Acta Medica Okayama

Volume 61, *Issue* 5 2007 *Article* 3

OCTOBER 2007

Linkage between Oxygen Uptake at Ventilatory Threshold and Muscle Strength in Subjects with and without Metabolic Syndrome

Nobuyuki Miyatake[*]
Takeshi Saito[†]
Jun Wada[‡]
Hidetaka Nishikawa[**]
Sumiko Matsumoto[††]
Motohiko Miyachi[‡‡]
Masafumi Fujii[§]
Hirofumi Makino[¶]
Takeyuki Numata[‖]

[*]Okayama Southern Institute of Health,
[†]Okayama Southern Institute of Health,
[‡]Okayama University,
[**]Okayama Southern Institute of Health,
[††]Okayama Southern Institute of Health,
[‡‡]National Institute of Health and Nutrition,
[§]Kawasaki Medical School,
[¶]Okayama University,
[‖]Okayama Southern Institute of Health,

Linkage between Oxygen Uptake at Ventilatory Threshold and Muscle Strength in Subjects with and without Metabolic Syndrome*

Nobuyuki Miyatake, Takeshi Saito, Jun Wada, Hidetaka Nishikawa, Sumiko Matsumoto, Motohiko Miyachi, Masafumi Fujii, Hirofumi Makino, and Takeyuki Numata

Abstract

We evaluated the linkage between oxygen uptake at the ventilatory threshold (VT) and muscle strength in subjects with and without metabolic syndrome. We used data of 226 Japanese men with metabolic syndrome and 265 Japanese men without the syndrome. Metabolic syndrome has recently been defined by a new criterion in Japan. Oxygen uptake at VT and muscle strength, i.e. grip strength and leg strength were measured. Oxygen uptake at VT and muscle strength/body weight were found to be significantly lower in subjects with metabolic syndrome than in those without the syndrome. However, the differences did not reach significant levels after adjusting for leg strength/body weight or oxygen uptake at VT. A combination of aerobic exercise and resistance training might be considered for preventing and improving metabolic syndrome.

KEYWORDS: metabolic syndrome, oxygen uptake, ventilatory threshold, muscle strength

---

*PMID: 17971842 [PubMed - indexed for MEDLINE]

Acta Med. Okayama, 2007
Vol. 61, No. 5 pp. 255-259

Acta Medica Okayama
http://www.lib.okayama-u.ac.jp/www/acta/

Original Article

Linkage between Oxygen Uptake at Ventilatory Threshold and Muscle Strength in Subjects with and without Metabolic Syndrome

Nobuyuki Miyatake[a]*, Takeshi Saito[a], Jun Wada[b], Hidetaka Nishikawa[a], Sumiko Matsumoto[a], Motohiko Miyachi[c], Masafumi Fujii[d], Hirofumi Makino[b], and Takeyuki Numata[a]

[a]Okayama Southern Institute of Health, Okayama 700-0952, Japan, [b]Department of Medicine and Clinical Science, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan, [c]National Institute of Health and Nutrition, Shinjuku, Tokyo 162-8636, Japan, and [d]Department of Health Care Medicine, Kawasaki Medical School, Kurashiki, Okayama 701-0192, Japan

We evaluated the linkage between oxygen uptake at the ventilatory threshold (VT) and muscle strength in subjects with and without metabolic syndrome. We used data of 226 Japanese men with metabolic syndrome and 265 Japanese men without the syndrome. Metabolic syndrome has recently been defined by a new criterion in Japan. Oxygen uptake at VT and muscle strength, *i.e.* grip strength and leg strength were measured. Oxygen uptake at VT and muscle strength/body weight were found to be significantly lower in subjects with metabolic syndrome than in those without the syndrome. However, the differences did not reach significant levels after adjusting for leg strength/body weight or oxygen uptake at VT. A combination of aerobic exercise and resistance training might be considered for preventing and improving metabolic syndrome.

Key words: metabolic syndrome, oxygen uptake, ventilatory threshold, muscle strength

Metabolic syndrome is a common disorder and has become a public health challenge in Japan [1, 2]. Lifestyle modifications, especially exercise, are important for preventing and improving metabolic syndrome. We have previously reported that a lower level of oxygen uptake at VT (ventilatory threshold) [3], which is the upper limit of aerobic exercise and is thought to serve as an accurate and reliable standard for exercise prescription [3], and lower muscle strength/body weight [4] were characteristic in subjects with metabolic syndrome. However, the relation between oxygen uptake at VT and muscle strength in subjects with and without metabolic syndrome remains to be investigated. In this study, we compared both oxygen uptake at VT and muscle strength in Japanese men with and without metabolic syndrome. In addition, the linkage between oxygen uptake at VT and muscle strength was also examined.

Received February 2, 2007; accepted April 19, 2007.
*Corresponding author. Phone:+ 81-86-246-6250; Fax:+81-86-246-6330
E-mail:center@okakenko.jp (N. Miyatake)

Subjects and Methods

Subjects. We used retrospective data of 226 Japanese men with metabolic syndrome and 265 Japanese men without metabolic syndrome, aged 21-

77 years from a data base of 14,345 subjects. All subjects met the following criteria: (1) they had received an annual health checkup from June 1997 to May 2006 at Okayama Southern Institute of Health; (2) they had received a fasting blood examination, a cardiopulmonary exercise test and muscle strength measurements as part of their annual health checkups; and (3) they provided informed consent. Ethical approval for the study was obtained from the Ethical Committee of Okayama Health Foundation.

Oxygen uptake at VT. A graded ergometer exercise protocol [5] had been carried out at the subjects' checkups. After breakfast (2 h), resting ECG was recorded and blood pressure was measured. All subjects were then given a graded exercise after 3 min of pedaling on an unloaded bicycle ergometer (Excalibur V2.0, Lode BV, Groningen, Netherlands). The profile of incremental workloads was automatically defined by the methods of Jones [5], in which the workloads reach the predicted $\dot{V}O_2$max in 10 min. A pedaling cycle of 60 rpm was maintained. Loading was terminated when the appearance of symptoms forced the subject to stop. During the test, ECG was monitored continuously together with the recording of heart rate. Expired gas was collected, and rates of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured breath-by-breath using the cardiopulmonary gas exchange system (Oxycon Alpha, Mijnhrdt b.v., Netherlands). The ventilatory threshold (VT) was determined by the standard of Wasserman *et al.* [6], Davis *et al.* [7] and the V-slope method of Beaver [8] from $\dot{V}O_2$, $\dot{V}CO_2$, and minute ventilation ($\dot{V}E$).

Measurements of muscle strength. To assess muscle strength, grip and leg strength had been measured. Grip strength was measured using THP-10 (SAKAI, Tokyo, Japan), while leg strength was measured by COMBIT CB-1 (MINATO, Osaka, Japan). Isometric leg strength was measured as follows: the subject sat in a chair, grasping the armrest in order to fix the body position. The dynamometer was then attached to the subject's ankle joint by a strap. Next, the subject extended the leg to 60 degrees [9]. To standardize the influence of the total body weight, we calculated the muscle strength (kg) per body weight (kg) [10].

Anthropometric measurements. Anthropometric parameters *i.e.* height, weight, and waist circumference were measured. The waist circumference was measured at the umbilical level.

Definition of metabolic syndrome. Metabolic syndrome was defined, among men with a waist circumference in excess of 85 cm, as the appearance of 2 or more of the following symptoms: 1) dyslipidemia: triglycerides $\geqq$ 150 mg/dl and/or HDL cholesterol $<$ 40 mg/dl, 2) high blood pressure: blood pressure $\geqq$ 130/85 mmHg, and 3) impaired glucose tolerance: fasting plasma glucose $\geqq$ 110 mg/dl [1].

Statistical analysis. Data are expressed as means $\pm$ standard deviation (SD) values. A comparison of parameters between the 2 groups was made using the unpaired *t*-test and covariance analysis. Simple correlation analysis was performed as well to test for the significance of the linear relationship among continuous variables: $p < 0.05$ was considered to be statistically significant.

Results

The measurements of oxygen uptake at VT and muscle strength in subjects with and without metabolic syndrome are indicated in the Table 1. There was no significant difference in age between subjects with and without the syndrome. Body weight and waist circumference in subjects with metabolic syndrome were higher than those in subjects without the syndrome. In subjects with metabolic syndrome, oxygen uptake at VT, grip strength/body weight and leg strength/body weight (WBI: weight bearing index) were significantly lower than those without the syndrome. Leg strength in subjects with metabolic syndrome was significantly higher than that without the syndrome.

To avoid the influence of muscle strength on oxygen uptake at VT, we used WBI as a covariate and compared oxygen uptake at VT using covariance analysis. In subjects with metabolic syndrome, oxygen uptake at VT showed comparable levels to that of subjects without the syndrome. The differences in oxygen uptake at VT between men with and without metabolic syndrome did not show statistical significance after adjusting for other parameters of muscle strength *i.e.* grip strength, leg strength and muscle strength/body weight. In turn, to eliminate the influence of oxygen uptake at VT on muscle strength, we used oxygen uptake at VT as a covariate and compared muscle strength. After adjusting for oxygen uptake at VT, no significant dif-

ference in leg strength and muscle strength/body weight was observed between Japanese men with and without metabolic syndrome.

We investigated the relationship between oxygen uptake at VT and the parameters of muscle strength and muscle strength/body weight. Oxygen uptake at VT was weakly correlated with muscle strength and muscle strength/body weight parameters in metabolic syndrome, non-metabolic syndrome and all subjects (Table 2).

Discussion

We investigated the linkage between oxygen uptake at VT and muscle strength in metabolic syndrome.

In some of the literature, cardiorespiratory fitness and muscle strength are closely associated with metabolic syndrome [11–14]. There are few studies focusing on the reciprocal effect of oxygen uptake at VT and muscle strength on metabolic syndrome. Jurca R *et al.* have reported examining the associations for muscle strength with the prevalence of metabolic syndrome using the National Cholesterol Education Program definition [14]. They concluded that muscle strength has an inverse association with metabolic syndrome, but the association was attenuated when further adjusted for cardiorespiratory fitness. In this study, using the new Japanese criteria for metabolic syn-

Table 1 Comparison of parameters between Japanese men with and without metabolic syndrome

	Metabolic syndrome (+)	Metabolic syndrome (−)	*p*	*p*	*p*
Number of subjects	226	265	Unpaired t test	Adjusting for WBI	Adjusting for VT
Age	49.1 ± 10.5	49.3 ± 11.1	0.8428		
Height (cm)	168.6 ± 5.8	168.3 ± 5.7	0.5756		
Body weight (kg)	81.2 ± 12.8	71.9 ± 12.1	< 0.0001		
Waist circumference (cm)	95.6 ± 8.4	85.9 ± 9.2	< 0.0001		
Oxygen uptake at VT (ml/kg/min)	13.2 ± 2.2	14.8 ± 3.4	< 0.0001	0.0611	
Right grip strength (kg)	44.5 ± 8.3	43.5 ± 8.6	0.1792		0.5528
Left grip strength (kg)	42.6 ± 7.9	42.0 ± 8.0	0.4282		0.5790
Leg strength (kg)	68.2 ± 18.1	64.9 ± 17.5	0.0405		0.7202
Right grip strength (kg)/body weight (kg)	0.55 ± 0.10	0.61 ± 0.11	< 0.0001		0.1377
Left grip strength (kg)/body weight (kg)	0.53 ± 0.10	0.59 ± 0.10	< 0.0001		0.1381
WBI	0.84 ± 0.20	0.90 ± 0.20	0.0008		0.9420

VT: Ventilatory threshold
WBI: Weight bearing index [leg strength (kg)/body weight (kg)]

Table 2 Simple correlation analysis between oxygen uptake at VT and muscle strength parameters

	Total		Metabolic syndrome (+)		Metabolic syndrome (−)	
	r	*p*	r	*p*	r	*p*
Right grip strength (kg)	0.160	0.0004	0.199	0.0026	0.180	0.0033
Left grip strength (kg)	0.152	0.0007	0.175	0.0082	0.170	0.0055
Leg strength (kg)	0.145	0.0013	0.140	0.0350	0.204	0.0008
Right grip strength (kg)/body weight (kg)	0.365	< 0.0001	0.281	< 0.0001	0.345	< 0.0001
Left grip strength (kg)/body weight (kg)	0.350	< 0.0001	0.248	0.0002	0.330	< 0.0001
WBI	0.336	< 0.0001	0.212	0.0013	0.371	< 0.0001

VT: Ventilatory threshold
WBI: Weight bearing index [leg strength (kg)/body weight (kg)]

drome, leg strength was found to be significantly higher in subjects with than in those without the syndrome. Oxygen uptake at VT and muscle strength/body weight were significantly lower in subjects with metabolic syndrome than in those without it. However, the differences weren't significant when adjusted for WBI or oxygen uptake at VT.

Kawano H *et al.* evaluated the effects of moderate resistance training as well as combined resistance and aerobic training intervention on carotid arterial compliance. They concluded that aerobic training could prevent the stiffening of carotid arteries caused by resistance training [15]. Sandvik L *et al.* reported that physical fitness was a graded, independent, long-term predictor of mortality from cardiovascular causes in healthy, middle-aged men [16]. Metter EJ *et al.* also reported that lower and declining muscle strength was associated with increased mortality, independent of physical activity and muscle mass [17]. These findings suggest that a combination of aerobic exercise and resistance training should be considered for primary prevention of metabolic syndrome. In this study, we found lower levels of oxygen uptake at VT and lower muscle strength/body weight in subjects with metabolic syndrome, as previously reported [3, 4]. However, the differences were not significant after adjusting for muscle strength parameters and oxygen uptake at VT. In addition, oxygen uptake at VT was weakly correlated with muscle strength and muscle strength/body weight parameters. Therefore, oxygen uptake at VT and muscle strength partially depend on each other in subjects with and without the syndrome. Especially in subjects with metabolic syndrome, lower WBI was also noted. A low level of WBI and reduced exercise activity seems to accelerate metabolic syndrome. Although aerobic exercise has traditionally been advocated as the most suitable for reducing fat mass [18, 19], it is difficult for subjects with metabolic syndrome to support the entire body's weight; it is also difficult for subjects with metabolic syndrome to carry out aerobic exercise *i.e.* walking and jogging. A combination of aerobic exercise and resistance training might be considered for preventing and improving metabolic syndrome. It is important for metabolic syndrome patients to maintain or maximize the muscle strength of their lower limbs as well as to carry out aerobic exercise.

Potential limitations remain in our study. First, the cross-sectional study design as well as the small sample size in our study makes it difficult to infer causality between metabolic syndrome, oxygen uptake at VT and muscle strength. Second, we could not accurately prove the mechanism of linkage between oxygen uptake at VT and muscle strength.

In conclusion, both aerobic exercise and resistance training are necessary for the prevention and treatment of metabolic syndrome.

Acknowledgments. This research was supported in part by Research Grants from the Ministry of Health, Labor, and Welfare, Japan (H18-J-W-002).

References

1. Definition and the diagnostic standard for metabolic syndrome-Committee to evaluate diagnostic standards for metabolic syndrome. Nippon Naika Gakkai Zasshi (2005) 94: 794–809 (in Japanese).
2. Miyatake N, Kawasaki Y, Nishikawa H, Takenami S and Numata T: Prevalence of metabolic syndrome in Okayama prefecture, Japan. Intern Med (2006) 45: 107–108.
3. Miyatake N, Saito T, Wada J, Miyachi M, Tabata I, Matsumoto S, Nishikawa H, Makino H and Numata T: Comparison of ventilatory threshold and exercise habits between Japanese men with and without metabolic syndrome. Diabetes Res Clin Prac (2007) 77: 314–319.
4. Miyatake N, Wada J, Saito T, Nishikawa H, Matsumoto S, Miyachi M, Makino H and Numata T: Comparison of muscle strength between Japanese men with and without metabolic syndrome. Acta Med Okayama (2007) 61: 99–102.
5. Jones NL, Makrides L, Hitchcock C, Chypchar T and McCartney N: Normal standards for an incremental progressive cycle ergometer test. Am Rev Respir Dis (1985) 131: 700–708.
6. Wasserman K, Whipp BJ, Koyl SN and Beaver WL: Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol (1973) 35: 236–243.
7. Davis JA, Frank MH, Whipp BJ and Wasserman K: Anaerobic threshold alterations caused by endurance training in middle-aged men. J Appl Physiol (1979) 46: 1039–1046.
8. Beaver WL, Wasserman K and Whipp BJ: A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol (1986) 60: 2020–2027.
9. Kigawa A, Yamamoto T, Koyama Y, Kageyama S and Arima K: Evaluation of knee extensor strength for prevention of sports injury. Japan Ortho Soc Sports Med (1987) 6: 141–145 (in Japanese).
10. Miyatake N, Takahashi K, Wada J, Nishikawa H, Morishita A, Suzuki H, Kunitomi M, Makino H, Kira S and Fujii M: Changes in serum leptin concentrations in overweight men after exercise. Diabetes Obes Metab (2004) 6: 332–337.
11. Laaksonen DE, Lakka HM, Salonen JT, Niskanen LK, Rauramaa R and Lakka T: Low levels of leisure-time physical activity and cardiorespiratory fitness predict development of the metabolic syndrome. Diabetes Care (2002) 25: 1612–1618.
12. Katzmarzyk PT, Leon AS, Wilmore JH, Skinner JS, Rao DC, Rankinen T and Bouchard C: Targeting the metabolic syndrome with exercise: evidence from the HERITAGE Family Study. Med

Sci Sports Exerc (2003) 35: 1703–1709.
13. Jurca R, Lamonte MJ, Church TS, Earnest CP, Fitzgerald SJ, Barlow CE, Jordan AN, Kampert JB and Blair SN: Associations of muscle strength and fitness with metabolic syndrome in men. Med Sci Sports Exerc (2004) 36: 1301–1307.
14. Jurca R, lamonte MJ, Barlow CE, Kampert JB, Church TS and Blair SN: Association of muscular strength with incidence of metabolic syndrome. Med Sci Sports Exerc (2005): 37: 1849–1855.
15. Kawano H, Tanaka H and Miyachi M: Resistance training and arterial compliance: keeping the benefits while minimizing the stiffning. J Hypertens (2006) 24: 1753–1759.
16. Sandvik L, Erikssen J, Thaulow E, Erikssen G, Mundal R and Rodahl K: Physical fitness as a predictor of mortality among healthy, middle-aged Norwegian men. N Engl J Med (1993) 25: 533–537.
17. Metter EJ, Talbot LA, Schrager M and Conwit R: Skeletal muscle strength as a predictor of all-cause mortality in healthy men. J Gerontol A Biol Sci Med Sci (2002) 57: B359–B365.
18. Ballor DL and Kessey RE: A meta-analysis of the factors affecting exercise induced changes in body mass, fat mass, and fat-free mass in males and females. Int J Obesity (1991) 15: 717–726.
19. Miyatake N, Nishikawa H, Morishita A, Kunitomi M, Wada J, Suzuki H, Takahashi K, Makino H, Kira S and Fujii M: Daily walking reduces visceral adipose tissue areas and improves insulin resistance in Japanese obese subjects. Diabetes Res Clin Pract (2002) 58: 101–107.