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CLINICAL INVESTIGATIONS

Effects of hydraulic circuit training following coronary artery bypass surgery

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ABSTRACT

HAENNEL, R. G., H. A. QUINNEY, and C. T. KAPPAGODA. Effects of hydraulic circuit training following coronary artery bypass surgery. *Med. Sci. Sports Exerc.*, Vol 23, No. 2, pp. 158–165, 1991. The effect of hydraulic circuit training (HCT) on stroke volume (SV), cardiac output (Q_c), aerobic power (peak $\dot{V}O_2$), and muscular strength and endurance was evaluated in 24 post-coronary artery bypass (CABS) patients (mean age = 52.8 ± 2.6 yr). All assessments other than muscular strength and endurance were based upon a symptom limited graded exercise test on a bicycle ergometer. Muscular strength and endurance were assessed on a Cybex II isokinetic dynamometer. Sixteen patients were assigned randomly to 8 wk of cycle training or HCT ($N = 8$ in each). Subjects assigned to cycle training exercised on bicycle ergometers. The HCT group exercised on a three-station circuit, completing three circuits per day. Each circuit consisted of three 20 s work intervals at each station with a 1:1 work:rest ratio. Results from the training groups were compared with results from eight patients who served as a nonexercising control group. Following training the peak $\dot{V}O_2$ was significantly increased in the training groups (20% and 11% for the cycle and HCT groups, respectively; $P < 0.05$). For both training groups, the increase in peak $\dot{V}O_2$ was associated with increases in SV and Q_c and a reduction in heart rate (HR) at submaximal levels of exercise ($P < 0.05$). Only the HCT group demonstrated an increase in both muscular strength and endurance during knee and shoulder exercises ($P < 0.05$). These findings suggest that a program of HCT can elicit improvements in cardiovascular fitness and muscular strength and endurance in post-CABS patients.

EXERTION, PHYSICAL TRAINING, STRENGTH TRAINING

Exercise training has become an integral part of the rehabilitation process for most cardiac patients. Traditional programs focus on aerobic activities such as walking, with the express purpose of improving cardiovascular fitness. While an improvement in cardiovascular fitness is achieved by such programs, they do not address the issue of optimizing upper body muscular strength and endurance (14). Hydraulic circuit training (HCT) is a form of conditioning which influences these parameters favorably and can be devised to condition all the major muscle groups of the body. This type of exercise utilizes hydraulic cylinders to provide concentric exercise for both agonist and antagonist muscle groups involved in a given movement.

Previous investigations have shown that HCT improves maximal aerobic power in healthy middle-aged males (12). In the case of cardiac patients, HCT offers a potential advantage over other forms of resistance training. The passive nature of hydraulic devices minimizes the risk of muscular and joint strain which can result from the lifting and lowering of weights in a controlled manner. In addition, HCT is performed in an interval fashion, which reduces the need for a sustained stress on the cardiovascular system, such as that associated with continuous aerobic exercise.

The purpose of the present study was to demonstrate the effect of a program of HCT on the stroke volume response to dynamic exercise in a group of patients recovering from coronary artery bypass surgery (CABS). The changes in cardiac output (Q_c), aerobic power, muscular strength, and muscular endurance were evaluated also.

METHODS

Subject selection and general plan of study. The study was performed on 24 male patients 9–10 wk following CABS. All patients enrolled were in NYHA Class I or II and had no angina following surgery. The patients were instructed as to the nature of the study, and written informed consent was obtained. The study was approved by the Ethics Committee of the Faculty of Medicine at the University of Alberta. Sixteen of the patients were randomly assigned to either a cycle training or HCT group ($N = 8$ in each). Their results were compared with the responses from eight patients who did not wish to participate in an exercise program but volunteered to serve as a nonexercising control group. The study was designed in this way so as not to withhold

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exercise training program from any patient who wished to participate in one.

A routine clinical examination was performed before and after the training period. In addition, the following investigations were performed at these times: i) electrocardiogram (ECG), ii) symptom limited graded exercise test (SL-GXT), iii) measurements of muscular strength and endurance, and iv) estimation of body fat from skinfold thicknesses (24). The control group underwent the same sequence of investigations at corresponding time intervals. Angiography was not undertaken before commencement of the study.

Measurement of aerobic power. Aerobic power was defined as the peak oxygen uptake (peak $\dot{V}O_2$) achieved during a SL-GXT on a bicycle ergometer (model 740, Siemens Electric Ltd.). The $\dot{V}O_2$ was measured at each workload using a continuous flow technique (1). All patients were familiar with the apparatus. The workload was set initially at 30 W and subsequently increased by 20 W every 3 min until one or more of the following endpoints were achieved: attainment of a plateau or a decrease in $\dot{V}O_2$ with consecutive workloads (as indicated by a change <100 ml$\cdot$min^{-1}), attainment of 90% age predicted maximal heart rate, severe dyspnea, volitional exhaustion (Borg scale reading >18), chest pain, dizziness, electrocardiographic evidence of ischemia (≥ 1.0 mm horizontal or downsloping ST segment depression), or an abnormal blood pressure response (3).

Measurement of cardiac output. Stroke volume (SV), cardiac output (Q_c), and heart rate (HR) were measured by impedance cardiography (Minnesota Impedance Cardiograph, model 304A, Surcom Inc.). The use of this technique has been validated in this laboratory for endurance trained young male subjects and cardiac patients, both at rest and during exercise (16,30). The random error of the Q_c measurement as indicated by the coefficient of variation was $<5\%$ (30).

Readings were made at rest and immediately (within 3 s) upon completion of each workload during the SL-GXT. To avoid artifact due to respiratory movement during the measurements, subjects were required to stop pedaling and to hold their breath at normal end-expiration. The average of five cardiac cycles was used in the calculation of SV.

Blood pressure (BP) was measured using a mercury sphygmomanometer during the 2nd min of each stage of the SL-GXT. Mean arterial pressure (MAP) was determined at rest and during exercise by adding one third of the pulse pressure to the diastolic blood pressure (DBP). Systemic vascular resistance (SVR) was calculated by dividing the MAP by the Q_c (mm Hg$\cdot$min$\cdot$l^{-1}). The rate pressure product (RPP) was calculated by multiplying the HR by the systolic blood pressure (SBP) and was designated in arbitrary units (HR$\cdot$SBP$\cdot 10^{-2}$).

Measurement of muscular strength and endurance. A Cybex II isokinetic dynamometer (Lumex, Inc.) equipped with a two-channel recorder was used to measure muscular strength and endurance. Muscular strength was defined as the peak torque (N$\cdot$m) recorded during a given exercise. Muscular endurance was defined as the total work (kJ) accumulated over 12 repetitions of a given exercise and was estimated by multiplying the torque-time integral (N$\cdot$m$\cdot$s^{-1}) by the angular velocity (rad$\cdot$s^{-1}) (25). Measurements were made during a series of right knee extension/flexion and right shoulder extension/flexion exercises using the method described by Sapega et al. (26). All assessments were completed at a velocity of 3.14 rad$\cdot$s^{-1}. Prior to the assessments, the patients were familiarized with the system and the required limb actions. Limb alignment and stabilization procedures were standardized for each test. Upon completion of a given exercise, the recordings of the torque curves were examined to ensure that the subject had exerted a maximal effort, which is characterized by a gradual degradation of peak torque height with repeated contractions (26).

Training program. Upon completion of all preliminary assessments, the training subjects were randomly assigned to either a cycle training or HCT program. The cycle training group exercised 3 d$\cdot$wk^{-1} for 8 wk on bicycle ergometers. Each training session incorporated 24 min of continuous cycling and was preceded by a 5 min warm-up and followed by a 5 min cool-down period during which the patients exercised at zero load. The intensity of the training sessions was adjusted every 2 wk to maintain a workload corresponding to approximately 70% of the heart rate reserve (18).

Those subjects assigned to HCT exercised on a three-station hydraulic resistance device (Total Power Unit, Hydra-Fitness Canada Ltd.). The following movement patterns were employed: bilateral knee extension and flexion (knee exercise), bilateral elbow extension and flexion (chest exercise), and bilateral shoulder extension and flexion (shoulder exercise). These exercise stations were arranged in such a way that the patients completed the chest exercise first, followed by the knee and shoulder exercises, respectively. The circuit consisted of three 20 s work intervals at each exercise station with a 1:1 work:rest ratio. The first two work intervals were followed by 20 s rest intervals, while the third work interval was followed by a 60 s rest interval. Subjects completed three circuits per day. The cylinder settings on the hydraulic devices were adjusted every 2 wk to ensure that patients could complete 12–16 repetitions for the chest and knee exercises and 8–12 repetitions for the shoulder exercise. The duration of each training session was 24 min, and it was preceded by a 5 min warm-up and followed by a 5 min cool-down during which the patients exercised on the hydraulic device at a reduced intensity.

Estimation of the training stimulus. The training stimulus was assessed in two ways. First, the HR and BP responses to training were monitored daily. The HR was monitored continuously using a CM_5 lead (Critical Care model 128A, Kontron Medical Ltd.). The blood pressure response was measured using a mercury sphygmomanometer. For the cycle training group, HR and BP were measured during steady-state exercise. For the HCT group, the HR response was recorded at the completion of each work and rest interval. The BP response was assessed during completion of the bilateral knee exercise only. (For the HCT group, the RPP was calculated using the HR and SBP responses obtained during the knee exercise.)

Second, the metabolic demand, as indicated by the $\dot{V}O_2$ and Q_c, associated with the training programs, was assessed during a single exercise session after the completion of the first 2 wk of training. For the cycle group, $\dot{V}O_2$ was monitored continuously throughout the training session. The Q_c was measured at intervals of 5 min. For the HCT group, the same measurements were recorded during the third work interval of each exercise and during the rest interval at the completion of each circuit. The values for $\dot{V}O_2$, Q_c, and SV reported here are the group means for the entire session in which the measurements were made.

Statistical analysis. Group data are expressed as mean ± SEM. Baseline measurements were compared using a two-way analysis of variance to assess discrepancies between groups (29). A test of least significant difference was performed to assess the significance of the specific differences. The 8 wk data in the three groups were assessed by a second two-way analysis of variance. The magnitude of the *changes* which occurred during these 8 wk in the three groups was compared by a two-way analysis of variance of the differences.

The heart rate/workload relationship was examined by regression analysis (method of least squares). When regression lines were being compared, an analysis of covariance was used (29).

RESULTS

The study was completed on 24 male patients recovering from CABS. Mean (± SEM) values for their physical characteristics were: age, 52.8 ± 2.6 yr; height, 1.77 ± 0.02 m; and weight, 81.1 ± 3.8 kg. The peak $\dot{V}O_2$ for all subjects, assessed on a bicycle ergometer, was 1.58 ± 0.09 $l \cdot min^{-1}$. There were no significant changes in body weight or percent body fat in the three groups over the course of the study. There were no changes in medication over the course of the study. Patients on beta-blocking agents were not excluded from the study as it has been shown that beta blockade does not prevent such patients from demonstrating exercise training effects (6). Four out of eight patients in the control group were taking beta blockers, which could account for the slightly lower Q_c at rest in this group at the commencement of the study. This difference was not evident at the end of the study (Tables 1 and 2).

The Training Stimulus (Table 3)

Cycle group. The mean HR during the training sessions was 130 ± 3 $beats \cdot min^{-1}$, which corresponded to 68% of HR reserve. The average SBP and RPP were 157 ± 8 mm Hg and 202 ± 7 units, respectively. The $\dot{V}O_2$ associated with the cycle training was 1.16 ± 0.05 $l \cdot min^{-1}$, or 71% of the peak $\dot{V}O_2$ demonstrated at the pre-training SL-GXT. The corresponding SV and Q_c responses to cycle training were 98 ± 5 $ml \cdot beat^{-1}$ and 12.8 ± 0.8 $l \cdot min^{-1}$, respectively.

HCT group. The mean HR response during the training sessions was 113 ± 3 $beats \cdot min^{-1}$, which represents 56% of HR reserve. The average SBP and RPP were 152 ± 3 mm Hg and 171 ± 4 units, respectively. The

TABLE 1. Pre-training characteristic of the patients.

	Control	Cycle	HCT
Age (yr)	56.9 ± 1.4^a	51.5 ± 4.0^a	51.1 ± 2.3^a
Height (m)	1.77 ± 0.02^a	1.76 ± 0.02^a	1.78 ± 0.02^a
Weight (kg)	83.9 ± 3.3^a	77.7 ± 4.6^a	79.1 ± 3.6^a
% Body fat	25.9 ± 2.5^a	22.9 ± 1.4^a	23.4 ± 1.9^a
Weeks post-surgery ($\bar{X}$)	9.1 ± 0.2^a	9.2 ± 0.4^a	9.6 ± 0.4^a
No. of vessels bypassed			
($\bar{X}$)	2.9	2.8	2.8
(range)	2–3	2–5	2–4
Previous M.I. location	5	3	4
Anterior	3	2	3
Inferior	1	1	—
Ant. + Inf.	1	—	1
Drugs			
ACE inhibitors	1	1	1
Beta blockers*	4	1	2
Ca^{2+} blockers	—	3	—
Digoxin	2	—	—
Dipyridamole	6	7	8

Values are expressed as mean ± SEM. Values with similar superscripts denote no significant difference ($P > 0.05$). M.I.: myocardial infarction.

* All patients taking beta blockers were prescribed metoprolol (50 mg twice daily).

TABLE 2. The cardiovascular parameters at rest.

	Control	Cycle	HCT
Pre-training			
N	8	8	8
HR	77 ± 5^a	85 ± 3^a	85 ± 5^a
SV	67 ± 5^a	73 ± 3^a	71 ± 3^a
Q_c	5.1 ± 0.2^a	6.2 ± 0.3^b	6.0 ± 0.4^{ab}
MAP	91 ± 3^a	90 ± 3^a	92 ± 3^a
RPP	93 ± 6^a	102 ± 4^a	107 ± 8^a
Post-training			
HR	76 ± 4^a	$73 \pm 4^{a*}$	$74 \pm 5^{a*}$
SV	69 ± 6^a	$81 \pm 4^{b*}$	$79 \pm 4^{b*}$
Q_c	5.3 ± 0.3^a	5.9 ± 0.4^a	5.8 ± 0.4^a
MAP	89 ± 3^a	89 ± 4^a	87 ± 2^a
RPP	88 ± 6^a	$88 \pm 5^{a*}$	$82 \pm 6^{a*}$

Values are expressed as mean ± SEM. HR = heart rate ($beats \cdot min^{-1}$); SV = stroke volume ($ml \cdot beat^{-1}$); Q_c = cardiac output ($l \cdot min^{-1}$); MAP = mean arterial pressure (mm Hg); RPP = rate pressure product (units). *For each parameter*, values with similar superscripts indicate no significant difference ($P > 0.05$).

* Significant difference vs pre-training data ($P < 0.05$).

TABLE 3. Mean HR, blood pressure, and rate pressure product responses to the training programs.

		Cycle	HCT
N		8	8
HR	pre-exercise	66 ± 3^a	60 ± 5^a
	exercise	130 ± 3^c	113 ± 3^b
% HR reserve	exercise	68%	56%
SBP	pre-exercise	116 ± 5^a	116 ± 5^a
	exercise	157 ± 8^b	152 ± 3^b
DBP	pre-exercise	73 ± 3^a	73 ± 2^a
	exercise	79 ± 4^{ab}	83 ± 4^b
RPP	pre-exercise	99 ± 4^a	97 ± 6^a
	exercise	202 ± 7^c	171 ± 4^b

Values are expressed as mean ± SEM and are averaged over the 8 wk of training. *For each parameter*, values with similar superscripts denote no significant difference ($P > 0.05$). HR = heart rate (beats · min^{-1}); SBP = systolic blood pressure (mm Hg); DBP = diastolic blood pressure (mm Hg). RPP = rate pressure product (units). For the HCT group, RPP was calculated using the HR and SBP responses to the knee exercise. % HR reserve = [(exercise HR − RHR)/(peak HR − RHR)] × 100. RHR = resting HR which was taken from the pre-training SL-GXT. Peak HR was taken from the highest HR obtained from the pre-training SL-GXT.

$\dot{V}O_2$ during the work intervals was 1.05 ± 0.05 l · min^{-1}, and it was 0.87 ± 0.05 l · min^{-1} during the rest intervals. The $\dot{V}O_2$ during the work intervals averaged 67% of the peak value observed during the pre-training SL-GXT. The SV and Q_c responses to HCT were 93 ± 6 ml · beat^{-1} and 11.1 ± 0.9 l · min^{-1}, respectively. It is emphasized that the measurements for HCT, unlike those in the cycle group, do not represent steady state measurements.

Effects of the Training Programs on the Cardiovascular System

Rest. Training resulted in a significant reduction in HR at rest in both training groups ($P < 0.05$). This reduction in HR was associated with an increase in SV. In the control group, there were no significant changes in HR or SV. The RPP was significantly lower for both exercising groups following training ($P < 0.05$). There were no significant changes in the Q_c, MAP, or SVR for the three groups (Table 3).

Submaximal exercise. Following training there was a significant reduction in the HR responses to exercise in the cycle training and HCT groups. In the two training groups, the elevations of the regression lines, as indicated by the adjusted means (29), were significantly reduced by training (cycle: $F = 9.8$, $P < 0.01$; HCT: $F = 6.8$, $P < 0.01$). A corresponding difference was not observed in the control group ($F = 1.0$, $P > 0.05$) (Fig. 1). For the cycle training and HCT groups, the reduction in HR was associated with an increase in SV at corresponding values of HR. This effect was not evident in the control group (Fig. 2).

Peak exercise. The peak $\dot{V}O_2$ achieved during the SL-GXT was significantly increased in the two training groups ($P < 0.05$). The increase observed in the cycle group was significantly greater than that observed in the HCT group ($P < 0.05$). For both training groups the increment in peak $\dot{V}O_2$ was associated with an increase in total work at the post-training SL-GXT ($P < 0.05$). As the highest HR did not change in the three groups, the increase in Q_c observed in the training groups may be attributed to an increase in SV ($P < 0.05$ for both). The effects of 8 wk of training on the other cardiovascular variables are presented in Table 4. Overall, the findings in the three patients (one in the cycle group and two in the HCT group) on beta blockers were qualitatively similar to those not taking these drugs.

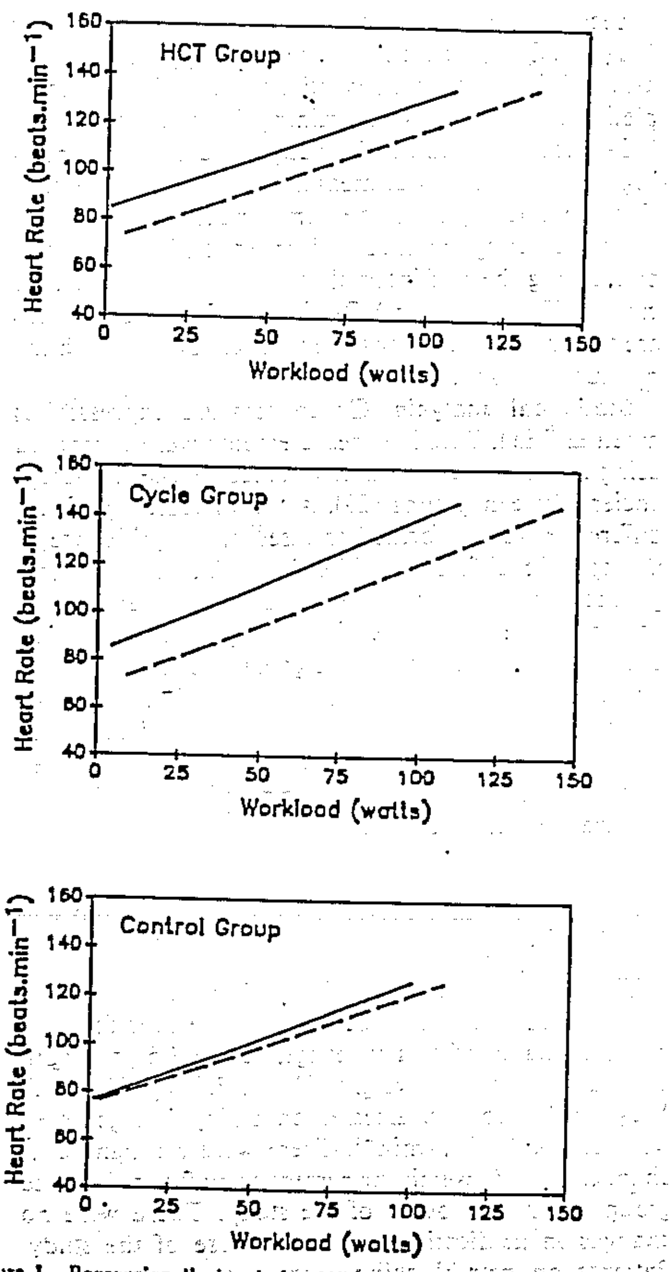

Figure 1—Regression lines relating HR to workload for the three groups before (*solid*) and after (*dashed*) training. *Top*, HCT group: *solid*, $y = 0.44(x) + 84.9$; *dashed*, $y = 0.45(x) + 72.2$. *Middle*, cycle group: *solid*, $y = 0.51(x) + 84.4$; *dashed*, $y = 0.52(x) + 68.6$. *Bottom*, control group: *solid*, $y = 0.49(x) + 76.1$; *dashed*, $y = 0.47(x) + 74.3$.

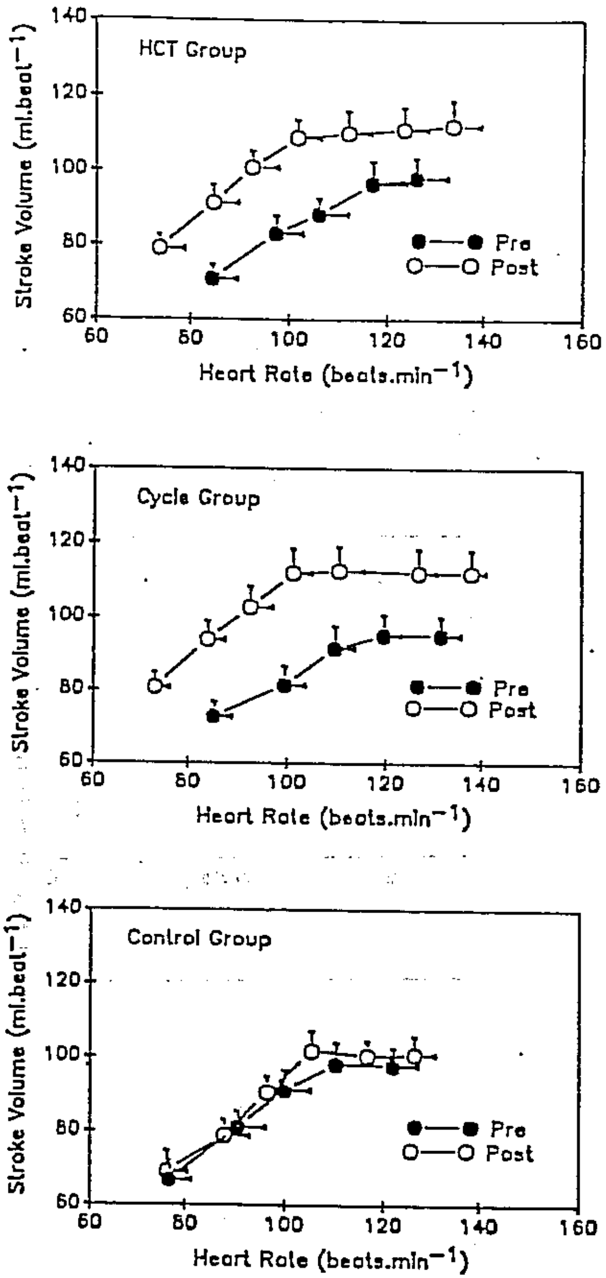

Figure 2—Mean heart rate/stroke volume profile of the three groups pre- (*filled circles*) and post-training (*open circles*). For each group, the data points represent the coordinates of the mean heart rate/stroke volume response to the particular workload during the SL-GXT. The data presented are limited to those workloads which all subjects in a particular group completed. The peak stroke volume is increased in the cycle and HCT groups following training.

Muscular Strength and Endurance

Muscular strength. Alterations in peak torque resulting from training are presented in Table 5. For the HCT group, the peak torque recorded during knee extension and flexion and during shoulder extension and flexion was significantly increased following training ($P \leq 0.05$). The cycle trained group recorded a significant increase in peak torque during knee extension only ($P < 0.05$). No changes in peak torque were observed in the control group.

Work. Following training the HCT group recorded a significant increase in accumulated work during both knee and shoulder exercise ($P < 0.05$ for both). The cycle group demonstrated a significant increase in accumulated work only during the knee exercise ($P < 0.05$). There were no significant changes in accumulated work observed in the control group (Fig. 3).

DISCUSSION

The present study was undertaken to determine the efficacy of HCT on SV and muscular strength and endurance of patients recovering from CABS. A conventional program of physical training involving dynamic exercise causes an increase in maximum aerobic power. These changes are associated with a reduction in HR and SV at submaximal workloads (4). In the investigation reported here, a group undergoing dynamic exercise training on a bicycle ergometer was included in order to establish our ability to demonstrate the anticipated effects of this form of training. As expected, in the bicycle training group a decrease in HR and an increase in SV were observed at submaximal workloads. Similar changes were observed in the HCT group also. In addition, the HCT group demonstrated increases in muscular strength and endurance in both upper and lower limbs.

Peak exercise. The studies completed to date have focused mainly on the adaptations of CABS patients to aerobic training programs. The 20% increase in peak $\dot{V}O_2$ observed in the cycle trained group was similar to that reported for other surgically treated patients following cycle training (13,23). The finding of 14% increase in peak $\dot{V}O_2$ for the HCT group has not been reported previously. However, this finding is consistent with results reported by Kelemen et al. (19), who noted a 12% increase in treadmill time among cardiac patients who completed a 10 wk circuit weight training program.

There are some aspects of these measurements which merit comment. In normal individuals, the criteria for estimation of maximal aerobic power are well defined. These are the attainment of plateau in heart rate and $\dot{V}O_2$ with exhaustion in the face of increasing workloads (3). In patients with heart disease, there are practical difficulties in achieving these criteria. The conventional practice of resorting to a symptom limited graded exercise test (SL-GXT) under these circumstances may well underestimate the "maximal" value and thereby distort the effect of a training program. In the present study, although the workloads achieved in the pretraining SL-GXT were similar in the three groups, the physiological endpoints such as HR and $\dot{V}O_2$ were different (Table 4). Thus, the maximal nature of the

BLE 4. Changes observed at peak exercise over the study period.

	Control		Cycle		HCT	
	Pre	Post	Pre	Post	Pre	Post
Peak $\dot{V}O_2$ (+)	1.50 ± 0.09^a	1.57 ± 0.08^a	1.64 ± 0.12^b	1.97 ± 0.08^d	1.58 ± 0.05^{ab}	1.80 ± 0.08^c
Peak $\dot{V}O_2$ (#)	18.0 ± 1.1^a	18.7 ± 1.1^a	21.4 ± 1.7^b	25.7 ± 1.5^d	21.2 ± 1.2^b	23.6 ± 1.1^c
Highest WL	100 ± 5^a	110 ± 4^{ab}	112 ± 5^b	145 ± 8^d	108 ± 7^a	130 ± 9^c
HR	127 ± 5^a	128 ± 5^a	151 ± 2^b	150 ± 3^b	135 ± 6^a	137 ± 6^a
SV	97 ± 5^a	100 ± 3^a	95 ± 5^a	112 ± 6^b	98 ± 5^a	110 ± 5^b
Q_c	12.3 ± 0.5^a	12.8 ± 0.7^a	14.3 ± 0.4^b	16.8 ± 0.4^c	13.1 ± 0.7^a	15.1 ± 0.9^c
MAP	113 ± 3^a	112 ± 3^a	115 ± 4^a	113 ± 5^a	108 ± 4^a	108 ± 4^a
SL-GXT terminated due to:						
Fatigue	5	4	2	1	5	5
$\dot{V}O_2$/HR	2	3	5	6	2	3
Symptoms	1	1	1	1	1	0
Angina	0	0	0	0	0	0

Values are expressed as mean ± SEM. $N = 8$ in each group. For each parameter, values with similar superscripts indicate no significant difference ($P > 0.05$). WL = workload (W); peak $\dot{V}O_2$ = peak oxygen uptake; (+) = $l \cdot min^{-1}$; (#) = $ml \cdot kg^{-1} \cdot min^{-1}$; HR = heart rate ($beats \cdot min^{-1}$); SV = stroke volume ($ml \cdot beat^{-1}$); Q_c = cardiac output ($l \cdot min^{-1}$); MAP = mean arterial pressure (mm Hg).

TABLE 5. Changes in muscular strength (peak torque) demonstrated on a Cybex II isokinetic dynamometer during exercise at 3.14 $rad \cdot s^{-1}$.

	Control		Cycle		HCT	
	Pre	Post	Pre	Post	Pre	Post
Knee						
Extension	80 ± 3	82 ± 4	74 ± 15	$97 \pm 7^*$	89 ± 11	$111 \pm 10^*$
Flexion	52 ± 7	59 ± 6	48 ± 11	67 ± 6	68 ± 6	$81 \pm 5^*$
Shoulder						
Extension	53 ± 8	58 ± 8	49 ± 10	59 ± 6	61 ± 6	$81 \pm 7^*$
Flexion	35 ± 5	40 ± 4	35 ± 6	39 ± 4	42 ± 4	$52 \pm 4^*$

es are in N·m and are expressed as mean ± SEM; $N = 8$ in each group.
.e vs post data significantly different ($P < 0.05$).

effort exerted during the tests could be questioned. However, within each group, the endpoints for individual patients in the two tests were similar (Table 4). Hence, it is suggested that both forms of training are likely to enhance aerobic power, but no conclusions could be drawn regarding the relative effects of the two.

In addition, the situation could be complicated further by the "specificity principle", whereby the changes induced by training are specific to the muscles involved and to the pattern in which they are used (21). Thus, using a bicycle ergometer to compare the effects of cycle training with HCT could bias the results in favor of cycle training. However, as Gettman and Pollock (11) reported, the relative changes induced by exercise training on different modalities were evident even when evaluated by nonspecific tests.

As the peak HR did not change over the course of the study, the increase in peak $\dot{V}O_2$ observed in the training groups may be attributed to an increase in maximal SV (Table 4). The increase in SV observed in the cycle trained patients is in agreement with previous reports on dynamic exercise training following myocardial infarction (5,9). The increase in SV following HCT [illegible]nsistent with findings in healthy individuals following a program of HCT (12) or circuit weight training (10).

Submaximal exercise. The criteria used for assessing a training response at submaximal workloads do

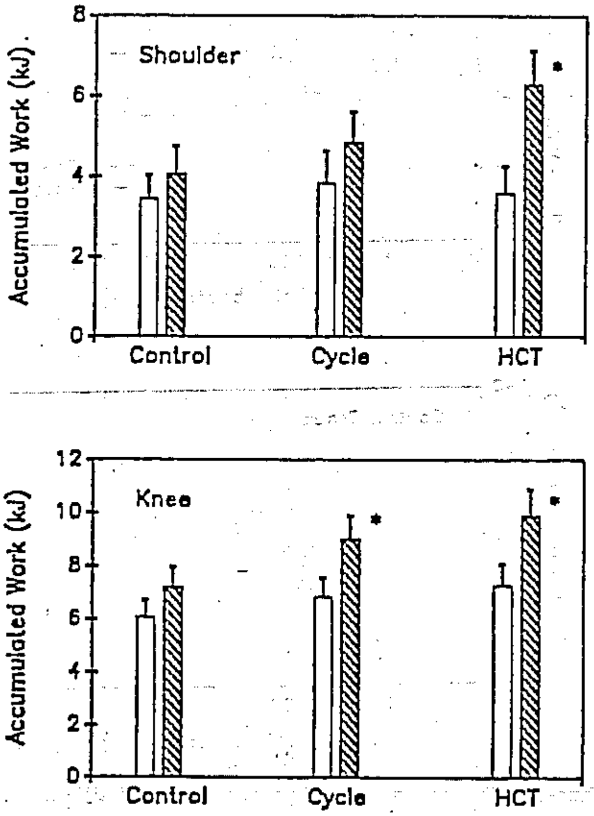

Figure 3—Accumulated work over 12 repetitions of knee extension/flexion and shoulder extension/flexion exercise at 3.14 $rad \cdot s^{-1}$ on a Cybex II isokinetic dynamometer. *Open bars*: pre-training; *hatched bars*: post-training. *Pre vs post test significantly different ($P < 0.05$).

not suffer from the logistic difficulties described above for maximal exercise. It is accepted that the most common response of the cardiovascular system to exercise training is a reduction in HR at submaximal loads. Such a change was observed in both training groups (Fig. 1).

The HR-SV relationship in the three groups is also of interest. The pre-training HR-SV profiles for the three groups were characterized by an increase in SV from rest to a maximum value, which was achieved at

HRs between 100 and 120 beats·min^{-1}. This peak SV was subsequently retained through peak HRs and workloads. These observations are similar to those reported previously in untrained middle-aged males (15). Following training, the HR-SV profiles of the exercising groups were altered, such that for a given HR there was an increase in SV (Fig. 2). Although this relative increase in SV is likely to be a consequence of an increase in ventricular volume, a change in myocardial contractility cannot be excluded (27,28). The control group did not show a similar change.

Muscular strength and endurance. Compared with the control and cycle trained groups, the HCT group demonstrated a significant increase in peak torque during knee flexion and shoulder flexion and extension. The HCT group also demonstrated a significant increase in accumulated work about the shoulder when compared with the control and cycle trained groups. The gains in muscular strength observed for the HCT group were similar to those reported in cardiac patients (19) and healthy individuals following a program of circuit weight training (10). Present findings suggest that patients recovering from CABS can safely participate in a HCT program with the expectation of improving muscular strength and endurance. This improvement may be of practical importance to cardiac patients as many occupational and recreational activities entail a combination of static and dynamic exertion of the arm rather than the leg (7,8). In addition, previous studies (20,22) have shown that the pressor response to static exertion is proportional to both the muscle mass involved and the percentage of maximal voluntary contraction (%MVC). The increase in strength demonstrated by the HCT group may attenuate the HR and blood pressure responses to a given load because that load now represents a lower %MVC. Such improvements may facilitate a safe return to employment.

The training stimulus. The threshold intensity necessary to produce a cardiovascular training effect has been reported to be approximately 60% of maximal HR reserve (2). On the basis of this calculation, using the pre-training SL-GXT data, the overall HR response to training averaged 68% and 56% of the HR reserve for the cycle and HCT groups, respectively (see Table 3). These findings suggest that the magnitude of the HR response to HCT is sufficient to improve aerobic power. However, it is necessary to emphasize a r. [illegible] of caution in making an extrapolation of this nature. HCT, unlike a continuous dynamic activity such as cycling, involves "non-steady-state" exercise. Thus, comparisons of calculated training intensities based upon the cardiovascular responses such as HR are likely to be erroneous when fundamentally different forms of exercise are being considered.

An alternative method of assessing the training stimulus is the aerobic demand associated with the program. It has been suggested that the overall aerobic demand associated with circuit strength training programs, such as HCT, may be insufficient to achieve a cardiovascular training effect (17). However, the mean $\dot{V}O_2$ for the HCT group during the work and rest intervals averaged 67% and 55% (respectively) of the peak $\dot{V}O_2$ observed during the initial SL-GXT. The corresponding value in the cycling group was 71%. These findings suggest that this three-station HCT program meets the recommended intensity for an aerobic training stimulus.

A major concern regarding the use of strength training exercises in cardiac rehabilitation is the possibility of an exaggerated increase in blood pressure. In the present study, both SBP and DBP increased in response to the HCT knee exercise, but these values were not significantly different from those observed durin[illegible]e SL-GXT. No significant cardiac arrhythmias were observed during the HCT in this group of patients. It is important to emphasize that the increased demands on the cardiovascular system during HCT occur in bouts of short duration (e.g., 20 s periods of this study). With more conventional forms of dynamic exercise training such as cycling, the demands on the cardiovascular system are sustained over a relatively long period (e.g., 20–25 min). This difference is potentially advantageous in patients with heart disease.

The present findings show that HCT provides a stimulus of sufficient intensity to improve both cardiovascular fitness and muscular strength and endurance among post-CABS patients.

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