Gass and Camp, 1984; Davis and Shephard, 1988; Yamasaki et al., 1994). It seems that the extent of the change in peak $\dot{V}o_2$ may be very much dependent upon the level of spinal cord injury because of the reduced functional muscle mass and strength in the upper body. In fact, some authors indicated that peak $\dot{V}o_2$ is significantly related to the level of spinal cord injury (Wicks et al., 1983; Veeger et al., 1991; Lin et al., 1993).

Reduced pulmonary function has been suggested as a limitation to exercise performance in the person with a spinal cord injury, particularly in the tetraplegic (Silver, 1963). Since the impairment of pulmonary function in the paraplegic depends on the level of spinal cord injury (Fugl-Meyer, 1971; Kokkola et al., 1975), it may be considered that there is some effect of restricted pulmonary function on peak $\dot{V}o_2$ in the paraplegic person. However, few studies concerning the relationship between peak $\dot{V}o_2$ and pulmonary function in the paraplegic have been conducted.

This study examined, therefore, whether pulmonary function in the paraplegic person is one of the limiting factors of attaining a high peak $\dot{V}o_2$. For this purpose, we investigated the effect of the level of spinal cord injury on pulmonary function and peak $\dot{V}o_2$ in the paraplegic, and assessed the relationship between pulmonary function and peak $\dot{V}o_2$.

Methods

Subjects

Fourteen Japanese male paraplegics with complete lesions were recruited for the study. All were disabled by a neuromuscular lesion between T3 and L3 but were otherwise healthy. The subjects were divided into two groups according to the functional classification of the International Stoke Mandeville Games Federation

Table 1 Physical characteristics of the subjects

Subject (HL)	Age (yr)	Injury Level	Years since Injury	Body Mass (kg)	Body Length* (cm)
1	27.4	Th3, 4	6.0	51.0	168.0
2	44.1	Tr4, 5	20.0	50.8	171.5
3	29.0	Th5	7.5	45.2	171.5
4	35.6	Th5	7.9	58.0	173.0
5	28.6	Th7	1.9	54.0	170.0
6	24.4	Th7	7.5	40.7	157.1
7	27.1	Th8	17.0	50.5	150.0
Mean	30.9		9.7	50.0	165.9
SD	6.8		6.4	5.6	8.8
(LL)					
8	30.5	Th11	7.8	53.6	175.0
9	38.5	Th12	26.0	67.0	170.0
10	26.1	L1	13.5	67.1	158.1
11	32.3	L1	7.6	46.0	164.0
12	41.7	L1	17.0	51.9	158.0
13	37.9	L2	2.0	56.5	160.0
14	24.3	L3	1.0	60.1	165.0
Mean	33.0		10.7	57.5	164.3
SD	6.6		8.8	7.8	6.4

*Body length was assessed in the supine position with manual stretching of the limbs.

(ISMGF) (Guttmann, 1976; McCann, 1984). Subjects with a high lesion between Th3 and Th7 were classified as the HL group with completely or partly paralyzed abdominals (ISMGF class II and III) and subjects with a low lesion between Th11 and L3 were considered the LL group with good abdominal function (ISMGF class IV). The physical and general characteristics of the subjects in each group are shown in Table 1. Prior to their participation in the study, written informed consent was obtained from all subjects.

Testing Protocols

An arm cranking exercise test was performed using a mechanically braked arm cranking ergometer (Monark model 881E) with a subject seated in their immobilized wheelchair. The arm cranking ergometer was operated at a cadence of 50 revolutions per minute, beginning at 0 W and increasing the power output by 5 W every minute until the subject could no longer keep pace with the metronome. Most tests were terminated after 11 to 15 minutes of exercise. Before experimental testing, subjects completed several practice sessions on the arm cranking ergometer. Thus, they were accustomed to the testing procedure to obtain peak $\dot{V}O_2$.

Physiological Variables

During each exercise test, oxygen consumption and pulmonary ventilation were measured on-line using an automated gas and flow analyzer with a computer, Aeromonitor AE-280 (Minato Medical Science Co., Ltd.) and recorded at 30-second intervals throughout the exercise. Heart rate was continuously monitored by chest electrodes (modified CM5 placement). Peak $\dot{V}O_2$, peak $\dot{V}_E$ and peak HR were utilized for analysis; peak $\dot{V}_E$ and peak HR are defined in this study as pulmonary ventilation and heart rate at the time peak $\dot{V}O_2$ was obtained, respectively. Peak $\dot{V}O_2$ was determined as the greatest oxygen uptake during each test.

Before exercise, pulmonary function, including tidal volume, residual volume (RV) and vital capacity (VC), was measured by an electro-spirometer (F.R.C. computer COMF-100, Fukuda Sangyo) in each subject in the sitting position in their wheelchair. The helium dilution technique was used to determine the RV. Three measurements of RV and VC were taken and averaged. Total lung capacity (TLC) was calculated by adding RV to VC. The predicted value of VC for each subject was obtained from the scales reported by Baldwin et al. (1948) using the age and body height of each subject. The percentage of predicted VC was calculated for each subject.

Statistical Analysis

The mean and standard deviation for each variable was calculated in each group. An unpaired t test was used for statistical comparison of the response of a measured variable to the exercise stimulus between the HL and LL group. A regression technique was employed to examine the relationship between the ventilatory functions and peak $\dot{V}O_2$. Furthermore to test which variable is more important in determining peak $\dot{V}O_2$,

Table 2 Peak oxygen uptake (Peak $\dot{V}O_2$), peak ventilation (Peak $\dot{V}_E$), and peak heart rate (Peak HR)

Subject (HL)	Peak $\dot{V}O_2$ (ml·min^{-1})	(ml·kg^{-1}·min^{-1})	Peak $\dot{V}$ (l·min^{-1})	Peak HR (beats·min^{-1})	Subject (LL)	Peak $\dot{V}O_2$ (ml·min^{-1})	(ml·kg^{-1}·min^{-1})	Peak $\dot{V}_E$ (l·min^{-1})	Peak HR (beats·min^{-1})
1	1197	23.5	53.3	140.6	8	1990	37.1	90.1	173.0
2	1477	29.1	60.5	153.8	9	1726	25.8	86.8	165.1
3	1053	23.3	53.3	141.7	10	1872	27.9	72.6	149.5
4	1793	30.9	89.3	168.2	11	1666	36.2	83.0	171.4
5	1618	30.0	87.8	176.4	12	1438	27.7	67.4	180.0
6	1045	25.7	64.6	168.2	13	1445	25.6	96.4	180.0
7	1319	26.1	61.1	166.6	14	1498	24.9	72.4	179.5
Mean	1357*	26.9	67.1	159.4	Mean	1662	29.3	81.2	171.2
SD	286	3.1	15.2	14.1	SD	216	5.2	10.7	11.1

*$P \leq 0.05$ compared with LL.

Table 3 Total lung capacity (TLC), residual volume (RV), vital capacity (VC), predicted vital capacity (Pr. VC), and % of predicted vital capacity (% Pr. VC)

Subject (HL)	TLC (l)	RV (l)	VC (l)	Pr. VC (l)	% Pr. VC
1	4.95	1.97	2.98	4.13	72.2
2	4.56	2.47	2.09	3.89	53.7
3	4.73	1.87	2.86	4.18	68.4
4	5.57	1.87	3.70	4.09	90.5
5	4.51	2.15	2.36	4.30	54.9
6	4.24	1.80	2.44	3.91	62.4
7	4.22	1.20	3.02	3.69	81.8
Mean	4.68	1.90*	2.78*	4.03	69.1*
SD	0.47	0.39	0.54	0.21	13.6
(LL)	(l)	(l)	(l)	(l)	
8	5.27	1.51	3.76	4.24	88.7
9	4.63	1.04	3.59	3.90	92.1
10	4.87	1.72	3.15	3.62	87.0
11	5.19	1.40	3.79	3.94	96.2
12	5.28	1.46	3.82	3.63	105.2
13	4.36	1.29	3.07	3.74	82.1
14	5.07	1.24	3.83	4.17	91.8
Mean	4.95	1.38	3.57	3.89	91.9
SD	0.35	0.22	0.33	0.25	7.4

*$P \leq 0.05$ compared with LL

multiple linear regression was applied to the data of peak $\dot{V}O_2$, body mass, RV and VC. All P values less than or equal to 0.05 were considered significant.

Results

Table 2 shows the peak $\dot{V}O_2$, peak $\dot{V}_E$ and peak HR of each subject during maximal arm cranking exercise, along with the mean and standard deviation of each group. Mean peak $\dot{V}O_2$ in the LL group was significantly greater than in the HL group, corresponding to 82% of that in the LL group ($P \leq 0.05$). Although the difference was not significant, there was a tendency for the LL group to show a greater peak $\dot{V}O_2$ expressed as a function of body mass (ml·kg^{-1}·min^{-1}), peak $\dot{V}_E$, and peak HR than the HL group.

Table 3 shows the spirometric data for each subject of the LL and HL group separately. The difference in TLC between the two groups was not significant. In contrast, the HL group showed significantly greater RV and lesser VC compared with the LL group ($P \leq 0.05$). The mean VC of the HL group was only 69.1% of the predicted normal value. This was much less than the 91.9 % of the predicted normal value in the LL group ($P \leq 0.05$). Thus, the HL group showed marked restrictive impairment of ventilatory function, while the ventilatory function in the LL group was only slightly affected.

The relationship between pulmonary function and peak $\dot{V}O_2$ expressed as a function of body mass (ml·kg^{-1}·min^{-1}) is shown in Figure 1 (RV) and 2 (VC). Regression analyses revealed that there was no clear-cut correlation between pulmonary function and peak $\dot{V}O_2$. In addition, to confirm more important variable in determining peak $\dot{V}O_2$ (ml·min^{-1}), a multiple linear regression analysis was applied to the data and significance of partial regression coefficient was tested (Table 4). This analysis demonstrated that VC and RV were not important variables to determine peak $\dot{V}O_2$ (ml·min^{-1}).

Discussion

The peak $\dot{V}O_2$ of paraplegics varies within a wide range and depends upon many physiological and psychological factors (Cowell et al., 1986); injury level is one of the main factors influencing the peak $\dot{V}O_2$ of the para-

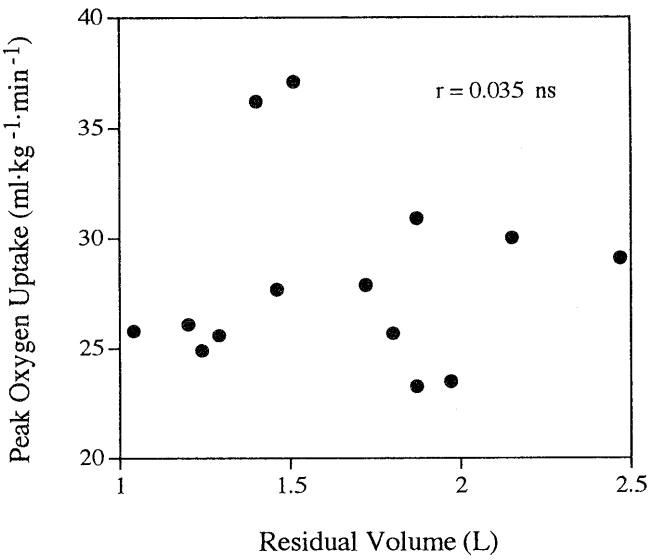

Fig. 1 The relationship between residual volume and peak oxygen uptake as a function of body mass.

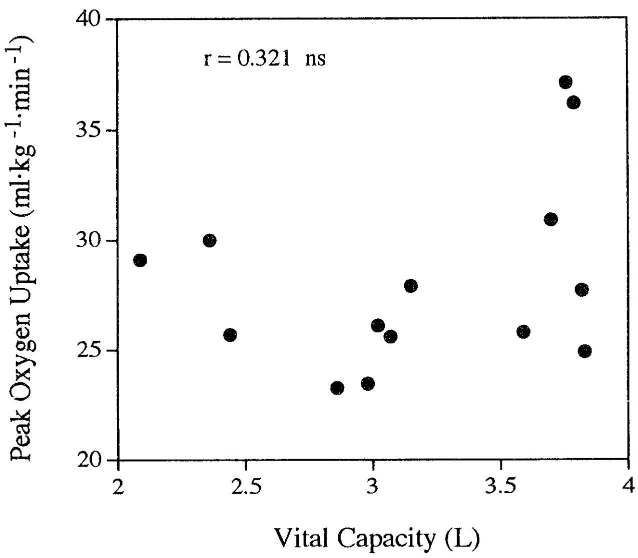

Fig. 2 The relationship between vital capacity and peak oxygen uptake as a function of body mass.

Table 4 Test of significance of partial regression coefficient

Variables	SPRC	SE of SPRC	PRC	SE of PRC	t value	
Body Mass	0.594	0.218	22.63	8.32	2.72	$P \leq 0.05$
RV	0.408	0.286	0.292	0.204	1.43	ns
VC	0.553	0.291	0.271	0.142	1.9	ns

SPRC: Standardized partial regression coefficient
PRC: Partial regression coefficient
SE: Standard error
ns: not significant

plegic (Wicks et al., 1983; Hjeltnes, 1984; Veeger et al., 1991; Lin et al., 1993). Hjeltnes (1984) pointed out that there was a close correlation between the range of injury level and maximal oxygen uptake. Wicks et al. (1983) showed that the paraplegic with an injury level between Th1 and Th5 had a significantly lower peak $\dot{V}O_2$ than one with a lesion below T6. However, these authors did not find a significant difference between peak $\dot{V}O_2$ of a paraplegic with an injury between Th6 - Th10 and that of a person with an injury between Th11 - L3. Coutts et al. (1983) and Lin et al. (1993) reported that the peak $\dot{V}O_2$ of the high-lesion paraplegic (Th1 - Th5) was significantly less than that of the low-lesion paraplegic (Th11 - L3), but not significantly different from the middle-lesion paraplegic (Th6 - Th10). In the present study, we found a significant difference in peak $\dot{V}O_2$ expressed in $ml \cdot min^{-1}$ between the HL and LL group. Thus, although there is some difference in the results of the present investigations from previously reported studies, it should be recognized that with a higher injury level, the physical work capacity of the paraplegic decreases.

In this study, paraplegics were divided into two groups using a demarcation between Th8 and Th11. The paraplegic with an injury level between T1 and T5 or between T5 and T10 had no function in the abdominals or no function in the lower abdominals, respectively (McCann, 1984). In contrast, the paraplegic with an injury level between Th11 and L3 has good abdominal function. In the paraplegic with partially or wholly impaired abdominal muscle function, respiration is influenced by the degree of relative impairment of abdominals which normally act as auxiliary respiratory muscles. In fact, the HL group in this study showed a significantly lower VC than the LL group (Table 3). Our results agreed closely with those of Fugl-Meyer (1971) who observed a reduction in VC to 62% of the predicted normal in the high-lesion paraplegic (Th2 - Th4), to 78% in the middle-lesion paraplegic (Th8 - Th12), and to 95% in the low-lesion paraplegic (L1 - L2).

The lower peak $\dot{V}O_2$ in the HL group is probably due to the smaller functional muscle mass compared with that of the LL group. In addition, we expected that impaired pulmonary function in the HL group also influences the decrease in peak $\dot{V}O_2$ in the HL group. As shown in Figure 1 and 2, however, peak $\dot{V}O_2$ expressed as a function of body mass ($ml \cdot kg^{-1} \cdot min^{-1}$) was not related with RV and VC. Using peak $\dot{V}O_2$ expressed in $ml \cdot min^{-1}$ as a dependent variable and body mass, RV and VC as independent variables, a multiple linear regression analysis demonstrated that body mass was a significantly important variable. In contrast, RV and VC was not associated with determining peak $\dot{V}O_2$. These results showed that although the difference in RV and VC between the HL and LL group was apparent, RV and VC had little influence on peak $\dot{V}O_2$ in the paraplegic.

References

Baldwin E DEF, Cournand A and Richards DW (1948) Pulmonary insufficiency, I. Physiological classification, clinical methods of analysis, standard values in normal subjects. Medicine 27: 243-278

Coutts KD, Rhodes EC and McKenzie DC (1983) Maximal exercise responses of tetraplegics and paraplegics. J Appl Physiol 55: 479-482

Cowell LL, Squires WG and Raven PB (1986) Benefits of aerobic exercise for the paraplegic: a brief review. Med Sci Sports Exerc 18: 501-508

Davis GM and Shephard RJ (1988) Cardiorespiratory fitness in highly active versus inactive paraplegics. Med Sci Sports Exerc 20: 463-468

Fugl-Meyer AR (1971) Effects of respiratory muscle paralysis in tetraplegic and paraplegic patients. Scand J Rehab Med 3: 141-150

Gass GC and Camp EM (1984) The maximum physiological responses during incremental wheelchair and arm cranking exercise in male paraplegics. Med Sci Sports 16: 355-359

Glaser RM, Sawka MN, Brune MF and Wilde SW (1980) Physiological responses to maximal effort wheelchair and arm crank ergometry. J Appl Physiol: Respirat Environ Exercise Physiol 48: 1060-1064

Guttmann L (1976) Textbook of Sport for the Disabled. Aylesbury, England: HM+M pp34-36

Hjeltnes H (1984) Control of medical rehabilitation of para- and tetraplegics by repeated evaluation of endurance capacity. Int J Sports Med 5: 171-174 (Suppl)

Kokkola K, Möler K and Lehtonen T (1975) Pulmonary function in tetraplegic and paraplegic patients. Ann Clin Res 7: 76-79

Lin KH, Lai JS, Kao MJ and Lien IN (1993) Anaerobic threshold and maximal oxygen consumption during arm cranking exercise in paraplegia. Arch Phys Med Rehabil 74: 515-520

McCann BC (1984) Classification of the locomotor disabled for competitive sports: theory and practice. Int J Sports Med 5: 167-170 (Suppl)

Nilsson S, Staff DH and Pruett EDR (1975) Physical work capacity and the effect of training on subjects with long standing paraplegia. Scand J Rehabil Med 58: 467-476

Silver JR (1963) The oxygen cost of breathing in tetraplegic patients. Paraplegia 1: 204-214

Veeger HEJ, Yahmed MH, Van Der Woude LHV and Charpentier P (1991) Peak oxygen uptake and maximal power output of Olympic wheelchair-dependent athletes. Med Sci Sports Exerc 23: 1201-1209

Wicks JR, Oldridge NB and Cameron BJ, Jones NL (1983) Arm cranking and wheelchair ergometry in elite spinal cord-injured athletes. Med Sci Sports Exerc 15: 224-231

Yamasaki M, Irizawa M and Ishii K (1994) Effects of sports participation on physical and mental condition in persons with spinal cord injury. Descente Sports Sci 15: 100-106 (in Japanese with English abstract)

Zwiren L and Bar-Or O (1975) Responses to exercise of paraplegics who differ in conditioning level. Med Sci Sports 7: 94-98

Received: April 28, 1995
Accepted: October 26,1995

Correspondence to: Masahiro Yamasaki,
Department of Health Science, Hiroshima University,
1-7-1 Kagamiyama, Higashi-Hiroshima 739, Japan