Aerobic and Resistance Training in Coronary Disease: Single versus Multiple Sets

SUSAN MARZOLINI1,2, PAUL I. OH1, SCOTT G. THOMAS3, and JACK M. GOODMAN3

1Toronto Rehabilitation Institute, Cardiac Rehabilitation and Secondary Prevention Program, Toronto, Ontario, CANADA
2Institute of Medical Science, University of Toronto, Toronto, Ontario, CANADA; and 3Faculty of Physical Education and Health, University of Toronto, Toronto, Ontario, CANADA

ABSTRACT

MARZOLINI, S., P. I. OH, S. G. THOMAS, and J. M. GOODMAN. Aerobic and Resistance Training in Coronary Disease: Single versus Multiple Sets. Med. Sci. Sports Exerc., Vol. 40, No. 9, pp. 1557–1564, 2008. Purpose: The purpose of this study was to compare resistance training (RT) (one set vs three sets) combined with aerobic training (AT) versus AT alone in persons with coronary artery disease. Methods: Subjects (n = 72) were randomized to AT (5 d wk−1) or combined AT (3 d wk−1) with either one set (AT/RT1) or three sets (AT/RT3) of RT performed 2 d wk−1. VO2peak, ventilatory anaerobic threshold (VAT), strength and endurance, body composition, and adherence were measured before and after 29 wk of training. Results: Fifty-three subjects (mean ± SEM age 61 ± 2) completed the training. The increase from baseline in VO2peak (L·min−1) averaged 11% for AT (P < 0.05), 14% for AT/RT1 (P < 0.01), and 18% for AT/RT3 (P < 0.001), however, the difference between groups was not significant. VAT improved significantly in the AT/RT3 group only (P < 0.05). The AT/RT3 group gained more lean mass than the AT group (1.5 versus 0.4 kg, P < 0.01), yet gains between AT/RT1 and AT were similar (P = 0.2). Only AT + RT groups demonstrated a reduction in body fat (P < 0.05). Strength and endurance increased more in the AT + RT groups than AT alone (P < 0.05). Adherence to number of sets performed was lower in AT/RT3 than AT/RT1 (P < 0.02). Conclusions: Combined AT + RT yields more pronounced physiological adaptations than AT alone and appears to be superior in producing improvements in VO2peak, muscular strength and endurance, and body composition. The data support the use of multiple set RT for patients desiring an increased RT stimulus which may further augment parameters that affect VO2peak, VAT, lower body endurance, and muscle mass in a cardiac population. Key Words: CARDIAC REHABILITATION, BODY COMPOSITION, OXYGEN UPTAKE, ADHERENCE

Combined aerobic training (AT) and resistance training (RT) rehabilitation programs are rapidly becoming standard treatments for individuals with coronary artery disease (CAD). Although recommendations for the AT prescription are widely known, the RT prescription when combined with AT remains unclear. Recently established RT practice guidelines for patients with CAD advocate the use of one set of six to ten exercises (41). Although the one set intervention may yield desired gains in strength, other key outcomes including body composition, VO2peak, ventilatory anaerobic threshold (VAT), and local muscular endurance may benefit from a greater stimulus; yet it is unknown if more substantial gains in these parameters can be realized with multiple set RT. Prescribing the appropriate volume of RT remains a dilemma for the exercise specialist guiding CAD patients toward the goals of eliciting the optimal muscle mass accretion and associated benefits.

The loss of muscle mass secondary to aging and physical inactivity is of clinical relevance in the cardiac population given its association with a lower resting metabolic rate which leads to gains in fat mass (39), and its contribution to diminished exercise performance (VO2peak) (10). The amount and distribution of fat combined with a reduction in skeletal muscle mass is associated with elevated cardiovascular and diabetes risk (8,11). Moreover, reductions in muscular strength and endurance, contribute to increased risk of injury from falls, decreased ability to perform activities of daily living, and loss of independent living (10,40). This suggests that restoring muscle mass in patients with CAD
may optimize the response to aerobic conditioning. In fact, indirect evidence supports the contention that multiple sets may be more effective at increasing muscle mass than the single set intervention (16,30), however, this has not been examined in a cardiac population. Accordingly, we sought to determine whether multiple sets of RT exercises would provide significantly greater improvements in physiological parameters than one set of exercises without negatively affecting adherence. We hypothesized that three sets of RT combined with AT would elicit more profound physiological gains than AT combined with one set of RT or than AT alone.

METHODS

Subjects and study design. Subjects were eligible for the study if they had documented CAD and in the 6 months before the study did not participate in more than 20 min of aerobic or resistance exercise more than twice weekly. Exclusion criteria included uncontrolled hypertension defined as a systolic blood pressure >160 mm Hg or diastolic blood pressure >110 mm Hg; inguinal hernia; proliferative diabetic retinopathy; musculo-skeletal limitations that would be aggravated by RT; severe depression; severe chronic obstructive pulmonary disease; peripheral vascular disease; and current tobacco use. The study was approved by the Research Ethics Boards of the Toronto Rehabilitation Institute and University of Toronto and informed written consent was obtained from each subject.

Baseline testing to assess VO_{2peak}, VAT, body composition, and muscular strength, and endurance was conducted before the initiation of exercise and randomization to treatment groups. The assignment to the respective groups was performed by random draw by an independent observer uninvolved in the study. Three options for group assignments (AT, AT/RT1, and AT/RT3) were identified on an equal number of identical cards and blindly chosen from a selection box. This method was maintained for the duration of subject recruitment and no reassignment of treatment group occurred. All subjects participated in AT 5 d\text{-}wk^{-1} in the first 5 wk of the study after which the combined training groups replaced 2 AT days with RT (one set for AT/RT1 and three sets for AT/RT3), while the AT group continued with AT 5 d\text{-}wk^{-1} for a further 24 wk. Supervised exercise training was performed once per week at the Centre (23 AT sessions and 6 RT sessions for combined training groups) with the balance being conducted in the home/community, thereby mitigating the inconvenience of multiple supervised sessions which has proved to be both safe and effective (23). Patients were required to keep a detailed record of each exercise session, noting the precise distance walked/jogged, duration, resting and peak heart rate, Borg rating (3), and any symptoms experienced during exercise. RT records included the Borg rating of the last repetition of the last set performed, any symptoms encountered, the amount of weight lifted, and the number of repetitions and sets performed for each workout. This log was submitted and cross-validated by a cardiac rehabilitation supervisor at the patient’s weekly visit to the Centre. Patients were trained to measure resting and exercise heart rates at orientation to the program and accuracy was checked at each weekly visit to the center.

Exercise intervention. Subjects from all three groups participated in the AT program, which included 30 to 60 min of walking and/or jogging. The initial walking prescription was set at a distance of approximately 1.6 km and an intensity equivalent to 60% of VO_{2peak} (see exercise testing below). Prescriptions were progressed every 2 wk, increasing distance to a maximum of 6.4 km and then increasing intensity to a maximum of 80% of VO_{2peak} (maximum duration of 60 min). Thereafter, training intensity was adjusted to maintain an exercise heart rate equivalent to that achieved at 80% of VO_{2peak} on the graded exercise test. Exercise diary information, heart rates measured at the centre, as well as communication with the patient assisted the cardiac rehabilitation supervisor in deciding when to increase the pace and/or distance of the exercise.

Subjects randomized to AT/RT1 or AT/RT3 attended 6 RT exercise training sessions during their scheduled weekly classes within a period of 24 wk; three consecutive weekly RT classes at weeks 6, 7 and 8 and follow-up sessions at weeks 12, 16, and 22. Exercises included three specific to the lower body (2 with dumbbells one with Theraband™ exercise bands), 5 upper body (dumbbells) and two trunk-stabilizing exercises (patient’s body weight). Each exercise was designed to target a single muscle group only once during a single circuit. All patients performed the bent over dumbbell row, half squat, alternating right and left arm bicep curl, heel raises, standing lateral raise, leg curl, supine lateral raise, curl up abdominal exercise, tricep extension, and four point alternate arm and leg lift. Subjects were initially prescribed a weight load equivalent to 60% of 1 repetition maximum (1RM) (described below) or the exercise band that was one band color below the 1RM. Patients were advised to gradually progress from 10 to 15 repetitions and then to increase resistance by 5 kg or one band level and reduce repetitions to 10. After subsequent testing procedures at weeks 16 and 22 the weight load was progressed to 70% to 75% of 1RM.

Exercise testing. A symptom-limited graded exercise test on a cycle ergometer (Ergoline 800 EL) was performed by all patients. This testing is standard practice at the cardiac rehabilitation program and eliminates the effects of habituation of walking and results in minimal ECG interference due to negligible upper body movement. Workload was increased by 16.7 W every minute and breath-by-breath gas samples were collected and averaged over a 20-s period via calibrated metabolic cart (Vmax SensorMedics 2900). The technician and supervising physician were blinded to the group assignments of all subjects. VO_{2peak} and the VAT were determined, the latter by the V-slope method (1) by two independent assessors blinded to group assignments.
12 lead electrocardiogram (Marquette Case 800) was monitored continuously. 

**Body composition and dietary assessment.** Total body and regional measurements (arms, legs, and trunk) of lean and percent fat were determined by dual energy x-ray absorptiometry. Scheduling issues required 45 subjects to be evaluated on one device (General Electric Lunar Corporation, Madison, WI, enCORE 2002 software, version 6.50.069) and eight subjects on another (Hologic QDR 4500 W, Software version 12.3). Each subject was tested on the same scanner pretraining and posttraining by the same operator blinded to group assignment.

Each patient completed a 3-d food record (including 1 weekend day) at weeks 0 and 29. Records were analyzed using Nutritionist Pro software version 2.3.1 (2006 First Databank Inc.). The analyst was blinded to the patient assignment.

**Strength and local muscular endurance assessment.** The 1RM test was performed on 8 of 10 exercises, excluding the alternate arm and leg lift and the abdominal curl up. After three repetitions of a warm-up weight, a slightly heavier weight was attempted one time after a 2-min recovery period. One repetition at a heavier weight was attempted every 2 min until the patient was unable to lift the weight with proper technique. Maximal isokinetic knee extension/flexion strength (N·m) was tested on an isokinetic dynamometer (Biodex Corporation, Shirley, USA) at a test velocity of 60°·s⁻¹. Local muscular endurance was measured on a separate day from strength and was determined from two exercises (leg curl and bicep curl) performed to exhaustion at a load of 60% of the subjects' original 1RM at a rate of 2-s concentric and 3-s eccentric.

**Adherence to exercise.** Indices of exercise adherence were examined through several measures determined by attendance records and exercise logs including: the number of weekly sessions attended; the distance, duration, preexercise and postexercise heart rates for AT; and weight, repetitions, and sets performed per exercise for RT participants. Mean AT heart rate was calculated using the immediate 10-s postexercise heart rates recorded on the exercise logs.

**Statistical analysis.** All data are expressed as the mean ± SEM. Differences between the groups at baseline were assessed using independent samples Student t-tests for continuous variables and χ² tests for categorical variables. Student t-test for paired samples was used to determine within group changes from baseline to posttraining. Between group differences were analyzed by using two-way ANCOVA with baseline measure as the covariate. Probability values <0.05 were considered significant.

### RESULTS

**Subjects.** Sixty-five men and 7 women agreed to participate in the study (60% of the 119 eligible patients). Nineteen subjects (26%) discontinued at least one of the modes of exercise prescribed to them in the 7-month study period (7 from AT, 6 from AT/RT1, and 6 from AT/RT3). These were considered dropouts and were excluded from the final analysis. The reason for dropouts included disinterest (four), relocation (two), medical complications (four), lack of time (two), psychosocial issues (three), and musculoskeletal issues unrelated to AT or RT precluding exercise (four). The final analysis included 16 patients from the AT group, 19 from the AT/RT1 group, and 18 from the AT/RT3 group mean age 61 ± 2 yr. There were no

### TABLE 1. Baseline characteristics.

<table>
<thead>
<tr>
<th></th>
<th>AT (n = 16)</th>
<th>AT/RT1 (n = 19)</th>
<th>AT/RT3 (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>57.9 ± 2.6</td>
<td>60.9 ± 2.3</td>
<td>62.7 ± 2.7</td>
</tr>
<tr>
<td>Male/female (n)</td>
<td>14/2</td>
<td>17/3</td>
<td>17/1</td>
</tr>
<tr>
<td>Primary cardiac diagnosis (%)</td>
<td>4 (25%)</td>
<td>8 (42%)</td>
<td>12 (67%)</td>
</tr>
<tr>
<td>CAD (%)</td>
<td>2 (12.5%)</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td>Myocardial infarction (%)</td>
<td>2 (12.5%)</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
<tr>
<td>Diabetes diagnosis (%)</td>
<td>2 (12.5%)</td>
<td>0*</td>
<td>4 (22%)*</td>
</tr>
<tr>
<td>Beta blocker use (%)</td>
<td>14 (67.5%)</td>
<td>13 (68%)</td>
<td>17 (94%)</td>
</tr>
<tr>
<td>Time postdiagnosis to exercise (wk)</td>
<td>9.8 ± 6.5</td>
<td>14.1 ± 2.5</td>
<td>10.2 ± 1.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.5 ± 2.1</td>
<td>173.8 ± 1.5</td>
<td>170.4 ± 1.7</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>80.4 ± 3.8</td>
<td>83.5 ± 2.8*</td>
<td>75 ± 2.9*</td>
</tr>
<tr>
<td>Body mass index</td>
<td>26.8 ± 0.7</td>
<td>27.6 ± 0.8</td>
<td>25.7 ± 0.7</td>
</tr>
<tr>
<td>Total lean body mass (kg)</td>
<td>54.4 ± 2.6</td>
<td>54.9 ± 1.8</td>
<td>50.5 ± 2.0</td>
</tr>
<tr>
<td>Total percent body fat</td>
<td>29.8 ± 1.4</td>
<td>31.2 ± 1.2</td>
<td>29.6 ± 1.3</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SEM, unless otherwise indicated. * Significant difference in baseline values (P < 0.05).

### TABLE 2. Cardiopulmonary exercise test and strength data.

<table>
<thead>
<tr>
<th></th>
<th>AT group (n = 14)</th>
<th>AT/RT1 group (n = 18)</th>
<th>AT/RT3 group (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂peak (mL·kg⁻¹·min⁻¹)</td>
<td>21.4 ± 0.9</td>
<td>23.4 ± 1.2†</td>
<td>20.3 ± 1.3</td>
</tr>
<tr>
<td>VO₂peak (L·min⁻¹)</td>
<td>1.66 ± 0.10</td>
<td>1.83 ± 0.12†</td>
<td>1.67 ± 0.10</td>
</tr>
<tr>
<td>VO₂max (L·min⁻¹)</td>
<td>1.2 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>1.3 ± 0.1*</td>
</tr>
<tr>
<td>Peak heart rate</td>
<td>128 ± 4</td>
<td>131 ± 5</td>
<td>125 ± 5</td>
</tr>
<tr>
<td>Knee extension strength (N·m)</td>
<td>96.1 ± 6.8</td>
<td>102.2 ± 7.7</td>
<td>101.8 ± 7.3*</td>
</tr>
<tr>
<td>Knee flexion strength (N·m)</td>
<td>61 ± 5.4</td>
<td>67.5 ± 4.9</td>
<td>65.6 ± 4.8*</td>
</tr>
</tbody>
</table>

Values are mean ± SEM. VO₂peak = peak oxygen uptake; VO₂max = oxygen uptake at VAT. Sample size as indicated except for knee extension and flexion strength where n = 16 for AT, n = 19 for AT/RT1, and n = 18 for AT/RT3. * Significant difference in baseline values (P < 0.05). † Significant difference from initial value within group (P < 0.05). ‡ Significant difference from initial value within group (P < 0.001).
significant differences in baseline characteristics between the completers and those who discontinued the study. No significant injuries or cardiovascular complications related to RT or AT were incurred during the study.

**Baseline characteristics.** Baseline characteristics for the three cohorts are shown in Table 1 and Table 2. The average time postdiagnosis to exercise ranged from 9.6 ± 0.85 wk to 14.1 ± 2.5 wk. Randomization yielded more patients with a primary diagnosis of CABG and fewer with PCI in the AT group compared to the AT/RT3 group (P < 0.05). A greater proportion of the AT/RT3 group had type II diabetes than did the AT/RT1 group (P < 0.05). The AT/RT1 group had a significantly greater total body mass, lean leg mass, 60°-s^-1^ isokinetic extension and flexion leg strength and a higher VAT (L-min^-1^), than the AT/RT3 group (P < 0.05).

**Cardiovascular adaptations.** Absolute values for VO2peak and VAT are presented in Table 2. Three patients (two from AT and one from the AT/RT1 group) were excluded from the analysis as the cardiopulmonary tests were stopped early because of ischemia (two) and a technical difficulty (one). In addition, two subjects from AT and 2 from AT/RT1 had no discernable VAT. No gender-based differences were present in adaptations.

VO2peak increased in all groups after 29 wk of training. The increase from baseline in VO2peak (L-min^-1^) averaged 11% (P < 0.05) for AT, 14% (P < 0.01) for AT/RT1, and 18% (P < 0.001) for AT/RT3, however, the difference between groups failed to reach statistical significance. There was a significant increase in VAT (L-min^-1^) from baseline (P < 0.05) for only the AT/RT3 group.

There was a weak but significant correlation between change in VO2peak (L-min^-1^) and change in total lean mass (r = 0.34, P = 0.02) across all subjects but no significant correlation with change in strength. Change in the VAT (L-min^-1^) was not significantly associated with change in lean mass but was correlated with change in knee extension and flexion isokinetic strength for the AT/RT3 group (r = 0.6, P = 0.01 and r = 0.57, P = 0.02 respectively).

**Muscular strength and endurance.** The AT group had no significant improvement in 1RM strength scores except for the leg curl exercise. Although there was no

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**FIGURE 1**—The change in one repetition maximum strength is expressed as a percentage of the mean (± SEM) change from baseline. * P < 0.05 and † P < 0.001 from change in baseline value within each group. ‡ P < 0.01 for difference between groups.

**FIGURE 2**—The change in muscular endurance is expressed as a percentage of the mean (± SEM) change from baseline. * P < 0.05 and † P < 0.002 and ‡ P < 0.001 from change in initial value within each group. § P < 0.05 for difference between groups.
significant between group differences among AT/RT1 and AT/RT3 groups the overall strength gain for the AT group was significantly lower ($P < 0.001$) than for either of the two combined training groups (Fig. 1).

Isokinetic knee flexion and extension strength increased significantly in AT/RT1 and in AT/RT3 (both $P < 0.05$). No significant improvements were seen for the AT group in either measure (Table 2).

Upper and lower body local muscular endurance increased significantly in the combined training groups ($P < 0.05$) but not for the AT group (Fig. 2). Gains in both upper and lower body endurance were significantly greater in combined training groups than for the AT group ($P < 0.05$).

**Body composition and dietary analysis.** Changes in body composition are shown in Figure 3. There was a significant increase in total body lean mass with training for the AT/RT1 ($P < 0.02$) and the AT/RT3 group ($P < 0.001$) and trend for increase in the AT group ($P = 0.054$). The AT/RT3 group gained close to four times more lean mass than the AT group ($1.5 \pm 0.3$ kg versus $0.4 \pm 0.2$ kg, $P < 0.01$), and gains in lean mass between AT/RT1 and AT were not significantly different ($0.9 \pm 0.3$ vs $0.4 \pm 0.2$ kg respectively, $P = 0.2$). There was no significant change for any group in measures of total body mass, waist or hip circumference, or body mass index.

Regional body composition analyses (Fig. 3) revealed increased lean arm mass only in the combined training groups: AT/RT3 showing a significantly greater increase compared with the AT group ($P < 0.005$). Change in lean leg mass was significant for the AT/RT3 ($P < 0.002$) and the AT group ($P < 0.02$) but not for the AT/RT1 group ($P = 0.2$). There was a significant difference between change in lean leg mass between AT/RT1 and AT/RT3 ($P < 0.05$). Lean trunk mass increased significantly after training in the AT/RT1 and AT/RT3 groups only ($P < 0.05$ both).

There was a significant reduction in total percent body fat in the AT/RT3 group ($-2.0 \pm 0.9\%$, $P < 0.05$) and AT/RT1 group ($-2.7 \pm 0.9\%$, $P < 0.02$) with no change seen in the AT group ($-0.1 \pm 0.4\%$, $P = 0.8$) (Fig. 4). Regional analyses revealed a significant decrease in percentage of arm, trunk and leg body fat in AT/RT1 group ($P < 0.05$). There was a significant decrease in percent fat in the legs ($P < 0.03$) and trend for reduction in percent fat in the trunk ($P = 0.058$) in the AT/RT3 group. There were no significant changes in any regional measurement for the AT group.

Of the total mean fat mass loss in the AT/RT3 ($1.5 \pm 0.9$ kg) and the AT/RT1 group ($2.4 \pm 0.9$ kg), 73% was from the trunk region in both groups. There was a weak negative correlation between change in fat mass and change in muscle mass ($r = 0.328$, $P < 0.02$), across all subjects.
Dietary analysis indicated that the AT/RT1 group significantly decreased the total number of mean kilocalories consumed per day from baseline ($\Delta = -262 \pm 88.8$ kcal, $P < 0.05$), while there were no significant changes observed for the AT and AT/RT3 group. All groups met or exceeded the recommended dietary allowance of protein (0.8 g kg$^{-1}$ bodymass d$^{-1}$) before and after the study.

**Exercise performance and adherence to training.** Total walking and/or jogging distance completed over the 29-wk training period for the AT, AT/RT1 and AT/RT3 groups were 445.6 ± 44, 361.6 ± 29 and 282.6 ± 29 kilometers, respectively. The AT group completed more distance than the AT/RT3 group ($P < 0.006$) but not significantly more than the AT/RT1 group. Mean aerobic exercise heart rate during the training period was not significantly different between the AT, AT/RT1 or AT/RT3 groups (73.1 ± 2.8%, 80.6 ± 2.1%, and 81.4 ± 2.6% of peak heart rate achieved on the pretraining exercise test respectively).

Both RT groups completed a similar number of RT sessions during the training period (40.6 ± 1.9 and 35 ± 2.1 sessions respectively). As expected, the AT/RT3 group performed a significantly greater number of sets over the training period than the AT/RT1 group ($P = 0.001$); however, the AT/RT1 group was significantly more compliant to the number of sets prescribed than was the AT/RT3 group (completing 84 ± 3.9% versus 63.2 ± 7.3% of the sets prescribed respectively) ($P < 0.02$). There was no significant difference in compliance to the weight load (intensity) that was prescribed to the AT/RT1 group (96.8%) and the AT/RT3 group (96%).

**DISCUSSION**

The major findings of this study are that two RT exercise sessions at the expense of two AT sessions each week elicited similar or higher changes in cardiovascular fitness ($\dot{V}_O^{\text{peak}}$) than AT alone (5 sessions per week) with the added benefits of significant gains in muscle strength, local muscle endurance, lean mass accretion and reduction in percent body fat in CAD patients. These data support the hypothesis that combined RT/AT training was superior in eliciting physiological adaptations, with more substantial gains seen with increased volume of RT for lean muscle mass, lower body muscular endurance, VAT, and $\dot{V}_O^{\text{peak}}$. Although patients may be less compliant to an increasing number of sets prescribed, the multiple set group performed a significantly greater number of sets than the single set group. Moreover, the performance of multiple sets did not affect AT adherence or number of RT sessions performed. These data indicate that a CR program consisting of a mixed facility and home-based approach with only six instructional sessions of RT can be safely administered and yield favorable outcomes.

**Aerobic power.** A compelling observation is that combined AT/RT training (single or multiple set) yielded similar improvements in $\dot{V}_O^{\text{peak}}$ to AT alone, despite completing close to 30% less aerobic exercise sessions (at the same relative AT intensity) as the AT group. Maximizing the gains in $\dot{V}_O^{\text{peak}}$ in cardiac rehabilitation is desirable given the link between $\dot{V}_O^{\text{peak}}$ and survival in patients with CAD (24) and given the relatively poor compliance rates seen in cardiac rehabilitation (7) identifying strategies to optimize the training modality is critical. Studies of healthy older individuals have shown improvements of between 6 and 10% in $\dot{V}_O^{\text{peak}}$ after RT alone (12,13,18), with evidence from muscle biopsy and magnetic resonance methods indicating the improvement may be secondary to increased mitochondrial volume, oxidative capacity (22), oxidative enzymes (12), as well as an increased capillary-to-muscle fiber ratio (12,17). These peripheral adaptations have been reported to have a direct association with $\dot{V}_O^{\text{peak}}$ by potentially improving the muscles’ capacity for oxygen flux (17,35). A small percentage of the variance in $\dot{V}_O^{\text{peak}}$ may also be explained by a change in lean mass due to the weak linear relationship between change in total body lean mass and change in $\dot{V}_O^{\text{peak}}$ across all subjects in this study. The effect of RT on $\dot{V}_O^{\text{peak}}$ may also be linked to muscle mass accretion as seen in the AT/RT3 group, and these gains may have been associated with increased capillarity and energy storage capacity, both of which have been linked to skeletal muscle hypertrophy (15,27,32). These data support a permissive role of RT in augmenting $\dot{V}_O^{\text{peak}}$ in older subjects who may also have evidence of age-related sarcopenia. Our data suggest that combined AT and RT in patients with CAD with an increasing number of sets does amplify the gains in $\dot{V}_O^{\text{peak}}$ that would be seen with AT alone.

**VAT.** Although improvements in $\dot{V}_O^{\text{peak}}$ may be important for prognostic outcome (24), delaying lactate accumulation may be more clinically relevant to submaximal endurance performance (29) given that many activities of daily living for patients with CAD are performed below or near the VAT. Only subjects performing AT/RT3 training in this study showed a significant increase in the VAT. There was no significant correlation between the change in VAT and change in lean mass measures in this study, which is consistent with findings by Goreham et al. (15) who demonstrated that attenuating the lactate increase after chronic RT occurred before muscle fiber hypertrophy. Conversely, change in leg strength significantly correlated with the change in VAT in the AT/RT3 group. Others reporting similar findings suggest that increased strength may reduce the percentage of local muscle tension required for force generation, thereby eliciting less mechanical vascular occlusion and thereby less plasma lactate accumulation (19,29). A more plausible explanation may be gleaned from research that shows that single set protocols elicit a lower and less sustained acute lactate response than three-set protocols (16,30), thereby failing to increase the VAT. It is also possible that the overall training stimulus for either AT/RT1 and AT groups was inadequate to elicit a significant gain in the VAT.
**Body composition.** To our knowledge, this is the first study to demonstrate in CAD patients that multiple set RT performed in combination with AT was superior in yielding improvement in total body, arm, or leg lean mass accretion than single-set RT/AT, or AT alone. Single set protocols have yielded a lower acute anabolic hormonal response than multiple set RT (16,30), thereby acting as a weaker stimulus for lean mass accretion. This is supported by our finding that the AT/RT1 program failed to induce a significant hypertrophic response in the legs, and by others showing AT 5 d per week (26), but not less than 3 d, results in a significant increase in leg lean mass (2,31). Maximizing lower body muscle mass accretion in cardiac rehabilitation is desirable given the age-related declines seen in lower body muscle mass after the fifth decade (21), and the potential for enhanced metabolic control for those with, or at risk for diabetes (6,20).

The failure of AT but success of combined training to elicit a reduction in percent body fat is consistent with prior studies (2,31). Importantly, 73% of the fat mass loss in both AT/RT groups was from the trunk region, producing a desirable regional fat loss with respect to risk for both metabolic and cardiovascular disease (9,36).

Dietary analysis revealed that only the AT/RT1 group significantly reduced kilocalorie consumption after training, which may have contributed to enhanced loss of fat mass compared to the AT/RT3 group. The negative correlation between change in fat mass and change in muscle mass ($r = 0.328, P < 0.02$) suggests that the addition of RT contributes to the negative energy balance, possibly by inducing an elevation in the resting metabolic rate secondary to increased muscle mass as reported in older men after RT (5,33,38). This appears to more than compensate for the significant reduction in kilocaloric expenditure derived from fewer AT sessions.

**Muscular strength and endurance.** Our data suggests that RT in CAD clearly increases muscular strength and endurance. However, our data do not agree with other findings that support a dose–response effect for higher volume RT (4,37) yielding additional strength gains beyond single-set protocols (34). It is notable that most prior studies included young healthy subjects lifting weights to volitional fatigue, a load that is contraindicated for cardiac patients. The strength gains of the AT/RT1 set group (+34%) and AT/RT3 group (+38%) are comparable to that seen in other studies involving CAD patients performing RT alone (14,28). Despite variation in strength outcomes between studies due to differing testing techniques, our data suggest strength gains are not compromised with the addition of AT in a cardiac population. A larger sample size may be required to establish a dose–response effect.

**Adherence.** To minimize the effect that study participation may have on adherence, the patients received the same rehabilitation program under the same conditions and following the usual practice at this cardiac rehabilitation program without compensation. The 7-month study compliance rate (74%) was similar to that of the cardiac rehabilitation program at the Toronto Rehabilitation Institute, which is historically higher than widely reported in other programs (25).

Although the AT/RT3 group completed the required number of RT sets less frequently than the AT/RT1 group, they performed a significantly greater number of sets than the AT/RT1 group. Moreover, all groups completed the same proportion of RT and/or AT workouts prescribed.

**STUDY LIMITATIONS**

Our study does have limitations. We cannot fully explain how randomization resulted in the AT/RT1 group having a significantly greater VAT (L·min⁻¹), leg strength and leg lean mass at baseline than the AT/RT3 group and the imbalance in diagnoses between groups. The greater leg lean mass may be explained in part by the AT/RT1 group being taller (mean = 3.4 cm) than the AT/RT3 group (21). It is also possible that our sample is not large enough to detect significant differences between the AT/RT1 and AT/RT3 groups in certain variables. The lack of an inactive control group poses some limitations to our study as spontaneous recovery may have contributed in part to our observations. However, all groups started exercise at a similar and early point in time after diagnosis. Also, the graded exercise tests were conducted on a cycle ergometer, whereas the aerobic exercise prescription included walking. Therefore, results may be less relevant to activities of daily living.

**CONCLUSIONS**

Combined AT and RT is well tolerated in patients with CAD and yields more pronounced physiological adaptations than AT alone. Although RT prescription beyond one set may be associated with lower adherence to the number of sets prescribed, it may further augment parameters that affect VO₂peak, VAT, lower body endurance, and muscle mass in a cardiac population.

The combination of RT and AT yields greater improvements in cardiovascular endpoints of exercise performance, skeletal muscle function, and body composition compared to AT alone, in spite of a 28% reduction in the actual AT training stimulus. These data strongly support a combined training intervention in CAD patients, and supports the use of multiple-set RT for patients desiring an increased RT stimulus.

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