Relations Between Strength and Endurance of Leg Skeletal Muscle and Cardiopulmonary Exercise Testing Parameters in Patients With Chronic Heart Failure

Kengo SUZUKI, MD
Kazuto OMIYA, MD
Sumio YAMADA, PhD[*1]
Toru KOBAYASHI, PT[*2]
Noriyuki SUZUKI, MD
Naohiko OSADA, MD
Fumihiko MIYAKE, MD,

Abstract

Objectives. The relations between muscle strength, muscle endurance, and cardiopulmonary parameters were investigated in patients with chronic heart failure.

Methods. The subjects comprised 33 outpatients with stable chronic heart failure (27 men, 6 women, mean age 60.3 ± 12.7 years). A pedal-type isokinetic device was used throughout the study. The safety of the study protocol was examined first. Maximum muscle power (peak power), an index of muscle strength, was measured for 6 consecutive revolutions (3 revolutions of each leg). The strength decrement index (SDI) was measured for 20 consecutive maximal revolutions (10 revolutions in each leg). The SDI is an index of muscle endurance and compares the mean power for revolutions 9 and 10 with that for revolutions 2 and 3. Each subjects underwent symptom-limited cardiopulmonary exercise testing with a cycle ergometer on another day.

Results. No subject experienced continuous abnormal heart rate or blood pressure response, chest pain, ischemic ST-T change, or severe arrhythmia. The peak power and the SDI were correlated with the anaerobic threshold ($r = 0.42$, 0.52, respectively), with peak oxygen uptake ($r = 0.66$, 0.61), and with the increase in oxygen uptake per unit increase in work rate ($r = 0.43$, 0.63). However, the slope of the ventilation equivalent to carbon dioxide output was correlated only with the SDI ($r = -0.54$) and the time constant for the oxygen uptake decrease was correlated only with the peak power ($r = -0.46$).

Conclusions. Peak functional capacity depends on both muscle strength and endurance, and subjective symptoms in daily activity, especially dyspnea on exertion, depend mainly on muscle endurance in patients with chronic heart failure.

J Cardiol 2004 Feb; 43(2): 59−68

Key Words
■**Muscle, skeletal** ■**Exercise tests** ■**Heart failure** ■**Ventilation**

聖マリアンナ医科大学 循環器内科：〒216−8511 川崎市宮前区菅生2−16−1；*1名古屋大学医学部 保健学科，名古屋；*2聖マリアンナ医科大学病院 リハビリテーション部，川崎

Division of Cardiology, Department of Internal Medicine, St. Marianna University School of Medicine, Kawasaki; *1School of Health Sciences, Nagoya University, School of Medicine, Nagoya; *2Department of Rehabilitation Medicine, St. Marianna University Hospital, Kawasaki

Address for correspondence: OMIYA K, MD, Division of Cardiology, Department of Internal Medicine, St. Marianna University School of Medicine, Sugao 2−16−1, Miyamae-ku, Kawasaki 216−8511

Manuscript received May 12, 2003; revised August 14 and October 8, 2003; accepted October 8, 2003

PT = physical therapist

INTRODUCTION

Many investigators have evaluated the effectiveness of exercise training in terms of functional capacity in patients with chronic heart failure whose cardiac and skeletal muscle functions were impaired[1-3]. However, even though a slight increase in stroke volume with exercise training has been observed, no improvement in myocardial contractility with exercise training has been found. The muscle hypothesis[4] suggests that the functional improvement after exercise training is not due mainly to a central effect such as cardiac performance but to peripheral effects such as adjustments of blood flow in skeletal muscle or of muscle function. Considering the aging population of chronic heart failure patients, it is important to identify the skeletal muscle function that predominantly determines functional capacity in the normal elderly population.

There are several methods to evaluate skeletal muscle functions, such as ^{31}P-nuclear magnetic resonance spectroscopy for evaluating aerobic metabolic competence[5], and near infrared spectroscopy for evaluating the relative change in the state of oxygenation and deoxygenation[6]. However, these methods have disadvantages for repetitive measurements, such as the need for highly skilled operators and high cost. Therefore, isometric muscle strength expressed by peak joint torque has been used clinically as an index for skeletal muscle functional capacity[7,8], and no analysis of muscle endurance for repetitive exercise has been done. The strength decrement index (SDI), which was first reported by Clarke *et al*[9], can be used in isokinetic exercise as a simple measure of muscle endurance.

This study was designed to assess the relations between several parameters measured in cardiopulmonary exercise testing, and muscle strength and endurance in terms of skeletal muscle function. The safety of measuring isokinetic muscle strength and muscle endurance with the present equipment was first evaluated because it had not been previously done.

Table 1 Characteristics of patients

Number of patients	33
Mean age (yr)	60.3±12.7
Male/female	27/6
Etiology	
Dilated cardiomyopathy	19
Old myocardial infarction	9
Anterior	5
Inferior	4
Number of diseased vessels	
One-vessel disease	4
Two-vessel disease	4
Three-vessel disease	1
Valvular heart disease	4
Moderate AR	1
Mild MS	1
Severe MR	2
Hypertensive heart disease	1
Left ventricular ejection fraction (%)	38.9±14.9
Brain natriuretic peptide (pg/ml)	174.7±166.3
NYHA classification	1.93±0.70
Medication	
Nitrates	5
Calcium channel antagonists	2
Angiotensin converting enzyme inhibitors	14
Angiotensin II receptor antagonists	15
Beta blockers	9

Continuous values are mean±SD.
AR=aortic valve regurgitation; MS=mitral valve stenosis; MR=mitral valve regurgitation; NYHA=New York Heart Association.

SUBJECTS AND METHODS

Subjects

This study included 33 chronic heart failure outpatients (27 men and 6 women, mean age 60.3±12.7 years) who had typical symptoms and various degrees of left ventricular dysfunction from underlying cardiac disorders. They were all stable clinically and none had been hospitalized or had a change in medication during the previous three or more months. Any subjects who met the European Society of Cardiology criteria for exercise training contraindications in patients with chronic heart failure[10] were excluded from the study. Patient characteristics are listed in **Table 1**.

The safety of our protocol was evaluated in 23 of the 33 patients (17 men, 6 women, mean age 59.4±13.8 years). The underlying diseases were dilated cardiomyopathy in 13 patients, previous myocardial infarction in 7 (4 anterior, 3 inferior), and preoperative valvular heart disease in 3 (1 mitral stenosis, 1 mitral regurgitation, 1 aortic regurgitation).

The study protocol was approved by the Committee of Human Investigation of our

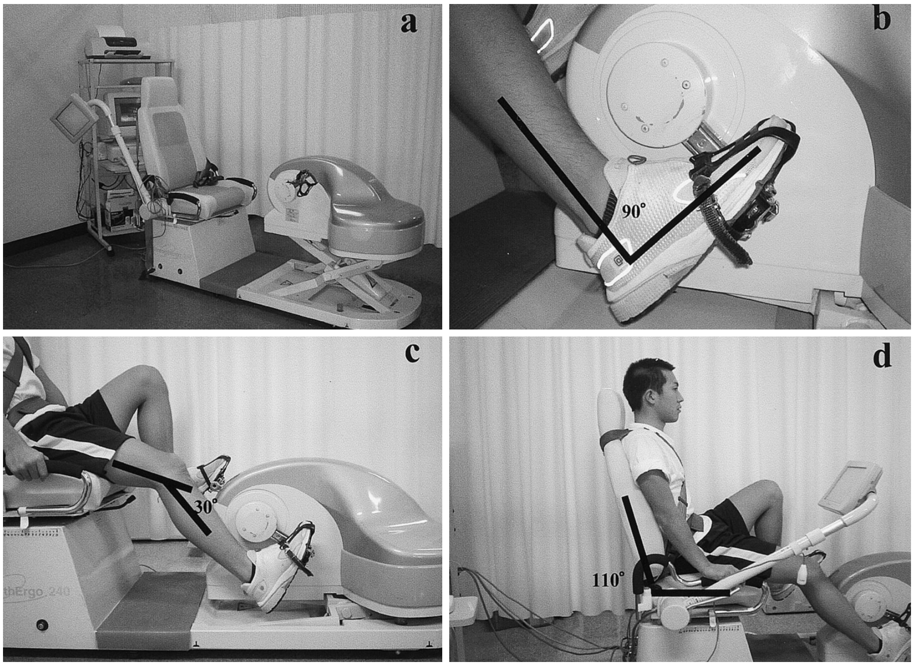

Fig. 1 Photographs showing the complete pedal-type isokinetic device StrengthErgo240™ (SE240)
a: Over view. *b*: The ankle joint is set to 90 degrees of flexion. *c*: Seat position is set to ensure a 30 degree of knee flexion on leg extension. *d*: The angle of the backrest is set at 110 degrees to the horizontal plane.

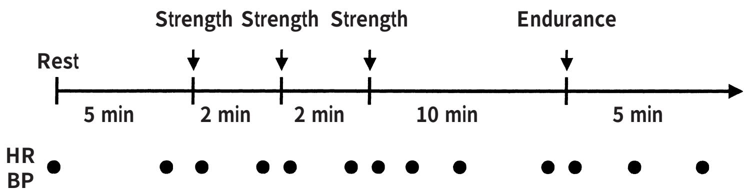

Fig. 2 Schema of muscle strength and muscle endurance measurements
HR = heart rate; BP = blood pressure.

University, and written informed consent was obtained from each patient before participation in the study.

Study equipment

A StrengthErgo240™(SE240) pedal type isokinetic device (Mitsubishi Electric Corporation) was used throughout this study (**Fig. 1**). The measurement posture was a sitting position with backrest. The angle of the backrest was set at 110 degrees to the horizontal plane. The position of the seat was set to allow 30-degree knee flexion on leg extension. The exercise started with the left leg at the maximal flexed knee position. The body and pelvis were fixed to the seat with a belt, and the subject was asked to grasp the grips at the side of the seat during measurements. The pedal crank length was adjusted to 172 mm.

Measurements of muscle strength and endurance

To measure muscle strength, subjects were asked to pedal 6 consecutive revolutions (3 revolutions with each leg) with maximal effort at 50 revolutions per minute (rpm) after 5-minute rest (**Fig. 2**). Three sets of measurements were made, with a 2-minute rest between sets. The torque generated at the servomotor during pedaling was measured, and the work was calculated by multiplying the torque by pedaling time. The area enclosed by the parabola and horizontal bar in **Fig. 3** is a measure of muscle power. The maximum power (peak power) was used as an index of muscle strength.

Following muscle strength measurements, muscle endurance was measured after a 10-minute rest. Subjects pedaled for 20 consecutive revolutions (10 revolutions with each leg) at 60 rpm. The power at

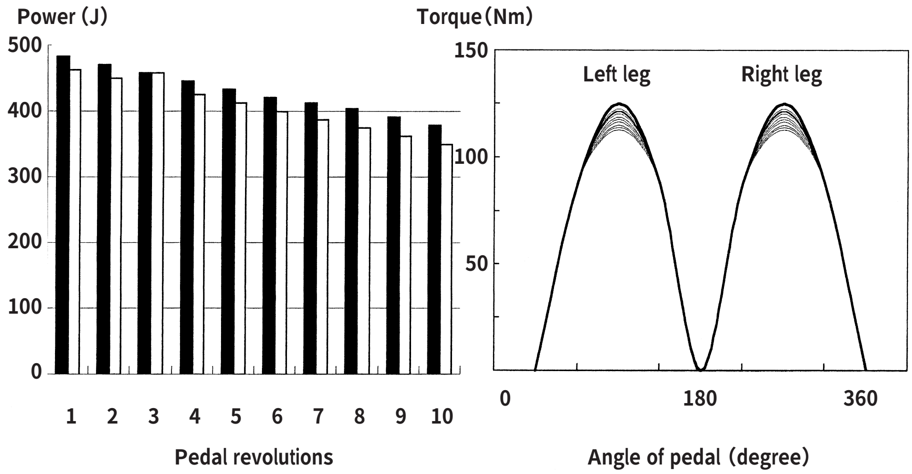

Fig. 3 Schema of strength decrement index measurement
Left: Isokinetic muscle power (J) decreases gradually from the first to 10th revolutions (*Black bars*: Left leg. *White bars*: Right leg).
Right: Isokinetic muscle power is the area enclosed by the parabola and the horizontal bar. Power decreases gradually with each revolution. Strength decrement index (%) is calculated from the mean power value obtained from the second and third and the ninth and 10th revolutions.

the first revolution was ignored because the speed at the first revolution usually did not reach the target speed. The SDI was calculated with the formula[9] (**Fig. 3**) : SDI = (S9-10) × 100/S2-3, where S9-10 is the mean power of the ninth and 10th revolutions, and S2-3 is that of the second and third revolutions. The SDI was calculated for each leg, and the lower value was used for evaluation. The peak power was expressed as the value divided by body weight (J/kg), and muscle endurance was expressed as the SDI (%). Preliminary experiments found that the SDI at 60 rpm was significantly lower than that at 50 rpm in patients with heart failure and that differences in the SDI are more demonstrable at 60 rpm.

Single-lead electrocardiographic monitoring was continued throughout the muscle strength and endurance measurements. Blood pressure was measured before, immediately after, and 1.5 min after strength measurements; and immediately after, 3, and 5 min after the endurance measurements. The rate pressure product was calculated as the product of heart rate and systolic blood pressure. Patients were asked to assign a rating to their perceived exertions of the chest and legs separately on a 6 to 20 category scale[11] during the measurements.

The criteria for terminating both the muscle strength and endurance tests were development of chest pain, severe dyspnea, severe fatigue, sustained blood pressure drop, sustained ventricular tachycardia, short runs of three or more ventricular premature contractions, pallor, and dizziness.

Cardiopulmonary exercise testing

Two muscle function tests and a cardiopulmonary exercise test were carried out on different days within 2 weeks. The cardiopulmonary exercise test was performed on a CORIVAL 400 sitting cycle ergometer (LODE B.V.) with a ramp exercise protocol. Exercise load intensity was increased gradually and linearly by 1 W per 6 sec after a 3-minute rest and 4-minute warm-up stage of 0 or 20 W. Heart rate response, ST-T changes, and arrhythmias during the exercise test were monitored continuously with a ML-5000 stress test system (Fukuda Denshi Co.), and standard 12-lead electrocardiography was performed every minute. Blood pressure was also recorded with a STBP-780 automated sphygmomanometer (Colin Co.) every minute.

The criteria for halting exercise testing in this study were according to the guidelines of the American College of Sports Medicine[12]. The expired gas was analyzed in the sitting position continuously for 5 min of a recovery phase without cool-down exercise to measure the time constant of the oxygen uptake ($\dot{V}O_2$) decrease in the early recovery phase (τ off).

Table 2 Heart rate, blood pressure and rate pressure product changes during measurements

	Rest	First strength	Second strength	Third strength	Endurance
Heart rate (beats/min) □	76.9±9.5 □	100.0±18.1 □	104.0±21.3 □	102.9±18.7 □	119.9±28.4 □
Systolic blood pressure (mmHg) □	123.0±18.8 □	128.6±19.5 □	128.8±20.3 □	129.8±21.0 □	136.3±21.6 □
Diastolic blood pressure (mmHg) □	71.7±12.3□	72.5±10.3□	73.8±9.6 □	72.9±11.0□	73.5±10.9□
Rate pressure product ($\times 10^2$) □	93.4±16.4	129.4±37.8	134.3±38.3	134.4±38.0	165.9±59.5

Values are mean±SD.

Expired gas analysis was performed throughout testing using a breath-by-breath basis with an AE-280 cart (Minato Medical Science). The quantities derived from cardiopulmonary exercise testing were anaerobic threshold, peak oxygen uptake (peak $\dot{V}O_2$), slope of the ventilatory equivalent to carbon dioxide output ($\dot{V}CO_2$) [$\dot{V}E/\dot{V}CO_2$ slope], and the change in $\dot{V}O_2$ relative to change in work rate (WR) [$\Delta\dot{V}O_2/\Delta WR$]. $\dot{V}E/\dot{V}CO_2$ slope and τ off were calculated with accessory software on the AE-280.

Statistical analysis

All values are expressed as mean ± standard deviation. Comparison of two parameters used Student's *t*-test, and analysis of the correlation of two parameters used Spearman's single regression. The statistical significance level of measurements was set at less than 5%.

RESULTS

Evaluation of safety in measuring muscle strength and muscle endurance

All subjects completed the protocol without complications. No subject complained of chest symptoms, such as chest pain, chest oppression, or shortness of breath, during the test period. Ratings of perceived exertion during muscle strength measurements ranged from 9 to 16 (mean 12.3 ± 1.5 for the chest, 12.5 ± 1.5 for the legs); and during endurance measurements, ratings of perceived exertion ranged from 11 to 17 (mean 13.5 ± 1.5 for the chest, 13.2 ± 1.7 for the legs).

Heart rate and blood pressure responses are given in **Table 2**. A transient decrease in systolic blood pressure from baseline occured in nine subjects immediately after the measurement of either muscle strength or muscle endurance (mean 7.9 ± 3.1 mmHg). Three of the nine subjects had chronic atrial fibrillation. None of the nine subjects had chest pain or ischemic ST-T changes. Systolic blood pressure in these subjects recovered within 1.5 min after the measurements. The systolic blood pressures in **Table 2** were measured after recovery from blood pressure decreases.

Chronic atrial fibrillation was present in 5 of 23 subjects. Monofocal ventricular premature contractions appeared after the measurements in 10 subjects, and monofocal atrial premature contractions appeared after the measurements in 4 others. Ventricular couplet beats appeared in one subject. No subject had short runs of three or more ventricular premature contractions or ischemic electrocardiogram (ECG) changes after the examination.

Relations between muscle strength and endurance and parameters measured by cardiopulmonary exercise tests

The peak power was 13.4 ± 3.1 J/kg (**Fig. 4**) and the SDI was 85.1 ± 4.8% (**Fig. 5**). The parameters measured by cardiopulmonary exercise tests were anaerobic threshold 14.8 ± 2.8 m*l*/min/kg; peak $\dot{V}O_2$ 21.6 ± 5.7 m*l*/min/kg; $\dot{V}E/\dot{V}CO_2$ slope 32.8 ± 6.8; $\Delta\dot{V}O_2/\Delta WR$ 9.8 ± 2.5 m*l*/W; τ off 62.5 ± 14.6 sec.

Both the peak power and the SDI had significant correlations with the anaerobic threshold ($r = 0.42$, 0.52, respectively), peak $\dot{V}O_2$ ($r = 0.66$, 0.61), $\Delta\dot{V}O_2/\Delta WR$ ($r = 0.43$, 0.63). However, the $\dot{V}E/\dot{V}CO_2$ slope was correlated only with the SDI ($r = -0.54$), and τ off was correlated only with the peak power ($r = -0.46$).

DISCUSSION

Safety of isokinetic muscle power and muscle endurance measurement

Recently, resistance training has been considered safe for cardiac patients, especially patients with ischemic heart disease or patients after coronary artery bypass surgery, because this type of training leads to an increase in diastolic blood pressure that contributes to an increase in coronary blood flow

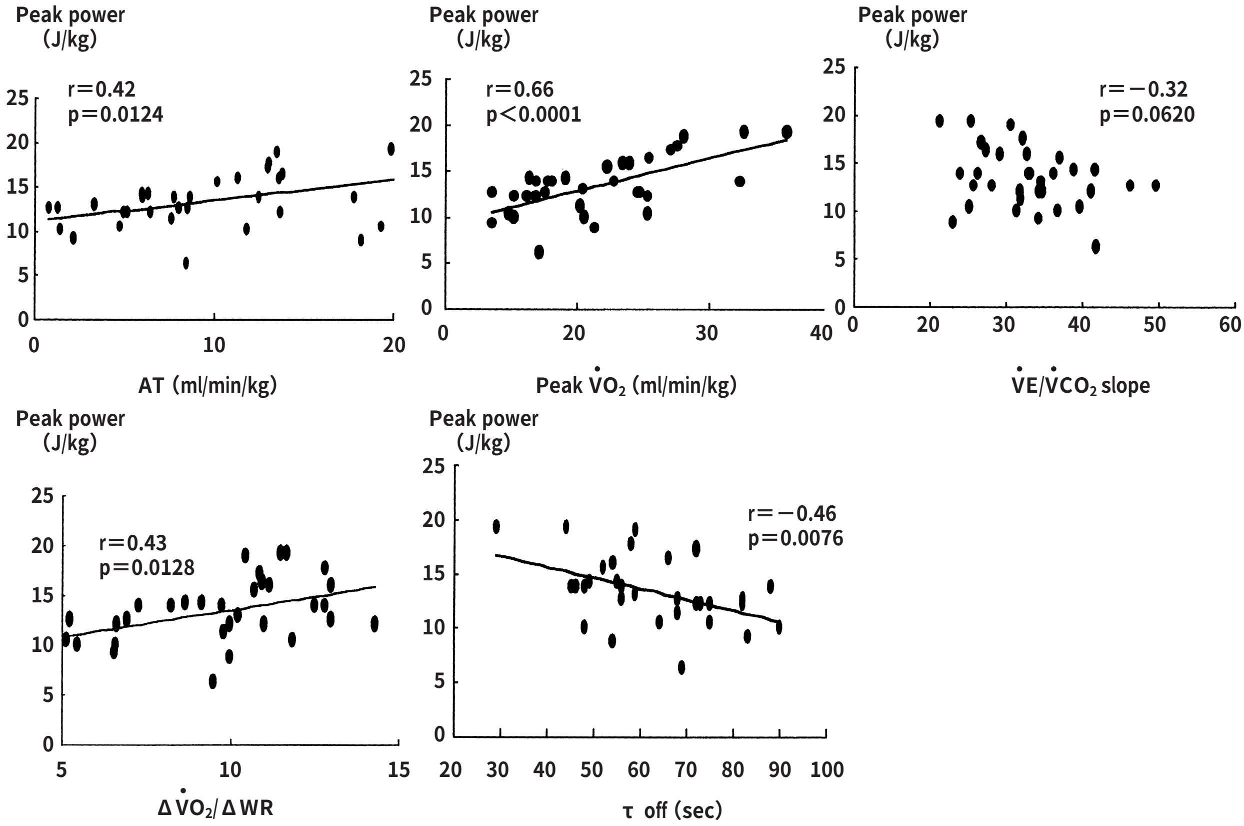

Fig. 4 Correlations between peak power and cardiopulmonary exercise parameters
Positive correlations are observed between peak power and AT, peak $\dot{V}O_2$ and $\Delta\dot{V}O_2/\Delta$ WR. A negative correlation is recognized between peak power and τ off. No correlation is seen between peak power and the $\dot{V}E/\dot{V}CO_2$ slope.
AT = anaerobic threshold ; $\dot{V}O_2$ = oxygen uptake ; $\dot{V}E/\dot{V}CO_2$ slope = slope of the ventilation equivalent to carbon dioxide output ; $\Delta\dot{V}O_2/\Delta$ WR = change in $\dot{V}O_2$ relative to change in work rate ; τ off = time constant for post-exercise $\dot{V}O_2$ decrease.

without a major increase in heart rate[13]. The few reports of resistance training or testing in patients with chronic heart failure indicated that in patients with heart failure in New York Heart Association (NYHA) class I to III and mean left ventricular ejection fraction of 35%[14], no significant differences were found in heart rate and blood pressure responses between the resistance training and stepwise recruitment load exercise tests. The load during isokinetic muscle power and endurance measurements was relatively low because peak heart rate and peak systolic blood pressure in the present study were much lower than peak values obtained from cardiopulmonary exercise testing.

Although several subjects had a transient blood pressure decrease, the cause is uncertain, but may have been due to delayed autoregulation of myocardial blood flow[15]. A single-formula exercise loading and suddenly strenuous exercise test without any warm-up stage caused a lower heart rate, blood pressure, rate pressure product, and left ventricular ejection fraction than the same protocol with a warm-up stage in healthy subjects[15]. The difference was explained by delayed autoregulation of myocardial blood flow, leading to low left ventricular ejection fraction and subendocardial ischemia in the sudden strenuous exercise test without warm-up. The blood pressure decreases were acceptable because of the very short duration and absence of ECG changes or severe arrhythmias.

Although the increases in blood pressure, heart rate, and rate-pressure product from rest to the end of the measurement of muscle endurance were higher than those in the strength measurements, no subject experienced severe arrhythmia or ischemic ECG change. Moreover, patient symptoms accord-

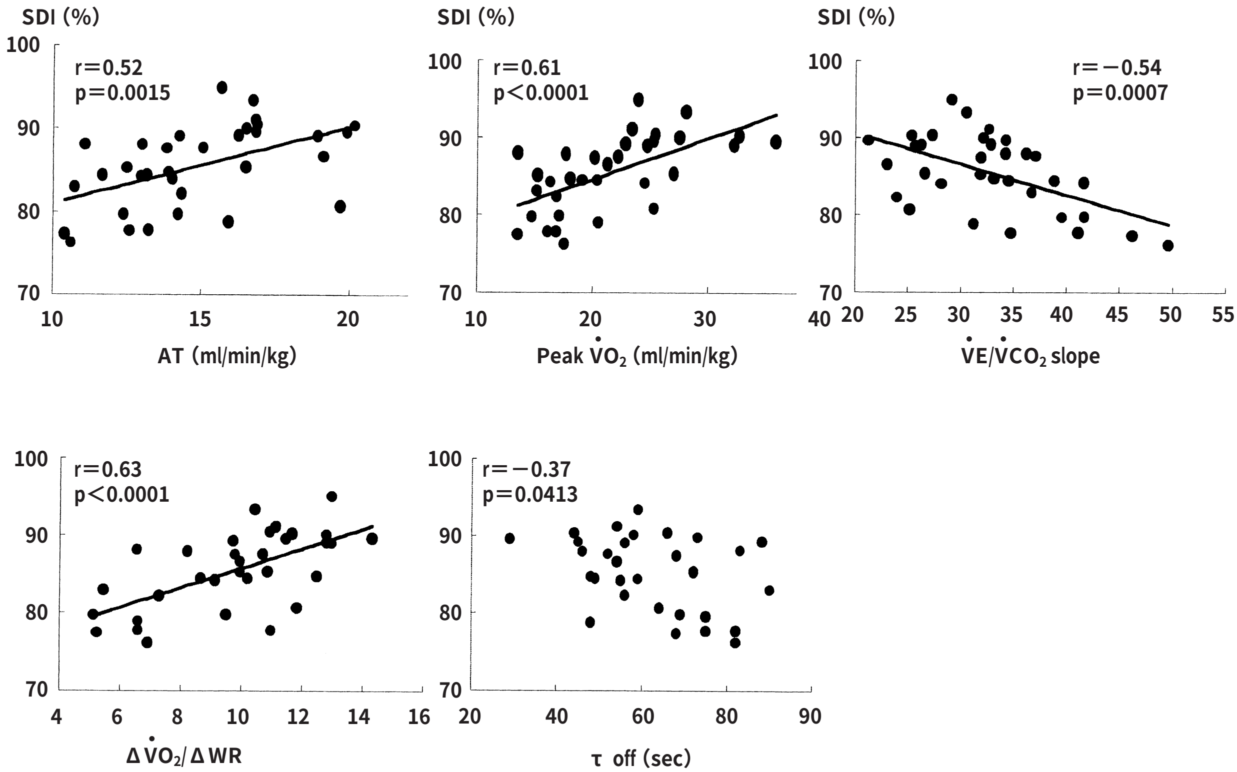

Fig. 5 Correlations between the strength decrement index and cardiopulmonary exercise parameters

Positive correlations are observed between the strength decrement index and AT, peak $\dot{V}O_2$, and $\Delta \dot{V}O_2/\Delta WR$. A negative correlation is noted between the SDI and the $\dot{V}E/\dot{V}CO_2$ slope. No correlation is seen between the strength decrement index and τ off.

SDI = strength decrement index. Other abbreviations as in Fig. 4.

ing to the ratings of perceived exertion were relatively mild. In general, the isokinetic exercise mode is thought to be relatively safe for cardiac patients because the load does not exceed the preset load and pedaling speed is regulated.

Relations between muscle power and muscle endurance and parameters measured by cardiopulmonary exercise testing

Resistance training does not achieve a significant improvement in peak $\dot{V}O_2$ in normal subjects[16,17], but a significant correlation was found between skeletal muscle volume and peak $\dot{V}O_2$ in patients with chronic heart failure[18]. These findings suggest that isokinetic muscle power is related to skeletal muscle volume, which is associated with peak $\dot{V}O_2$ in patients with chronic heart failure. We found that peak $\dot{V}O_2$ correlated with both muscle strength and endurance. The subjects in the present study had only mild heart failure, so possibly had not suffered skeletal muscle atrophy.

The τ off in the early recovery phase reflects the degree of oxygen debt or exercise intensity, and increases with the severity of cardiac dysfunction[19]. The τ off has close negative correlations with anaerobic threshold, peak $\dot{V}O_2$, and $\Delta \dot{V}O_2/\Delta$ WR in patients with left ventricular dysfunction[20]. Therefore, τ off may be a better predictor of hemodynamic abnormalities in cardiac diseases. We inferred that improvement of muscle strength might contribute to improved peak $\dot{V}O_2$ and reduced τ off because isokinetic muscle strength was correlated significantly with τ off. We suggest that improvement of isokinetic muscle strength is associated with improvement of muscle volume, which contributes to an increase in venous return and cardiac output during exercise.

The $\dot{V}E/\dot{V}CO_2$ slope increases with the severity of heart failure and the level of dead space ventilation, so is a useful index for dyspnea during exercise[21] and a strong predictor of mortality in patients with chronic heart failure[22]. A study of the relation between functional capacity and isokinetic muscle strength found that muscle strength had a significant negative correlation with the $\dot{V}E/\dot{V}CO_2$ slope but not with peak $\dot{V}O_2$[7]. Our findings that muscle endurance had a significant correlation with the $\dot{V}E/\dot{V}CO_2$ slope and that muscle strength was not correlated with the $\dot{V}E/\dot{V}CO_2$ slope differ from the previous findings[7]. The subjects in the previous study comprised 10 patients with chronic heart failure patients and 10 healthy controls who had very good values of peak $\dot{V}O_2$ and muscle peak torque. The $\dot{V}E/\dot{V}CO_2$ slope may be correlated more closely with muscle power in normal subjects than in heart failure patients.

Both dyspnea and the $\dot{V}E/\dot{V}CO_2$ slope were improved in patients with chronic heart failure after aerobic exercise training and low-level leg resistance training[23]. The peripheral muscle might be the location of the key transducer for the sensations of dyspnea and fatigue in cardiac patients rather than cardiac function. Our finding of a close correlation between muscle endurance and the $\dot{V}E/\dot{V}CO_2$ slope supports this hypothesis.

In patients with chronic heart failure, the blood supply to active skeletal muscle decreases due to low cardiac output, and oxygen utilization in active skeletal muscle is increased. As a result, the arteriovenous oxygen difference increases and compensatory blood flow redistribution occurs to increase oxygen transport to active skeletal muscle. Therefore, low $\Delta\dot{V}O_2/\Delta WR$ in patients with chronic heart failure implied low oxygen consumption at a constant workload. In our study, $\Delta\dot{V}O_2/\Delta WR$ was correlated with muscle endurance rather than with isokinetic muscle strength. This result suggests that muscle endurance, which is the ability to continue muscle activity under a constant workload, is associated with adequate oxygen transport to peripheral tissue.

Study limitations

The subject population was small and inhomogeneous. Moreover, all patients had mild heart failure (mean NYHA classification was 1.93 ± 0.7). These subjects may not have suffered any marked decrease in muscle strength, muscle endurance, and functional capacity. Thus, further investigation of patients with more severe heart failure is needed.

Clinical implications

The SDI had close correlations with both anaerobic threshold and the $\dot{V}E/\dot{V}CO_2$ slope, which are considered to be related to the quality of daily activity including dyspnea on exertion. Training to increase muscle endurance and muscle strength should be encouraged to improve the quality of life or dyspnea in patients with chronic heart failure. A training program for increasing muscle endurance may be developed with the equipment and the protocol used in this study.

CONCLUSIONS

Isokinetic muscle strength and endurance measurements can be made safely in patients with stable chronic heart failure. The peak $\dot{V}O_2$ in patients with chronic heart failure is correlated with both muscle strength and endurance, whereas subjective symptoms in daily activity including dyspnea are correlated mainly with muscle endurance.

Acknowledgements

We wish to thank S. Watanabe, PT, K. Izawa, PT, and the cardiac rehabilitation staff in the Department of Rehabilitation Medicine, St. Marianna University Hospital, for their technical assistance in this study.

要　約

慢性心不全患者における下肢骨格筋力，筋持久力と心肺運動負荷試験諸指標との関連

鈴木　健吾　　大宮　一人　　山田　純生　　小 林　 亨
鈴木　規之　　長田　尚彦　　三宅　良彦

目　的: 慢性心不全患者の運動耐容能を規定する因子として，下肢骨格筋の重要性が報告されているが，心肺運動負荷試験における指標との具体的な関連を検討した報告は少ない．本検討は，慢性心不全患者の下肢の筋力，ならびに筋持久力と呼気ガス分析諸指標との関連を明らかにすることを目的とした．

方　法: 対象は，状態の安定した慢性心不全患者33例(男性27例，女性6例，平均年齢60.3±12.7歳)である．ペダル駆動型等速性筋力測定装置を用い，初めに本プロトコルの安全性を検討した．6回連続ペダル駆動(各脚3回)における最高仕事量(最高パワー)を筋力の指標，また20回連続駆動(各脚10回)における仕事量の減衰率をstrength decrement index(SDI)とし，筋持久力の指標とした．SDIは9および10回転目のパワーの平均と2および3回転目のパワーの平均から求めた．また，別の日に自転車エルゴメーターを用いた症候限界性心肺運動負荷試験を行った．

結　果: 本プロトコル中に心拍数，血圧の過度の反応はなく，胸痛やST-T異常，重症不整脈も出現しなかった．最高パワーおよびSDIはいずれも，嫌気性代謝閾値(それぞれ$r=0.42$，$r=0.52$)，最高酸素摂取量($r=0.66$，$r=0.61$)および仕事率の増加量に対する酸素摂取量の増加量($r=0.43$，$r=0.63$)と有意な相関を有した．しかしながら，二酸化炭素排出量に対する換気当量の傾きはSDIのみと($r=-0.54$)，運動後酸素摂取量減衰時定数($r=-0.46$)は最高パワーのみと相関した．

結　論: 慢性心不全患者の最高身体能力は筋力および筋持久力の両者に依存しており，これに対して日常生活における自覚症状，とくに労作時の呼吸困難感は主に筋持久力に依存していると考えられた．

J Cardiol 2004 Feb; 43(2): 59－68

References

1) Adamopoulos S, Coats AJS, Brunotte F, Arnolda L, Meyer T, Thompson CH, Dunn JF, Stratton J, Kemp GJ, Radda GK, Rajagopalan B: Physical training improves skeletal muscle metabolism in patients with chronic heart failure. J Am Coll Cardiol 1993; **21**: 1101－1106
2) Belardinelli R, Georgiou D, Scocco V, Barstow TJ, Purcaro A: Low intensity exercise training in patients with chronic heart failure. J Am Coll Cardiol 1995; **26**: 975－982
3) Tyni-Lenné R, Gordon A, Jansson E, Bermann G, Sylvén C: Skeletal muscle endurance training improves peripheral oxidative capacity, exercise tolerance, and health-related quality of life in women with chronic congestive heart failure secondary to either ischemic cardiomyopathy or idiopathic dilated cardiomyopathy. Am J Cardiol 1997; **80**: 1025－1029
4) Coats AJS, Clark AL, Piepoli M, Volterrani M, Poole-Wilson PA: Symptoms and quality of life in heart failure: The muscle hypothesis. Br Heart J 1994; **72**(Suppl): S36－S39
5) Wilson JR, Fink L, Maris J, Ferraro N, Power-Vanwart J, Eleff S, Chance B: Evaluation of energy metabolism in skeletal muscle of patients with heart failure with gated phosphorus-31 nuclear magnetic resonance. Circulation 1985; **71**: 57－62
6) Terakado S, Takeuchi T, Miura T, Sato H, Nishioka N, Fujieda Y, Kobayashi R, Ibukiyama C: Early occurrence of respiratory muscle deoxygenation assessed by near-infrared spectroscopy during leg exercise in patients with chronic heart failure. Jpn Circ J 1999; **63**: 97－103
7) Clark A, Rafferty D, Arbuthnott K: Relationship between isokinetic muscle strength and exercise capacity in chronic heart failure. Int J Cardiol 1997; **59**: 145－148
8) Yamasaki H, Yamada S, Tanabe K, Osada N, Nakayama M, Itoh H, Murayama M: Effects of weight training on muscle strength and exercise capacity in patients after myocardial infarction. J Cardiol 1995; **26**: 341－347 (in Jpn with Eng abstr)
9) Clarke HH, Shay CT, Mathews DK: Strength decrement index: A new test of muscle fatigue. Arch Phys Med Rehabil 1955; **36**: 376－378
10) Giannuzzi P, Tavazzi L, for the Working group on Cardiac Rehabilitation & Exercise Physiology and Working Group on Heart Failure of the European Society of Cardiology: Recommendations for exercise training in chronic heart failure patients. Eur Heart J 2001; **22**: 125－135
11) Borg G: Perceived exertion as an indicator of somatic

stress. Scand J Rehabil Med 1970; **2**: 92－98
12) American College of Sports Medicine: Clinical exercise testing. *in* ACSM's Guidelines for Exercise Testing and Prescription (ed by Johnson EP), 6th Ed. Williams & Wilkins, Baltimore, 2000; pp 91－114
13) McCartney N: Role of resistance training in heart disease. Med Sci Sports Exerc 1998; **30** (Suppl): S396－S402
14) Karlsdottir AE, Foster C, Porcari JP, Palmer-McLean K, White-Kube R, Backes RC: Hemodynamic responses during aerobic and resistance exercise. J Cardiopulm Rehabil 2002; **22**: 170－177
15) Foster C, Dymond DS, Carpenter J, Schmidt DH: Effect of warm-up on left ventricular response to sudden strenuous exercise. J Appl Physiol 1982; **53**: 380－383
16) Frontera WR, Meredith CN, O'Reilly KP, Evans WJ: Strength training and determinants of $\dot{V}O_2$ max in older men. J Appl Physiol 1990; **68**: 329－333
17) Marcinik EJ, Potts J, Schlabach PG, Will S, Dawson P, Hurley BF: Effects of strength training on lactate threshold and endurance performance. Med Sci Sports Exerc 1991; **23**: 739－743
18) Cicoira M, Zanolla L, Franceschini L, Rossi A, Golia G, Zamboni M, Tosoni P, Zardini P: Skeletal muscle mass independently predicts peak oxygen consumption and ventilatory response during exercise in noncachectic patients with chronic heart failure. J Am Coll Cardiol 2001; **37**: 2080－2085
19) Koike A, Hiroe M, Itoh H: Time constant for $\dot{V}O_2$ and other parameters of cardiac function in heart failure. *in* Cardiopulmonary Exercise Testing and Cardiovascular Health (ed by Wasserman K). Futura Publishing Co, Inc, Armonk, NY, 2002; pp 89－102
20) Hayashida W, Kumada T, Kohno F, Noda M, Ishikawa N, Kambayashi M, Kawai C: Post-exercise oxygen uptake kinetics in patients with left ventricular dysfunction. Int J Cardiol 1993; **38**: 63－72
21) Metra M, Dei Cas L, Panina G, Visioli O: Exercise hyperventilation,chronic congestive heart failure, and its relation to functional capacity and hemodynamics. Am J Cardiol 1992; **70**: 622－628
22) Chua TP, Ponikowski P, Harrington D, Anker SD, Webb-Peploe K, Clark AL, Poole-Wilson PA, Coats AJS: Clinical correlates and prognostic significance of the ventilatory response to exercise in chronic heart failure. J Am Coll Cardiol 1997; **29**: 1585－1590
23) Beniaminovitz A, Lang CC, LaManca J, Mancini DM: Selective low-level leg muscle training alleviates dyspnea in patients with heart failure. J Am Coll Cardiol 2002; **40**: 1602－1608