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ORIGINAL RESEARCH ARTICLE

Age-Related Differences in Physiologic and Psychosocial Outcomes After Cardiac Rehabilitation

ABSTRACT

Izawa KP, Watanabe S, Oka K, Hiraki K, Morio Y, Kasahara Y, Osada N, Omiya K, Iijima S: Age-related differences in physiologic and psychosocial outcomes after cardiac rehabilitation. Am J Phys Med Rehabil 2010;89:24–33.

Objective: To examine differences in physiologic and psychosocial outcomes between age groups after an exercise-based supervised-recovery phase II cardiac rehabilitation outpatient program.

Design: This is a longitudinal observational study. The study assessed 442 consecutive cardiac patients. Patients were divided into the middle-aged group (<65 yrs, $n = 242$) and older-age group (≥65 yrs, $n = 200$). Peak oxygen uptake, handgrip and knee extensor muscle strength, upper- and lower-body self-efficacy for physical activity, and physical component summary and mental component summary scores as assessed by SF-36 were measured at 1 and 3 mos after the onset of acute myocardial infarction or cardiac surgery and were compared.

Results: All physiologic and psychosocial outcomes increased significantly between months 1 and 3 in both groups. However, increases were greater in the middle-aged *vs.* older-aged group in peak oxygen uptake (+13.1% *vs.* +8.7%, $P < 0.01$), knee extensor muscle strength (+17.6% *vs.* +13.3%, $P = 0.01$), lower-body self-efficacy for physical activity (+17.3% *vs.* +12.7%, $P = 0.02$), and physical component summary score (+5.4% *vs.* +2.7%, $P = 0.02$).

Conclusions: Age-related differences in various physiologic and psychosocial measures indicated greater improvement from an exercise-based supervised recovery-phase II cardiac rehabilitation outpatient program in middle-aged *vs.* older-aged patients. Older adults may derive equal mental or emotional benefit from such a cardiac rehabilitation program but do not experience as much improvement in physiologic outcomes as middle-aged adults.

Key Words: Age-Related Difference, Cardiac Rehabilitation, Physiologic Outcomes, Psychosocial Outcomes

Reduced physical and mental status has been reported in patients with cardiac disease after acute myocardial infarction (AMI) or cardiac surgery, such as coronary artery bypass grafting and valve replacement.[1–4] The reported goals of cardiac rehabilitation (CR) programs for these patients have been to improve exercise capacity; reduce coronary risk factors; improve health-related quality of life (HRQOL); and reduce subsequent cardiac events, hospitalization costs, sudden death, and all-cause mortality.[1–4] Our previous studies suggested that exercise-based supervised-recovery phase II CR outpatient programs for patients after AMI and cardiac surgery are effective in improving physiologic outcomes such as peak oxygen uptake (Vo_2), upper- and lower-body muscle strength, and HRQOL.[3,4]

Life table data from 2004[5] show the average life expectance of a Japanese newborn to be 85.6 yrs for women and 78.6 yrs for men, with the health and longevity record of Japan being the best in the world.[5,6] However, cardiac disease is a growing public health problem mainly because of the aging of the population and the increased prevalence of cardiac disease in the elderly.[7] One report suggested that for young and old cardiac patients alike, both postmyocardial infarction hospital-based and home-based CR is similarly effective over the short term and improves total work capacity as assessed by cardiopulmonary exercise testing (CPX) and HRQOL.[1] Another report suggested that older patients improve significantly more than younger patients in both exercise capacity (peak Vo_2) and mental health after CR, although the sample size was not large, and exercise capacity was not assessed by CPX.[2]

Regarding physiologic outcomes in apparently healthy adults and cardiac patients, both peak Vo_2 and muscle strength have been reported to relate to mortality, activities of daily living, self-efficacy, and HRQOL.[3,8–11] In addition, skeletal muscle mass and muscle strength are independent predictors of peak Vo_2 in stable patients with heart failure.[12] Lower-limb function is also associated with the abilities of older adults to maintain independence in activities of daily living such as bathing and grocery shopping.[11] Moreover, handgrip strength is a good indicator of overall muscle strength and predictor of mortality and functional limitation in middle-aged and elderly people.[13,14] In patients with coronary heart disease, handgrip strength decreases with age, is lower in women, and provides valuable information as an integrated predictor of physical function in older patients with cardiac disease.[15]

In regard to psychologic outcomes, self-efficacy for physical activity (SEPA) measures self-confidence for performance of a given activity or task and represents an individual's perceptions or beliefs about how capable he or she is of performing that specific activity or task.[16,17] Several previous studies[17,18] have suggested a cross-sectional correlation between self-efficacy and exercise adherence, physiologic outcomes, and HRQOL.

Although a few studies have investigated age-related differences in exercise capacity and HRQOL, the relation of age-related differences in regard to clinical characteristics, physiologic outcomes, and psychosocial outcomes in Japanese cardiac patients is unknown. Particularly, despite the benefits of exercise-based supervised-recovery phase II CR outpatient programs, limited data are available on these outcomes in older-aged patients. Thus, the purpose of this study was to investigate (1) whether age-related differences exist between Japanese cardiac patients in regard to physiologic outcome measures of peak Vo_2, handgrip strength, and knee extensor muscle strength, and psychosocial outcome measures of SEPA and HRQOL and (2) whether the effects of age-related differences in these outcomes can be recognized after an exercise-based supervised-recovery phase II CR outpatient program.

MATERIALS AND METHODS

Study Design and Subjects

The present longitudinal study comprised consecutive patients selected from outpatients who completed a routine 3-wk acute phase I CR inpatient program at St. Marianna University School of Medicine Hospital from July 2000 to June 2008. Inclusion criteria were age >40 yrs, first AMI, postcoronary artery bypass grafting or valve replacement, and successful completion of CPX and handgrip and knee extensor muscle strength testing at entry into the exercise-based supervised-recovery phase II CR outpatient program at 1 mo (T1) after AMI onset or cardiac surgery. Exclusion criteria included preexisting extensive comorbidity (e.g., cancer); New York Heart Association functional class IV; and neurologic, peripheral vascular, orthopedic, or pulmonary disease. At the end of their acute phase I CR inpatient program, physiologic outcomes of 591 patients were assessed, and the patients were asked to complete psychosocial outcome testing. This study was approved by the St. Marianna University School of Medicine Institutional Committee on Human Research (approval no. 356). Informed consent was obtained from each patient.

Clinical Characteristics of the Patients

We evaluated patient age, sex, body mass index, education level, marital status, and employment status. We also evaluated medications from hospital records. In addition, a cardiologist assessed left ventricular ejection fraction by echocardiography as the index of cardiac function and objective indication of cardiac disease severity. The patients underwent standard M-mode echocardiography (Apio, Toshiba, Tokyo, Japan) with a 3.5-MHz transducer in the parasternal long-axis view to obtain the left ventricular ejection fraction.

Measurement of Physiologic Outcomes

Peak Vo_2, handgrip strength, and knee extensor muscle strength were measured to assess physiologic outcomes of each patient at T1 and 3 mos later (T2) after the onset of myocardial infraction and cardiac surgery.

Peak Vo_2 was measured as an index of exercise capacity.[3,4,9,12] The measurements made from expired gasses were used as indices of cardiovascular dynamics during exercise. Symptom-limited exercise testing was performed on a MAT-2500 treadmill (Fukuda Denshi Co., Tokyo, Japan). Throughout the test, a 12-lead electrocardiogram was monitored continuously, and heart rate was measured from the R-R interval of the electrocardiogram (ML-5000, Fukuda Denshi Co.). Peak Vo_2 was measured during the exercise period with an AE-300S aero monitor (Minato Ikagaku Co., Tokyo, Japan) and calculated with a personal computer (Pentium Processor, Windows 98 SE, EPSON Co., Nagano, Japan). The endpoint of exercise testing was determined according to the criteria of the American College of Sports Medicine.[19]

A standard adjustable-handle JAMAR dynamometer (Bissell Healthcare Co., Grand Rapids, MI) was used for the measurement of handgrip strength as an index of upper-limb muscle power and was set at the second grip position for all subjects.[3,4,9,12] Attention was paid to a possible Valsalva effect, and measurements were made three times each on both hands. We calculated the average of the highest value of the right- plus left-side handgrip strength/2 (in kilogram force). The highest value measured was considered the index of handgrip strength.

The Biodex System 2 isokinetic dynamometer (Biodex Medical Systems, Inc., New York, NY) was used for the measurement of knee extension muscular strength as an index of lower-limb muscular strength. Testing was performed at a maximum of five repetitions for knee extensors at isokinetic speeds of 60 degrees per second. Isokinetic test results were analyzed with the Biodex System 2 software.[3,4,9,12] After measurement, we calculated the average of the highest value of the right- plus left-side knee extensor muscular strength/2 (in Newton meter per kilogram). The highest value measured was considered the index of knee extensor muscle strength.

Measurement of Psychosocial Outcomes

SEPA and HRQOL tests were used to assess psychosocial outcomes of each patient at T1 and T2. General SEPA was measured with the Japanese version of the SEPA because of its reliability and validity.[11,22] The SEPA consists of four subscales: domains of walking, stair climbing, weight lifting, and push off. After testing of the four domains, the upper-body SEPA (U-SEPA) score (average scores of weight lifting + push off/2) and lower-body SEPA (L-SEPA) score (average scores of walking + stair climbing/2) were calculated. U- and L-SEPA subscale scores range from 0 to 100. Lower scores indicate poorer, and higher scores better, levels of SEPA.[9,17]

General HRQOL was assessed with the Medical Outcome Study SF-36 Health Survey.[20] The SF-36 consists of 36 items representing eight subscales that cover the domains of physical functioning, role-physical, bodily pain, general health, vitality, social functioning, emotional role, and mental health. The SF-36 is a standardized, generic HRQOL measurement instrument that has been validated in the general normal Japanese population.[20] It measures multidimensional properties of HRQOL on a 0–100 scale with lower scores representing lower HRQOL and higher scores higher HRQOL.[20] The eight subscales in the SF-36 were further combined into two summary scales: the physical component summary (PCS) score and mental component summary (MCS) score.

Supervised CR Program

The supervised acute phase I CR inpatient program involved an interdisciplinary team approach to rehabilitation and included a cardiologist, nurse, physical therapist, dietician, and pharmacist. At the end of this program, diet and medication instructions were given to each patient at discharge by a dietician and pharmacist, respectively. A nurse gave each patient individual education at discharge on cardiovascular risk factors and smoking cessation. Exercise training performed during this phase included low-intensity treadmill walking with upper- and lower-limb and body stretches. The exercise-based supervised-recovery phase II CR outpatient program continued until T2 and was customized for each patient on the basis of CPX results and muscle strength testing performed at the end of the acute phase I CR inpatient program. Patients participated in supervised combined aerobic and resistance exercise twice a week for 1 hr. Each exercise session was composed of a warm-up, aerobic exercise, resistance training, and cool-down period. Exercise intensity during aerobic exercise was maintained at anaerobic threshold heart-rate level during treadmill walking. For resistance training, four sets of a series of two upper-limb exercises (shoulder flexion and abduction from anatomic position) were performed with an iron weight array at a resistance that allowed completion of five repetitions with a rating of perceived exertion of 11–13 (according to the Borg 6–20 scale). Four sets of a series of knee extensions, flexions, and calf raises comprised the lower-limb exercises. Knee extension was performed with a weight strapped to the ankle and at a resistance that allowed completion of five repetitions with a 50% of one repetition maximum. Exercise intensity for calf raises was maintained at a perceived exertion rating of 11–13. Each session was preceded and followed by series of upper- and lower-limb and body stretches.

Statistical Analysis

Results are expressed as mean ± standard deviation. Unpaired *t* test and χ test were used to analyze differences in clinical profiles of the patients because comparisons between the two groups were performed for handgrip strength, knee extensor muscle strength, and peak $\mathrm{Vo_2}$. In addition, the unpaired *t* test was used to test for differences between the two independent groups in average U- and L-SEPA and SF-36 PCS and MCS scores. Data were also analyzed using two-way repeated measures of analysis of variance with Tukey's post hoc tests. The between-group factor was age, and the within-group factor was time period. Post hoc testing was performed if a statistically significant main effect or interaction was detected. Statistical analyses were performed with SPSS 12.0J statistical software (SPSS Japan, Inc., Tokyo, Japan). A *P* value of <0.05 was considered statistically significant.

RESULTS

Study Participants

Of the 591 patients, 56 were excluded because of an inability to measure peak $\mathrm{Vo_2}$ or handgrip and knee muscle strength or because of inappropriate responses, such as missing data or answering the same question twice, to the psychosocial outcome tests. Therefore, 535 patients were recommended to participate in a supervised-recovery phase II CR outpatient program. However, 93 of these 535 patients were excluded because they refused to undergo exercise testing or assessment of psychosocial outcome, because peak $\mathrm{Vo_2}$ or handgrip and knee muscle strength could not be measured, or because of inappropriate responses to the psychosocial outcome tests at T2 after AMI onset or cardiac surgery. There were no significant differences in the excluded patients *vs.* those in the study group. Thus, we compared the differences in physiologic and psychosocial outcomes measured at T1 and T2 and the benefits gained from an exercise-based supervised-recovery phase II CR outpatient program from T1 to T2 in 242 patients younger than 65 yrs (middle-aged group) and in 200 patients aged 65 yrs and older (older-age group). Flow of the participants through this study is shown in Figure 1.

Clinical Characteristics of the Patients by Age

Clinical characteristics of all patients and differences between the middle-aged and older-aged groups at T1 are summarized in Table 1. Left ventricular ejection fraction, body mass index, AMI location, number of coronary artery bypass graftings, valve replacement, educational level, marital status, and medications were almost identical between the two groups. However, employment in the older-aged group was significantly lower than that in the middle-aged group.

Age-Related Differences in Physiologic Outcomes at T1

Physiologic outcome data collected from the two groups are presented in Table 2. No patient showed ischemic ST changes or experienced chest pain or serious arrhythmia during CPX after the exercise-based supervised-recovery phase II CR outpatient program. Comparisons were performed across the two groups after CPX and muscle strength testing. Peak $\mathrm{Vo_2}$ scores in the older-aged group were significantly lower than those in the middle-aged group ($t = 7.4$, $P = 0.01$). Scores for handgrip strength ($t = 5.1$, $P = 0.01$) and knee extensor muscle strength ($t = 6.7$, $P = 0.01$) in the older-aged group were also significantly lower than those in the middle-aged group (Table 2).

Age-Related Differences in Psychosocial Outcomes at T1

Age-related differences in U-SEPA and L-SEPA scores and PCS and MCS scores between the two groups at T1 are presented in Table 3. U-SEPA ($t = 3.8$, $P = 0.01$) and L-SEPA ($t = 4.2$, $P = 0.01$) scores in the older-aged group patients were significantly lower than those in the middle-aged group patients. SF-36 PCS scores ($t = 2.6$, $P = 0.01$) were significantly higher in the middle-aged than in the older-aged group. However, SF-36 MCS scores ($t = -3.5$, $P = 0.01$) were significantly lower in the middle-aged groups than in the older-aged group.

Effects of Aging After CR

Physiologic Outcomes

After exercise-based supervised-recovery phase II CR outpatient programs, the middle-aged group showed statistically significant improvements in peak

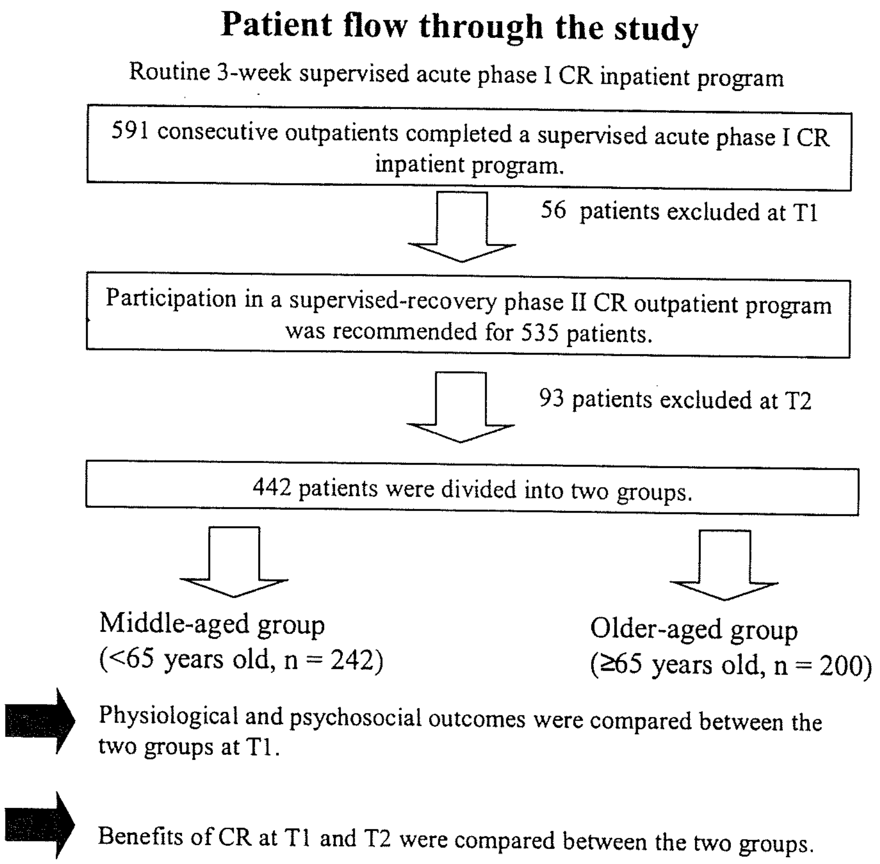

FIGURE 1 *Diagram of participant flow through this study. AMI, acute myocardial infarction; CR, cardiac rehabilitation; T1, at 1 mo after AMI onset or cardiac surgery; T2, at 3 mos after AMI onset or cardiac surgery.*

Vo_2 (+13.1%, $t = 13.2$, $P < 0.01$), handgrip strength (+6.9%, $t = 7.1$, $P < 0.01$), and knee extensor muscle strength (+17.6%, $t = 11.1$, $P < 0.01$) from T1 to T2 (Table 2). Statistically significant improvements also occurred in the older-aged group in peak Vo_2 (+8.7%, $t = 7.9$, $P < 0.01$), handgrip strength (+4.8%, $t = 5.9$, $P < 0.01$), and knee extensor muscle strength (+13.3%, $t = 7.1$, $P < 0.01$) from T1 to T2 (Table 2). Significant period (from T1 to T2) by group interactions (middle-aged and older-aged groups) (peak Vo_2: F [1/440] = 12.9, $P < 0.01$; knee extensor muscle strength: F [1/440] = 6.3, $P < 0.01$) were detected. Although there was a tendency toward difference, a significant difference was not present in period by group interaction for handgrip strength (F [1/440] = 3.1, $P = 0.07$). Thus, there was a significant age effect in response to exercise-based supervised-recovery phase II CR outpatient programs with the middle-aged group showing greater improvement in peak Vo_2 and knee extensor muscle strength than did the older-aged group.

Psychosocial Outcomes

After exercise-based supervised-recovery phase II CR outpatient programs, statistically significant improvements were found in the middle-aged group in U-SEPA (+10.8%, $t = 6.9$, $P < 0.01$), L-SEPA (+17.3%, $t = 10.6$, $P < 0.01$), PCS score (+5.4%, $t = 3.9$, $P < 0.01$), and MCS score (+4.2%, $t = 3.5$, $P < 0.01$) from T1 to T2. The older-aged group also showed statistically significant improvements in U-SEPA (+11.4%, $t = 3.7$, $P < 0.01$), L-SEPA (+12.7%, $t = 5.8$, $P < 0.01$), PCS score (+2.7%, $t = 2.4$, $P = 0.02$), and MCS score (+4.5%, $t = 3.1$, $P = 0.01$) from T1 to T2. Significant period by group interactions (L-SEPA: F [1/440] = 4.8, $P = 0.02$; PCS score: F [1/440] = 4.9, $P = 0.02$) were detected, as shown in Table 3. However, there was no significant period by group interactions in U-SEPA (F [1/440] = 2.2, $P = 0.13$) and MCS scores (F [1/440] = 0.2, $P = 0.60$). Thus, there was a significant age effect in response to CR as the middle-aged group showed greater improvement in L-SEPA and PCS scores than did the older-aged group.

DISCUSSION

The main findings of this study are that in measurements of physiologic and psychosocial outcomes, the older-aged group had lower SEPA and

TABLE 1 Age-related differences in patient clinical characteristics

	Middle-Aged Group (n = 242)	Older-Aged Group (n = 200)	t or χ^2	P
Age, yrs	54.5 ± 7.2	70.7 ± 4.3	−27.2	<0.001
Male, %	83.8	81.5	0.4	0.52
BMI, kg/m^2	23.0 ± 3.2	22.8 ± 2.4	0.6	0.52
Education, yrs	13.0 ± 2.7	12.5 ± 2.8	1.9	0.06
Married, %	82.4	86.4	1.8[a]	0.19
Employed, %	70.1	25.9	82.5[a]	<0.001
LVEF, %	51.7 ± 10.1	52.1 ± 11.0	−0.2	0.82
AMI location (n)				
Inferior	60	50	7.7[a]	0.09
Anterior	78	67	—	—
Lateral	16	11	—	—
CABG	53	54	—	—
VR	35	13	—	—
Medications (n)				
Nitrates	147	123	1.7[a]	0.20
Calcium antagonist	52	38	—	—
β-Blockers	76	64	—	—
ACE or ARB	138	102	—	—

[a] χ^2 value.

ACE, angiotensin-converting enzyme inhibitors; ARB, angiotensin receptor blockers; BMI, body mass index; CABG, coronary artery bypass grafting; LVEF, left ventricular ejection fraction; VR, valve replacement.

PCS scores and higher MCS scores than did the middle-aged group at entrance into an exercise-based supervised-recovery phase II CR outpatient program. Conversely, the MCS scores of the middle-aged group were reduced. Second, the increase in peak Vo_2, knee extensor muscle strength, L-SEPA, and PCS scores in the middle-aged group were greater than those in the older-aged group from T1 to T2. Thus, age-related differences occurred between the two groups in measures of physiologic and psychosocial outcomes during the recovery process.

Age-Related Differences in Patient Clinical Characteristics

No statistically significant age-related differences were present between the two groups in any clinical characteristic except for that of employment status, in which a significant difference was noted between the middle-aged group patients (70.1%) and the older-aged group patients (25.9%) (Table 1). With regard to age-related differences in employment status of Japanese, Tokuda et al.[5] reported that a significantly greater number of the middle-aged subjects (55-yr old, 66.0%; 60-yr old, 47.1%) in their study were employed compared with older subjects (65-yr old, 22.8%; 75-yr old, 16.8%). Our results support their findings. However, we did not ascertain what percentage of our middle-aged *vs.* older-aged group patients returned to work at T1, hence further investigation would be necessary in the future.

Age-Related Differences in Physiologic Outcomes

In cardiac patients, exercise capacity is strongly related to prognosis, and physical function is related to the ability of an individual to perform

TABLE 2 Age-related differences in physiologic outcomes

	Middle-Aged Group (n = 242)			Older-Aged Group (n = 200)			Interaction	
	T1	T2	% Change	T1	T2	% Change	F	P
Peak Vo_2	24.4 ± 5.0	27.6 ± 5.3[a]	+13.1	21.9 ± 4.5[b]	23.8 ± 5.2[a,c]	+8.7	12.9	<0.01
Handgrip	35.8 ± 9.3	38.3 ± 9.3[a]	+6.9	31.4 ± 8.3[b]	32.9 ± 8.4[a,c]	+4.8	3.1	0.07
KEMS	1.7 ± 0.4	2.0 ± 0.4[a]	+17.6	1.5 ± 0.3[b]	1.7 ± 0.4[a,c]	+13.3	6.3	0.01

[a] $P < 0.05$ between groups.

[c] $P < 0.05$ between terms.

KEMS, knee extensor muscle strength.

TABLE 3 Age-related differences in psychosocial outcomes

	Middle-Aged Group (n = 242)			Older-Aged Group (n = 200)			Interaction	
	T1	T2	% Change	T1	T2	% Change	F	P
SEPA								
U-SEPA	62.5 ± 26.3	69.3 ± 21.1^{a}	+10.8	52.5 ± 26.2^{b}	58.3 ± 24.4^{a,c}	+11.4	2.2	0.13
L-SEPA	68.3 ± 20.7	80.1 ± 17.2^{a}	+17.3	62.9 ± 23.5^{b}	70.9 ± 22.4^{a,c}	+12.7	4.8	0.02
HRQOL								
PCS	46.3 ± 6.2	48.8 ± 4.9^{a}	+5.4	44.0 ± 6.2^{b}	45.2 ± 6.2^{a,c}	+2.7	4.9	0.02
MCS	48.1 ± 8.5	50.1 ± 7.0^{a}	+4.2	51.1 ± 9.0^{b}	53.4 ± 7.6^{a,c}	+4.5	0.2	0.60

$^{a}P < 0.05$ between groups.
$^{c}P < 0.05$ between terms.

the physical tasks necessary for activities of daily living.[21] In this study, peak V_{O_2} in the older-aged group was significantly lower than that in the middle-aged group (Table 2). Previous studies[2,22] have reported that older cardiac patients consistently tend to have lower exercise capacity than younger cardiac patients. Balady et al.[22] reported that baseline exercise tolerance (estimated METS), which was measured in 778 cardiac patients entering CR, decreased as age increased. Lavie and Milani[2] reported that baseline exercise capacity (estimated METS) was lower in elderly patients (>65-yr old) than in younger patients (<65-yr old). This study strongly supports their findings. In addition, the extremely low peak V_{O_2} values of our patients, particularly those of the older-aged patients, on entry into the phase II CR outpatient program underscores the fact that one important goal of CR after a major cardiac event is to improve physical function and prognosis.

In this study, both handgrip strength and knee extensor muscle strength were also significantly lower for the older-aged group than for the middle aged group. Handgrip strength is a predictor of mortality and morbidity in the general population[13,14] and cardiac patients.[8] In addition, weak handgrip and knee extensor muscle strengths are associated with the incidence as well as prevalence of disability, suggesting that age-related loss of muscle mass and volitional muscle strength can be both a cause and a consequence of physical disability.[14] A previous study suggested that the reduction in muscle mass that occurs with aging has been shown to account for a large portion of the decline in peak V_{O_2} associated with aging.[23] It is possible that increasing muscle mass, or perhaps even only muscular strength, might result in an increase in peak V_{O_2} in older individuals.[23]

In a study to determine risk factors for falling in older men and women living in nursing homes and to compare characteristics of fallers *vs.* nonfallers, Sieri and Beretta[24] found that men who had fallen had greater deficits of ankle plantar-flexion strength and power, whereas women who had fallen had greater deficit of knee extensor muscle strength and lower walking speed. These results show that lack of muscle power affects ability in women and that interventions for improving contractile velocity should be pursued. Therefore, positive training should be enforced by concentrating on improving both upper- and lower-limb muscle strength in older-aged patients.

Age-Related Differences in Psychosocial Outcomes

U- and L-SEPA scores in the older-aged group were also lower than those in the middle-aged group in this study. Previous studies[17,18] suggest a cross-sectional correlation of self-efficacy with exercise adherence, physiologic outcomes, and HRQOL. In this study, the values of handgrip strength, knee extensor muscle strength, and peak V_{O_2} in the older-aged group were lower than those of the middle-aged group, suggesting that U- and L-SEPA may also be related to physiologic outcomes on entry into CR.

With regard to HRQOL in this study, the SF-36 PCS scores in the older-aged group were lower than those of the middle-aged group. The combination of the older-aged group's significantly lower physiologic outcome measures and lower U- and L-SEPA scores may be related to their lower PCS scores. Conversely, however, the middle-aged group's HRQOL and SF-36 MCS scores were significantly lower than those of the older-aged group (Table 3). In comparison with the older-aged group, many patients in the middle-aged group were employed at the time of their cardiac event. The goal for patients suffering a cardiac event is to return them to regular employment soon after discharge from hospital. However, the number of patients returning to work after hospital discharge is disappointingly low, even in younger patients experiencing a short period of hospitalization.[25] Picard et al.[26] previously reported that patients with AMI at low risk were able to return to work at

51 days after an uncomplicated AMI. In this study, at ~30 days after AMI or cardiac surgery, many patients might not have been able to return to work at T1. We do not have data on return to work after the onset of AMI or cardiac surgery in our middle-aged group patients and how that might be related to their MCS scores. In addition, exercise-based CR itself may weakly support a change in mental health. Therefore, particularly in middle-aged patients, we should consider improvements in exercise training in addition to stress management and group counseling.

Effects of Age After Exercise-Based Supervised-Recovery Phase II CR Outpatient Programs

Although exercise-based supervised-recovery phase II CR outpatient programs have been shown to have benefits after AMI and cardiac surgery, many previous reports have focused on an age bias in the approach to treat elderly patients. In this study, there were significant improvements in physiologic outcomes from T1 to T2 in both groups. We previously reported that exercise-based supervised-recovery phase II CR outpatient programs for cardiac patients after AMI, coronary artery bypass grafting, and valve replacement improved physiologic outcomes similar to those found in this study,[3,4] in which a similar phase II CR outpatient program was effective in changing physiologic outcomes between groups. However, there was a difference in the recovery process between groups in regard to peak $\dot{V}o_2$ and knee extensor muscle strength, both of which showed greater improvement in the middle-aged group than in the older-aged group (Table 2).

This improvement in functional capacity in the older-aged group has been documented previously in another study by Woo et al.[27] However, they showed in a study of healthy young and elderly subjects that improvement of peak $\dot{V}o_2$ in elderly subjects may be limited by other factors that decline with age despite activity or exercise training, such as maximal heart rate and diastolic filling rate. Although we did not have enough data to explain the difference in knee extensor muscle strength in the recovery process between our two patient groups, a possible explanation for this may be that, as Welle et al.[28] reported, muscle protein synthesis is slower in healthy older men and women than in young adults. Thus, this may be the reason for the between-group difference in the recovery of knee extensor muscle strength in this study.

One question raised by this study was why there was no difference between the two groups in the recovery of handgrip strength, our index of upper-limb muscle strength. One reason is that the reduction in muscle strength as a result of aging is different between lower- and upper-limb muscles in apparently healthy adults in that lower-limb muscle strength is reduced more by aging.[29] In addition, type II muscle fibers (fast-twitch fibers) reduce easily with aging.[29] Elder et al.[30] reported that the vastus lateralis, which is a component of knee extensor muscle strength, is composed predominantly of type II (fast-twitch) fibers. However, the larger muscles involved in handgrip muscle strength (i.e., biceps and triceps) comprise an individual variety of muscle fiber types (types I and II).[30] Moreover, Grimby et al.[31] previously reported a significant relation between the percentage of type II fibers and muscle strength in a population of elderly men. Thus, although the degree of knee extensor muscle strength and type II muscle fiber reduction in the older-aged group was greater than that in the middle-aged group in this study, the degree of handgrip muscle strength recovery was not so different between the two groups. Resistance training leads to muscle hypertrophy because of an increase in the size of the type I and II fibers.[32] The degree of handgrip strength was similarly improved between the two groups in our study, hence this may not be an effective measure of the recovery process during phase II CR.

Significant improvements in psychosocial outcomes such as U-, L-SEPA, and PCS and MCS scores occurred from T1 to T2 between the two groups in this study. The effects of resistance training on psychologic well-being and quality of life in patients with heart disease were described previously.[33] One of the most important contributions of CR may be to improve the patient's sense of well-being and self-efficacy, which should translate into enhanced quality of life.[34] Both patient groups in this study underwent endurance exercise training and upper- and lower-body resistance training. Thus, both the exercise and resistance training components might be one of the effects on the psychosocial outcomes of SEPA and HRQOL between the two groups. However, the increase in L-SEPA and PCS scores in the middle-aged group during the recovery process were greater than those in the older-aged group. In addition, the physiologic outcomes of peak $\dot{V}o_2$ and knee extensor muscle strength increased more greatly in the middle-aged group than in the older-aged group. Thus, improvement of peak $\dot{V}o_2$ and lower-limb muscle strength in the middle-aged group may have had a greater effect on L-SEPA and PCS scores than in the older-aged group, indicating that improvement of these physiologic and psychosocial outcomes may offer greater clinical benefit to middle-aged *vs.* older-aged patients. However, we do not have information on the relative improvement experienced by older adults compared with their age-matched peers who do not participate in exercise-based supervised-recovery phase II CR outpatient programs. For example, older adults may have more comorbid medical conditions that might serve to slow recovery. In future studies, an older-adult control group should be included, particularly given the risk of comorbidities in this age group, to determine what effect comorbidities have on older-aged patients participating in exercised-based CR.

There are several limitations in this study. First, many patients were excluded because of an inability to measure physiologic outcomes or because of inappropriate responses to the psychosocial outcome tests at T1 and T2, possibly resulting in selection bias. Second, in some of our very elderly patients, it was impossible to evaluate exactly when the changes that we associate with aging actually occurred. Third, a control group was not included, hence a more longitudinal study and evaluation of age-related differences in regard to the effect of exercise-based supervised-recovery phase II CR outpatient programs on physiologic and psychosocial outcomes over the long term after CR is necessary. Finally, although gender-related differences were addressed previously in our cross-sectional study of physiologic and psychosocial outcomes in cardiac patients,[11] we did not evaluate the effect of gender-related differences on physiologic and psychosocial outcomes in this study. This will be a topic of research for a future study. Despite these limitations, we believe that the current data support the beneficial effects of exercise-based supervised-recovery phase II CR outpatient programs, and the findings of this study are important because the sample size was large enough to yield significant results from the test instrument scores.

In conclusion, this study identified age-related differences in physiologic and psychologic outcomes in Japanese cardiac patients undergoing exercise-based supervised-recovery phase II CR outpatient programs. Baseline age-related differences in physiologic and psychosocial outcomes indicate that older cardiac patients may have lower SEPA and PCS scores and higher MCS scores than do middle-aged cardiac patients on entrance into such CR programs. Conversely, as a measure of psychosocial outcome, the MCS scores of middle-aged Japanese cardiac patients were reduced at entry into the programs. It may be that older adults derive equal mental or emotional benefit from phase II CR outpatient programs but do not experience as great an improvement in physiologic outcomes as middle-aged adults. Thus, exercise-based supervised-recovery phase II CR outpatient programs targeting middle-aged patients should focus not only on physiologic outcomes but also on psychosocial outcomes to improve the SF-36 MCS at entrance into phase II CR. Psychosocial approaches such as counseling for middle-aged patients at entrance into phase II CR may need to be added. This relatively short-term study lacks long-term follow-up data, and additional study will be required to evaluate whether such CR outpatient programs can influence long-term outcomes and age-related differences over longer periods in these patients.

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Heart-Rate Response to Sympathetic Nervous Stimulation, Exercise, and Magnesium Concentration in Various Sleep Conditions

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The aim of this study was to clarify the mechanism of impaired exercise tolerance in chronic sleep-restricted conditions by investigating variables related to heart-rate (HR) response to sympathetic nervous stimulation. Sixteen healthy men (mean age 21.5 years) were tested in a control state, acute sleep-loss state, and chronic sleep-restricted state. Participants underwent cardiopulmonary exercise testing in each state. Their norepinephrine (NE) concentration was measured before and immediately after exercise. Intracellular magnesium (Mg) concentration was measured in a resting state. Exercise duration was shorter and the ratio of HR response to the percentage increase in NE was higher in the chronic sleep-restricted state than in the control state. Intracellular Mg gradually decreased from control to chronic sleep restriction. There was a negative correlation between peak exercise duration and the ratios of HR response to the rate of increase in NE. Intracellular Mg was positively correlated with the ratios of HR response to the increase in NE both in control and in acute sleep loss. The authors conclude that the impaired exercise tolerance in a chronic sleep-restricted state is caused by hypersensitivity of the HR response to sympathetic nervous stimulation, which showed a compensation for decreased intracellular Mg concentration.

Keywords: sleep deprivation, sympathetic nervous stimulation, exercise tolerance

In the field of competitive sports, athletes always take care of their physical condition, including fatigue or sleep status, and try to control it during training. It is very important to control it because it directly influences their performance. In our previous studies, oxygen uptake (VO_2) was decreased during exercise, as indicated by anaerobic threshold (AT) and peak VO_2, in a state of chronic sleep restriction in young healthy participants (Osada et al., 1993; Tanabe et al., 1998; Yamamoto et al., 1996). Our results suggest that magnesium (Mg) metabolism plays an important role in the low VO_2 observed with chronic sleep restriction; the intracellular Mg concentration decreased in this condition, and VO_2 after Mg

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administration was improved in comparison with that without Mg (Tanabe et al.; Yamamoto et al.). In a comparative study of a control state and chronic sleep-restricted state, changes in intracellular Mg levels were positively correlated with changes in flow-mediated dilation of the brachial artery (Takase, Akima, Uehata, Ohsuzu, & Kurita, 2004). Although it has been suggested that Mg concentration is associated with sympathetic nervous activity, which regulates norepinephrine (NE) secretion, the precise mechanism remains unclear. Moreover, the differences in hemodynamic response to sympathetic nervous stimulation between chronic sleep restriction and acute sleep loss have not been fully investigated. In particular, heart-rate (HR) response to sympathetic stimulation in chronic sleep-restricted states has not been investigated despite multiple studies of exercise after acute sleep loss, after 30–120 hr of sleeplessness (Bulbulian, Heaney, Leake, Sucec, & Sjoholm, 1996; Vondra et al., 1981), or after partial sleep loss for 1–3 days (Mougin et al., 1996; Reilly & Piercy, 1994).

Thus, the aim of this study was to clarify the mechanism of impaired exercise tolerance in chronic sleep-restricted conditions by investigating variables related to HR response to sympathetic nervous stimulation.

Participants and Methods

Participants

Sixteen healthy male medical-college students (mean age 21.5 ± 2.6 years) with no history of serious disease were enrolled in the study. Their height and weight were 170.8 ± 3.5 cm and 68.3 ± 9.5 kg, respectively. The participants' health status was determined on the basis of their medical history, routine physical examination, and resting electrocardiogram (ECG). Participants who had ECG or clinical abnormalities were excluded.

In accordance with the study protocol approved by the Committee on Human Investigation at our university, written informed consent was obtained from each participant before he entered into the study.

Methods

Experiments were conducted under three conditions: a control condition (usual amount of good sleep for at least 1 week), an acute sleep-loss state (partial sleep restriction for one night, sleep time less than 3 hr), and a chronic sleep-restricted state for term-end examinations (a day preceded by a month during which average sleep lasted <60% of usual). Each participant first completed a cardiopulmonary-exercise test (CPX) in the control state. Participants then performed the CPX in the chronic sleep-restricted state. Finally, they performed the CPX in the acute sleep-loss state. The acute sleep-loss state and chronic sleep-restricted state were separated by at least 2 weeks of ordinary sleep. All exercise tests were performed at the same time of day between 5 and 9 p.m. under similar conditions.

Both chronic and partial sleep restriction were caused by office work, preparing for an examination, not for entertainment or leisure activity. All participants slept at home during the examination period and were not permitted to drink alcohol or take hypnotic drugs or sedatives. Before CPX under each condition, they were interviewed by physicians to determine how long they had slept the night before. During the chronic sleep-restricted state, they logged their sleep time themselves.

CPX

Symptom-limited CPX with a ramp protocol on a cycle ergometer (CORIVAL 400, Lode B.V., Groningen, Holland) was performed. After a 4-min rest on the cycle ergometer, exercise began with a 4-min warm-up (20 W) followed by an increase in load (1 W per 3 s). During exercise testing, participants underwent 12-lead ECG monitoring via a stress-test system (ML-5000, Fukuda-Denshi Co., Tokyo, Japan), and HR, ST- and T-wave change, and arrhythmias were identified and recorded. Blood pressure was measured at 1-min intervals with a cuff (STBP-780 COLIN Co., Aichi, Japan). The exercise test was terminated by discontinuation criteria of the American Heart Association (Fletcher et al., 2001), and VO_2, carbon dioxide output (VCO_2), and minute ventilation (VE) were measured throughout CPX with an RM-300 respiromonitor and an MG-360 gas analyzer (Minato Medical Science Co., Osaka, Japan). The measurement system for CPX was calibrated before the start of each study. Expired gas was sampled with a breath-by-breath technique, and AT was determined by conventional criteria (Wasserman, Hansen, Sue, Casaburi, & Whipp, 1999): VE/VO_2 increased after holding constant or decreasing, whereas VE/VCO_2 remained constant or decreased, and the gas-exchange ratio started to increase steeply. Exercise durations to reach AT and peak VO_2 also were recorded. We calculated ΔHR as peak value minus resting value of HR.

Measurement of Plasma NE Concentration

To measure the plasma NE concentration in nonworking regions of the body, venous blood was drawn from an 18-gauge cannula inserted into the antecubital vein and immediately aspirated into a polypropylene tube containing EDTA. The sampled blood was cooled on ice immediately and centrifuged at 3,000 rpm for 10 min at 4 °C to separate the plasma, which was maintained in frozen storage at –70 °C until analysis. Plasma NE concentrations at rest and immediately after exercise in each condition were analyzed by high-performance liquid chromatography assay. The increase (peak – rest = ΔNE) and rate of increase ([peak – rest]/rest = %ΔNE) in NE concentration were calculated.

Measurement of Erythrocyte Mg Concentration

Venous blood was obtained from the catheter with the participant in a resting state, and samples of heparinized blood for measuring the erythrocyte Mg concentration were centrifuged at 3,000 *g* at 4 °C for 10 min. After removal of plasma and the buffy coat, the erythrocyte sediment was washed three times with 9% NaCl solution and centrifuged at 4 °C at 3,000 *g* for 10 min. After removal of the supernatant, 9% NaCl solution was added until the total sample volume reached 4 ml; this volume was divided equally into two samples. One sample was used to count erythrocytes. The other sample was centrifuged at 3,000 *g* at 4 °C for 10 min. After removal of the supernatant fluid, distilled water was added until the total sample volume reached 2 ml to hemolyze the erythrocytes. Erythrocyte Mg concentration was measured by the atomic absorption method, and the value obtained was corrected for the number of erythrocytes; the Mg concentration was expressed per 400 × 10^4 mm^{-3}.

Calculation

To evaluate the HR response to sympathetic nervous stimulation by exercise, ΔHR/ΔNE and ΔHR/%ΔNE were calculated. These parameters were previously reported by Colucci et al. (1989) and modified by our coworker (Samejima et al., 2003).

Statistical Analysis

All data are expressed as *M* ± *SD*. Comparisons between the three sleep conditions were made by a two-way analysis of variance followed by Dunnett's post hoc tests. Correlation between variables was determined by calculating Pearson's correlation coefficient. A *p* value of <.05 was considered significant.

Results

The sleep time of participants was 7.56 ± 0.79 hr in the control state and 4.59 ± 0.95 hr for 34.8 ± 9.9 days in the chronic sleep-deprived state. The sleep time 1 day before CPX in the chronic sleep-deprived state was 4.28 ± 1.38 hr. The sleep time in the temporary sleep-deprived state was checked before CPX to confirm that participants had slept less than 3 hr.

For all participants, the exercise test was terminated when leg fatigue or shortness of breath occurred. No participant experienced ischemic ST- and T-wave change or severe arrhythmia. HR both at rest and at AT in the acute sleep-loss condition was lower than that in the control state ($p < .05$). Peak HR and ΔHR did not differ statistically between conditions. The mean AT was significantly lower in both the acute sleep-loss and chronic sleep-restricted states than in the control state ($p < .01$ for both). Although peak VO_2 was lower in both the acute sleep-loss and chronic sleep-restricted states than in the control state, there was no statistical difference between states. The periods of ramp exercise needed to reach AT and peak exercise were significantly shorter ($p < .05$ and $p < .01$, respectively) in the chronic sleep-restricted state than in the control state (see Table 1).

Plasma NE concentrations in the resting state and after peak exercise did not differ between conditions. The %ΔNE was significantly lower in the chronic sleep-restricted state (10.43 ± 5.23) than in the acute sleep-loss and control states (18.94 ± 12.23 and 19.25 ± 9.97, respectively). The intracellular Mg concentration decreased gradually from the control to the chronic sleep-deprived state (1.76 ± 0.33, 1.28 ± 0.23, and 1.14 ± 0.27 mg/dl, respectively; see Table 2).

ΔHR/%ΔNE was significantly higher ($p < .05$) in the chronic sleep-restricted state than in the acute sleep-loss state. ΔHR/ΔNE tended to be higher in the chronic sleep-restricted state than in the control state ($p = .08$).

In total amount of three conditions, both ΔHR/ΔNE and ΔHR/%ΔNE had weak negative correlations with peak exercise time ($r = -.29$, $p < .05$, and $r = -.32$, $p < .05$, respectively; see Figure 1).

Table 1 Cardiopulmonary-Exercise-Testing Parameters in Each Sleep Condition

	Control	Acute sleep loss	Chronic sleep restriction
Heart rate (beats/min)			
rest	79.6 ± 8.7	73.4 ± 8.4*	79.4 ± 10.6†
anaerobic threshold	123.1 ± 15.6	113.9 ± 15.6*	122.3 ± 14.5
peak	190.8 ± 10.1	187.7 ± 11.7	190.8 ± 10.4
ΔHR	111.2 ± 8.6	114.3 ± 13.0	111.3 ± 9.9
VO_2 ($\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$)			
rest	3.6 ± 0.5	3.4 ± 0.5	3.7 ± 0.4
warm-up	8.9 ± 1.1	8.7 ± 1.0	9.3 ± 1.0††
anaerobic threshold	17.3 ± 2.5	14.7 ± 2.5**	15.7 ± 1.9**
peak	42.3 ± 5.6	40.4 ± 6.3	40.3 ± 5.2
Exercise duration (s)			
anaerobic threshold	222.1 ± 44.2	180.9 ± 39.1**	193.3 ± 45.8*
peak	699.3 ± 72.7	677.0 ± 77.7	626.0 ± 56.7**†

Note. Δ = peak – rest.

*p < .05 vs. control, **p < .01 vs. control. †p < .05 vs. acute sleep loss, ††p < .01 vs. acute sleep loss.

Table 2 Serum NE, Intracellular Mg, and HR Response to Sympathetic Nervous Stimulation in Each Sleep Condition

	Control	Acute sleep loss	Chronic sleep restriction
NE (pg/ml)			
rest	300.5 ± 200.5	240.9 ± 103.0	315.1 ± 159.3
peak	4765.5 ± 1814.8	4553.7 ± 2293.9	3333.6 ± 1504.3
ΔNE	4054.8 ± 1841.6	3838.1 ± 2240.3	2948.1 ± 1336.4†
%ΔNE	18.94 ± 12.23	19.25 ± 9.97	10.43 ± 5.23†
RBC-Mg (mg/dl)	1.76 ± 0.33	1.28 ± 0.23*	1.14 ± 0.27**
ΔHR/%ΔNE	8.64 ± 5.58	7.23 ± 3.18	13.34 ± 6.84†
ΔHR/ΔNE	1.03 ± 0.20	1.13 ± 0.16	1.28 ± 0.36

Note. Δ = peak – rest; NE = norepinephrine; RBC = red blood cell; Mg = magnesium; HR = heart rate.

*p < .05 vs. control, **p < .01 vs. control. †p < .05 vs. acute sleep loss.

Although ΔHR/ΔNE in control and acute sleep loss had significantly positive correlations with intracellular Mg concentrations ($r = .67$, $p < .01$, and $r = .63$, $p < .05$ respectively), no significant correlation was observed between these in chronic sleep restriction.

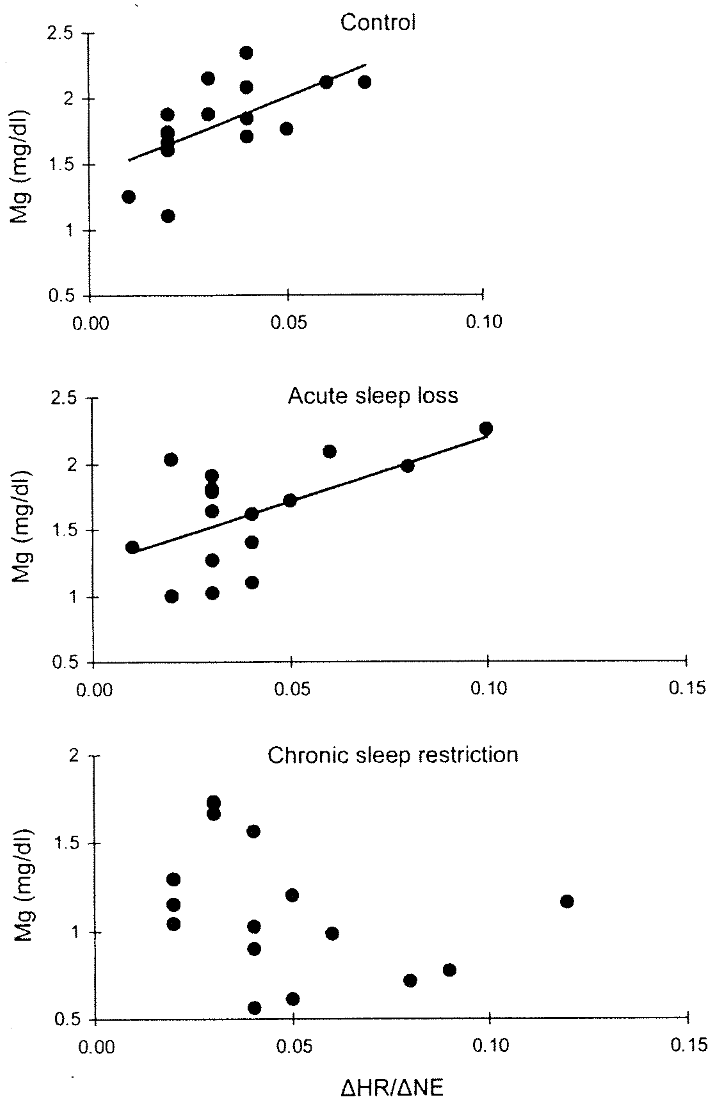

Figure 1 — Correlation between ΔHR/ΔNE and intracellular magnesium concentration. Mg = magnesium; ΔHR/ΔNE = change in heart rate divided by change in norepinephrine.

Discussion

Our coworker (Osada, 1994) previously reported that effects of acute sleep loss and chronic sleep restriction on functional capacity and stress-hormone secretion differed. He reported that although both peak VO2 and %ΔNE decreased with chronic sleep restriction in young healthy volunteers, there were no significant differences in these variables between the control state and the acute sleep-loss state. He concluded that the lack of increase in stress hormone might be a main cause of reduced functional capacity in the chronic sleep-restricted state and that a compensatory mechanism might be at work in acute sleep loss. The same finding that %ΔNE was high but not significantly so was obtained in the acute sleep-loss condition in the current study. NE has been reported not to increase with 50 hr of acute sleep loss (Martin & Chen, 1984) or with partial sleep restriction caused by early awakening or delayed bedtime (Mougin et al., 2001). These findings, as well as those of the current study, indicate only minor alterations in the NE responses to exercise after partial sleep restriction.

In our previous study (Yamamoto et al., 1996), %ΔNE in the chronic sleep-restricted state with Mg administration was equal to that in the control state, whereas %ΔNE was significantly lower in the chronic sleep-restricted state without Mg administration. We speculated that the repeated stress of chronic sleep restriction induced a shift in intracellular Mg to the extracellular space and finally to the urine. In addition, NE concentrations at rest, below AT, and at peak exercise were significantly higher in chronic sleep restriction with Mg administration than without Mg. Decreased intracellular Mg induces decreased NE secretion and low exercise tolerance even in young healthy participants. It has been reported that the NE concentration increased after Mg administration in patients who suffered disabling primary Raynaud's phenomenon and in control participants (Leppert et al., 1994). Those investigators suggested that the increased plasma NE concentration could be a result of either increased release or altered clearance. In the current study, the intracellular Mg concentration was low even in the acute sleep-loss state, which seemed to induce relatively low-grade stress in comparison with the control state.

Other investigators have reported inverse effects of Mg to catecholamine. It was reported that cardiac NE release was not increased after intravenous Mg infusion during handgrip stress in cardiac patients (Ohtsuka, Oyake, Seo, Eda, & Yamaguchi, 2002) and also that preoperative oral Mg supplementation led to NE reduction after coronary artery bypass surgery (Pasternak et al., 2006). Moreover, investigators showed that Mg infusion inhibited NE release by blocking n-type calcium channels at peripheral sympathetic nerve endings in spontaneous hypertensive rats, decreasing blood pressure independently during electrical spinal stimulation (Shimosawa, Takano, Ando, & Fujita, 2004). It is speculated that intracellular Mg had an effect of normalization or stabilization on catecholamine secretion, not only for NE increase but also for suppression when NE is not needed, which was also demonstrated in this study.

Plasma growth-hormone and NE values at rest, during submaximal or maximal exercise, and in recovery are reportedly the same after acute sleep loss as in a control state (Mougin et al., 2001). Investigators concluded that only minor alterations occur in the hormonal responses to exercise after acute sleep loss. Chronic sleep restriction might lead to chronic fatigue and decreased NE production after long-lasting sympathetic nerve stimulation. Moreover, plasma NE concentration, as well as intracellular Mg concentration, might decrease with chronic sleep restriction. This might be one of the mechanisms underlying low oxygen uptake during exercise in the chronic sleep-restricted state, because the %ΔNE in participants under chronic sleep restriction with Mg administration was significantly higher than in participants without Mg administration (Yamamoto et al., 1996).

It has been reported that the HR response to sympathetic nervous activity decreases and that the magnitude of decrease correlates with exercise intolerance in patients with chronic heart failure (CHF; Colucci et al., 1989; Samejima et al., 2003). In contrast, in the current study, increased HR response to sympathetic nervous stimulation correlated with exercise intolerance. The discrepancy between CHF patients and normal participants with chronic sleep restriction can be explained, in a part, by the difference in cardiac function, degree of injury in postsynaptic adrenal fibers, or cytokine levels. Postsynaptic β-adrenergic desensitization in the sinoatrial node is reportedly the main mechanism of chronotropic incompetence in patients with CHF (Colucci et al.). Inversely, it was speculated that β-adrenergic sensitization in the sinoatrial node in chronic sleep restriction occurred as a result of the same HR response to low NE concentration during exercise. In the chronic sleep-restricted state, efficiency of the HR increase would be good because ΔHR was almost the same in the chronic state as in the other two conditions, although low %ΔNE was observed. In the chronic sleep-restricted state, chronic stress resulting from sleep restriction led to the termination of NE production by low intracellular Mg but also to hypersensitive HR response to decreased NE. The HR response to NE secretion was inappropriately increased in the chronic sleep-restricted state, and this might be a mechanism of compensating for chronic stress. The HR response to NE in healthy participants also might be attenuated if chronic sleep restriction lasts much longer.

There were limitations to the study. The degree of fatigue caused by chronic sleep restriction might have differed between participants because sleep time in this study was reported by the participants themselves, and there were no lifestyle restrictions other than those against alcohol ingestion and hypnotic drug use. In addition, other stresses, especially psychic stress, would be added to that of chronic sleep restriction because the participants were in an extraordinary, end-term-examination period. Therefore, conditions could have varied somewhat because it was impossible to standardize participants' eating, sleeping, and working habits in their own homes during the observation period.

Conclusion

We conclude that impaired exercise tolerance in the chronic sleep-restricted state is caused by hypersensitivity of the HR response to sympathetic nervous stimulation, which showed a compensation for decreased intracellular Mg concentration.

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研究論文

回復期冠動脈疾患患者における身体活動量と下肢筋力との関連について*

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要旨

【目的】回復期冠動脈疾患患者の身体活動量（PA）の実態とその関連要因を明らかにすること。【方法】対象は，急性心筋梗塞発症および冠動脈バイパス術後1か月時点の冠動脈疾患外来患者50例である。基礎疾患および属性，PA，最高酸素摂取量（peak $\dot{V}O_2$），下肢筋力（膝伸展筋力）を調査，測定した。【結果】各指標の平均値±標準偏差は，PA：7893.3±2914.5歩/日，peak $\dot{V}O_2$：24.8±5.9 ml/kg/min，下肢筋力：1.7±0.4 Nm/kgであった。PAとpeak $\dot{V}O_2$間に$r = 0.32$（$p = 0.02$），PAと下肢筋力の間に$r = 0.41$（$p = 0.03$）の相関関係を認めた。重回帰分析の結果，PAの関連要因として下肢筋力が抽出された（$r = 0.48$，$R^2 = 0.23$，$p = 0.02$）。【結論】回復期冠動脈疾患患者のPAは7893歩で，その関連要因として下肢筋力が示された。

キーワード　冠動脈疾患患者，身体活動量，下肢筋力

序　文

動脈硬化性疾患の一次予防が叫ばれる中，我々は冠動脈疾患患者の二次予防として以前から身体活動（physical activity: PA）に着目してきた1)2)。一般的にPAの向上は，総死亡率の低下，高血圧症，糖尿病などの罹患率の低下に寄与する3-6)。PAとは，「安静にしている状態より多くのエネルギーを消費するすべての動きのこと」を指し，運動のみならず仕事や家事など日常生活動作を含めたものと定義されている7)。

これまでのPA向上に関する心疾患領域における報告は，日本循環器学会の「心筋梗塞二次予防に関するガイドライン」の中で，動脈硬化の危険因子の軽減，冠動脈疾患の一次および二次予防に寄与することから，その有効性が示されている8)。またPAに関連する要因の報告では，Berg-Emonsらが，慢性心不全患者を対象とし，PAの要因として下肢筋力が関与することから，心不全患者に対する下肢筋力トレーニングの有用性を示している9)。

このようにPA向上の効果は明らかであるが臨床上の具体的目標値は不明確のままであり，回復期冠動脈疾患患者のPA実態はつかめていない。また冠動脈疾患患者は心疾患の終末像である心不全患者に比し，最高酸素摂取量（peak oxygen uptake：peak $\dot{V}O_2$），下肢筋力，歩行能力および日常生活動作には相違を認め10-12)，PAに関する要因についても異なる可能性がある。

本研究の目的は，回復期冠動脈疾患患者のPAの実態を調査し，運動療法および運動指導における目標値について明らかにすることである。またPAの関連要因についても明らかにし，運動指導の参考にすることである。

対象および方法

1. 対象

対象は，2001年5月から2006年5月の間に，聖マリアンナ医科大学病院ハートセンターに急性心筋梗塞症あ

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* Relationships between Physical Activity and Lower Extremity Muscle Strength at Entry into Recovery Phase by Patients with Coronary Artery Disease

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