Effect of Exercise Training on Physical Fitness in Type II Diabetes Mellitus

JOANIE LAROSE1, RONALD J. SIGAL2,4, NORMAND G. BOULÉ5, GEORGE A. WELLS2, DENIS PRUD’HOMME1, MICHELLE S. FORTIER1, ROBERT D. REID1,2, HEATHER TULLOCH2,3, DOUGLAS COYLE2, PENNY PHILLIPS2, ALISON JENNINGS2, FARAH KHAN DWALA3, and GLEN P. KENNY1,2

1School of Human Kinetics, Faculty of Health Sciences, University of Ottawa, Ottawa, Ontario, CANADA; 2Clinical Epidemiology Program, Ottawa Health Research Institute, Ottawa, Ontario, CANADA; 3University of Ottawa Heart Institute, Prevention and Rehabilitation Centre, Ottawa, Ontario, CANADA; 4Departments of Medicine, Cardiac Sciences and Community Health Sciences, Faculties of Medicine and Kinesiology, The University of Calgary, Calgary, Alberta, CANADA; and 5Faculty of Physical Education and Recreation, University of Alberta, Edmonton, Alberta, CANADA

ABSTRACT

LAROSE, J., R. J. SIGAL, N. G. BOULÉ, G. A. WELLS, D. PRUD’HOMME, M. S. FORTIER, R. D. REID, H. TULLOCH, D. COYLE, P. PHILLIPS, A. JENNINGS, F. KHANDWALA, and G. P. KENNY. Effect of Exercise Training on Physical Fitness in Type II Diabetes Mellitus. Med. Sci. Sports Exerc., Vol. 42, No. 8, pp. 1439–1447, 2010. Few studies have compared changes in cardiorespiratory fitness between aerobic training only or in combination with resistance training. In addition, no study to date has compared strength gains between resistance training and combined exercise training in type II diabetes mellitus (T2DM). Purpose: We evaluated the effects of aerobic exercise training (A group), resistance exercise training (R group), combined aerobic and resistance training (A + R group), and sedentary lifestyle (C group) on cardiorespiratory fitness and muscular strength in individuals with T2DM. Methods: Two hundred and fifty-one participants in the Diabetes Aerobic and Resistance Exercise Trial were randomly allocated to A, R, A + R, or C. Peak oxygen consumption (VO2peak), workload, and treadmill time were determined after maximal exercise testing at 0 and 6 months. Muscular strength was measured as the eight-repetition maximum on the leg press, bench press, and seated row. Responses were compared between younger (aged 39–54 yr) and older (aged 55–70 yr) adults and between sexes. Results: VO2peak improved by 1.73 and 1.93 mL O2/kg · min−1 with A and A + R, respectively, compared with C (P < 0.05). Strength improvements were significant after A + R and R on the leg press (A + R: 48%, R: 65%), bench press (A + R: 38%, R: 57%), and seated row (A + R: 33%, R: 41%; P < 0.05). There was no main effect of age or sex on training performance outcomes. There was, however, a tendency for older participants to increase VO2peak more with A + R (+1.5 mL O2/kg · min−1) than with A only (+0.7 mL O2/kg · min−1). Conclusions: Combined training did not provide additional benefits nor did it mitigate improvements in fitness in younger subjects compared with aerobic and resistance training alone. In older subjects, there was a trend to greater aerobic fitness gains with A + R versus A alone. Key Words: AEROBIC EXERCISE, RESISTANCE EXERCISE, CARDIORESPIRATORY FITNESS, STRENGTH, RANDOMIZED CONTROLLED TRIAL

Previous studies have found that exercise training induces improvements in physical fitness among individuals with type II diabetes mellitus (T2DM), as demonstrated by increments in maximal oxygen consumption (VO2max) and muscular strength. For example, Boulé et al. (4) reported in a meta-analysis a mean increase of 9.5% in VO2max after moderate-intensity aerobic training (≤70% VO2max) compared with a 1% decrease in sedentary controls. Larger increases in aerobic capacity were found in individuals who engaged in higher-intensity endurance training (≥75% VO2max) (3). Recent evidence also suggests that resistance exercise training safely and effectively improves muscular strength and metabolic control in vulnerable populations (1,5,7,11,13,18,19). Castaneda et al. (7) and Dunstan et al. (11) studied the effects of high-intensity resistance training in older adults (≥55 yr) with T2DM. The former study reported a 33% increase in whole body strength (7), whereas the latter study found a 42% increase in upper body workload and a 28% increase in lower body workload after 6 months of training (11). Although these studies show promising effects of exercise in improving physical fitness among individuals with T2DM, the small sample sizes used limit the generalizability of the results.

There is also growing evidence that the effect of combined aerobic and resistance training may be more beneficial in the management of T2DM. Recently, we reported that hemoglobin A1c (HbA1c) values decreased significantly with aerobic exercise training compared with a nonexercising control group (−0.51%, P = 0.007) and with resistance exercise training compared with the control group (−0.38%, P = 0.038). With combined exercise training, HbA1c values...
decreased by an additional $-0.46\%$ and $-0.59\%$ compared with the aerobic exercise training ($P = 0.014$) and resistance exercise training ($P = 0.001$), respectively (30). Interestingly, however, only one study has compared the effects of combined exercise training with those of aerobic exercise training alone (10) in improvements in cardiorespiratory fitness in T2DM. Further, no study to date has compared increments in muscular strength with combined exercise training to those derived from resistance exercise training alone in individuals with T2DM. Among young healthy adults, combined exercise training proved as beneficial as aerobic exercise training alone in improving cardiorespiratory fitness, but it seemed to have a detrimental effect on strength development (9,17). In one study, however, participants exercised 5 d wk$^{-1}$, and thus, residual fatigue may have affected the development of strength (17). Conversely, Wood et al. (39) reported that 3 d wk$^{-1}$ of concurrent aerobic and resistance exercise training in healthy older adults (≥60 yr) led to similar improvements in strength as resistance exercise training alone.

The prevalence of T2DM typically increases with age, and aging is usually associated with progressive decrements in various components of physical work capacity and notable declines in cardiorespiratory fitness and muscle strength (6). Moreover, exercise capacity has been shown to be reduced in people with T2DM compared with age-, body mass–, and activity-matched controls even in the absence of diabetic complications (4,22,25). Low cardiorespiratory fitness and decrements in bone density and skeletal muscle strength are strong predictors of disability among older individuals (14–16). As previously mentioned, a combined exercise program seems to generate greater reductions in HbA$_{1c}$ value than either aerobic or resistance training alone. It remains unclear, nonetheless, whether combined exercise training would provide similar gains in both cardiorespiratory fitness and strength compared with either mode of training alone in individuals with T2DM. On the one hand, increased fatigue might have a negative impact on workout intensity compared with doing just one kind of exercise. Conversely, older individuals often have sarcopenia, and strength training might be helpful in permitting them to maximize their aerobic workouts (21).

In the present study, we report the effects of aerobic exercise training, resistance exercise training, and the combination of aerobic and resistance exercise training on cardiorespiratory fitness and muscular strength in the Diabetes Aerobic and Resistance Exercise (DARE) trial (30). An additional purpose of this investigation was to examine if fitness exercise responses in the training groups were affected by age and sex. We hypothesized that changes in cardiorespiratory fitness and strength would be similar in the aerobic exercise training and resistance exercise training groups, respectively, compared with the combined aerobic and resistance training group. We also hypothesized that younger and older adults as well as men and women would respond similarly to exercise training.

**METHODS**

**Design**

The DARE trial was a single-center, randomized controlled trial with a parallel group design that examined the effects of aerobic and resistance exercise training as well as their combination on glycemic control in T2DM (30). The trial included a 4-wk run-in phase plus a 22-wk intervention phase. This study was approved by the Ottawa Hospital Research Ethics Board, and written informed consent from all participants was obtained.

**Participants**

Previously sedentary individuals between the ages of 39 and 70 yr with T2DM were recruited through advertising, physicians, and word of mouth. Inclusion criteria for the DARE trial included type II diabetes for at least 6 months and baseline HbA$_{1c}$ between 6.6% and 9.9% (normal = 4%–6%). Exclusion criteria are described elsewhere (30). The participants’ baseline characteristics are presented in Table 1.

**Run-In Phase**

Participants exercised at community-based facilities, supervised by personal trainers. Before randomization, subjects entered a 4-wk run-in period to assess compliance. Subjects performed 15–20 min of aerobic exercise at moderate intensity (60% $V_{O2peak}$) and one to two sets of eight resistance exercises with supervision. Only subjects attending ≥10 of the scheduled 12 run-in sessions were eligible for randomization. Randomization was stratified by age (39–54 and 55–70 yr) and sex.

**Exercise Interventions**

**Aerobic exercise training (A).** During the run-in phase (weeks 1–4), participants exercised for 15–20 min

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**TABLE 1. Participants’ baseline characteristics.**

<table>
<thead>
<tr>
<th></th>
<th>Combined ($n = 64$)</th>
<th>Aerobic ($n = 60$)</th>
<th>Resistance ($n = 64$)</th>
<th>Control ($n = 63$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men/women, n/n</td>
<td>40/24</td>
<td>39/21</td>
<td>40/24</td>
<td>41/22</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>53.5 ± 7.3</td>
<td>53.9 ± 6.6</td>
<td>54.7 ± 7.5</td>
<td>54.8 ± 7.2</td>
</tr>
<tr>
<td>Non-Hispanic white race/other race, n/n</td>
<td>55/9</td>
<td>59/1</td>
<td>55/9</td>
<td>61/2</td>
</tr>
<tr>
<td>Duration of diabetes (yr)</td>
<td>5.2 ± 4.8</td>
<td>5.1 ± 3.5</td>
<td>6.1 ± 4.7</td>
<td>5.0 ± 4.5</td>
</tr>
<tr>
<td>HbA$_{1c}$ level (%)</td>
<td>7.67 ± 0.91</td>
<td>7.68 ± 0.85</td>
<td>7.71 ± 0.86</td>
<td>7.66 ± 0.89</td>
</tr>
<tr>
<td>Body weight</td>
<td>101.9 ± 30.4</td>
<td>103.5 ± 31.0</td>
<td>99.1 ± 30.4</td>
<td>101.3 ± 28.6</td>
</tr>
<tr>
<td>Body mass index</td>
<td>35.0 ± 9.6</td>
<td>35.6 ± 10.1</td>
<td>34.1 ± 9.6</td>
<td>35.0 ± 9.5</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
at a target intensity of 60% of maximum HR corresponding to a moderate exercise intensity of approximately 50% of $\dot{V}O_{2\text{peak}}$. During the intervention phase (weeks 5–26), training duration and intensity increased on a weekly basis to a maximum of 45 min per session at 75% of maximum HR (Table 2). HR monitors (Polar Electro Oy, Kempele, Finland) displaying the participant’s HR were used to standardize exercise intensity. Target HR were based on maximum HR achieved during the maximal treadmill exercise test performed at baseline. All aerobic activities were performed three times per week on a treadmill or cycle ergometer. Participants were free to vary the machine used from one session to the next. More details on the exercise training programs are available online (http://www.annals.org/cgi/content/full/147/6/357).

**Resistance exercise training (R).** Throughout the resistance training program, participants alternated between two groups of seven exercises targeting all major muscle groups. These were as follows: group A: abdominal crunch, seated row, biceps curl, bench press, leg press, shoulder press, and leg extension; and group B: abdominal crunch, lateral pull-down, triceps push-down, chest press, leg press, upright row, and leg curls. All resistance training exercises were performed on weight machines. During the run-in phase, participants performed one set for each resistance exercise twice weekly for the first 2 wk and two sets of each resistance exercise twice weekly during weeks 3 and 4. During the intervention phase (weeks 5–22), the frequency of resistance training increased from 2 to 3 d wk$^{-1}$, the number of sets performed for each exercise increased from two to three sets, the amount of weight lifted for a given exercise also increased, whereas the number of repetitions decreased to a maximum of eight repetitions. Resistance exercise training sessions lasted 45 min per session. Completion of each set of a single exercise took 30–60 s, and subjects were encouraged to rest for 2–3 min between sets to allow for maximal muscle recovery. Therefore, the amount of time spent on active exercise during a 45-min resistance exercise session was generally 15–20 min. When the participant could perform more than eight repetitions while maintaining proper form, the weight or the resistance of the exercise was increased by 5–10 lb.

**Combined exercise training (A + R).** The participants in the combined training group performed the full aerobic training program plus the full resistance training program to ensure an adequate dose of each type of exercise.

**Control group (C).** After the run-in phase, participants assigned to the control group were asked to revert to their level of activity at baseline and to maintain this level for the remainder of the study.

Direct supervision by trainers occurred with equal frequency in all exercising groups. Individual exercise supervision was provided weekly for the first 4 wk after randomization and biweekly thereafter. Attendance was verified through direct observation, exercise logs, and electronic scanning of membership cards.

**Outcomes and Measurements**

Dependent variables included $\dot{V}O_{2\text{peak}}$, maximal workload, treadmill time, maximum HR, as well as oxygen consumption ($\dot{V}O_2$), workload, and HR at the ventilatory threshold, and results from eight-repetition maximum (8RM) testing on the seated row, bench press, and leg press. Maximal cardiorespiratory fitness ($\dot{V}O_{2\text{peak}}$) was determined during a maximal treadmill exercise stress test at the University of Ottawa Heart Institute. The test followed a ramp treadmill protocol with continuous time and 12-lead ECG monitoring (v.4.03; GE Marquette Medical Systems, Inc., Milwaukee, WI) as well as breath-by-breath analysis of oxygen consumption and carbon dioxide production (CPX-D Metabolic Cart; MedGraphics, St. Paul, MN). Because older adults often do not reach a plateau in oxygen consumption, $\dot{V}O_{2\text{peak}}$ was measured as the highest minute rate of oxygen consumption achieved during the last 30 s of the test to volitional fatigue. Each participant performed the same ramp protocol during baseline and postintervention testing. We also obtained maximal workload (W), maximum HR (rpm), and treadmill time (min) from stress testing. Ventilatory threshold was determined from maximal exercise stress tests using two criteria: 1) the point where

| Table 2. Exercise program during the run-in and intervention phases. |
|-----------------|----------------|----------------|
| **Week** |  **Aerobic Training** |  **Resistance Training** |
| | **Duration** (min d$^{-1}$) | **Intensity (%) of Maximum HR)$^a$ | **Frequency (d wk$^{-1}$) | **Sets, $n$** | **Repetitions, $n$** | **Weight, Maximum Repetitions$^b$** | **Frequency, Sessions per Week** |
| Run-in phase | | | | | | | |
| 1–2 | 15 | 60 | 3 | 1 | 15 | 15 | 2 |
| 3–4 | 20 | 60 | 3 | 2 | 15 | 15 | 2 |
| Intervention phase | | | | | | | |
| 5–6 | 25 | 70 | 3 | 3 | 12 | 12 | 3 |
| 7–8 | 30 | 70 | 3 | 3 | 12 | 12 | 3 |
| 9–10 | 35 | 70 | 3 | 3 | 12 | 12 | 3 |
| 11–12 | 40 | 70 | 3 | 3 | 10 | 10 | 3 |
| 13–16 | 45 | 70 | 3 | 3 | 8 | 8 | 3 |
| 17–19 | 40 | 75 | 3 | 3 | 8 | 8 | 3 |
| 20–26 | 45 | 75 | 3 | 3 | 8 | 8 | 3 |

$^a$ The maximum HR achieved during the maximal treadmill exercise test performed at baseline.

$^b$ The maximum weight that can be lifted the slated number of times while maintaining proper form. For example, 15 maximum repetitions is the maximum weight that can be lifted 15 times while maintaining proper form.
ventilation (\(V_E\)) increased disproportionately relative to \(\dot{V}O_2\) (37) and 2) the point of nonlinear rise in carbon dioxide production (\(\dot{V}CO_2\)) relative to \(\dot{V}O_2\) (V-slope method) (2). Both criteria were met for most subjects, but in a few cases, the rise in \(V_E\) relative to \(\dot{V}O_2\) was easier to recognize and was used to determine the ventilatory threshold. These techniques have been shown to be sensitive and noninvasive measures for evaluating cardiorespiratory performance (25,26,37). Oxygen consumption, workload, and HR were measured at the ventilatory threshold. One evaluator determined the ventilatory threshold for all participants at 0 and 6 months. The same evaluator repeated the assessment of all ventilatory thresholds no less than 2 wk after the last ventilatory threshold had been determined to ensure consistency in the results and because a second evaluator was not available for this study (24).

Muscular strength was determined for the leg press, bench press, and seated row on a multistation gym (Body Solid EXM-2000S, Forest Park, IL). Strength was measured as the maximum weight that could be lifted eight times after an 8RM protocol. Proper lifting and breathing techniques were demonstrated by an exercise specialist before each exercise.

All participants were assessed as described at baseline (before the beginning of run-in phase) and at 6 months (the end of the intervention).

Statistical Analysis

We used linear mixed-effects models for repeated measures with an unstructured covariance matrix to model dependent variables by study groups over time. Dependent variables included measures for cardiorespiratory fitness \(\dot{V}O_2^{\text{peak}}\) mL \(O_2\) kg\(^{-1}\) min\(^{-1}\), \(\dot{V}O_2^{\text{peak}}\) adjusted for lean body mass (\(\dot{V}O_2^{\text{peak}}\) mL \(O_2\) kg\(^{-1}\) LBM min\(^{-1}\)), maximum HR, maximal workload, and treadmill time], submaximal aerobic fitness indices \(\dot{V}O_2\) mL \(O_2\) kg\(^{-1}\) min\(^{-1}\), \(\dot{V}O_2\) mL \(O_2\) kg\(^{-1}\) LBM min\(^{-1}\), HR, and workload at the ventilatory threshold), and strength (8RM for leg press, bench press, and seated row). To test whether changes in fitness outcomes differed according to age, we reran the model with an additional term for age (dichotomized into younger (39–54 yr) and older (55–70 yr) participants). We also reran the model to test for significant differences between sexes. Within the mixed models, we estimated the 95% confidence interval (CI) and \(P\) values for six intergroup comparisons (A + R vs A, A + R vs R, A + R vs C, R vs C, A vs C, and A vs R). Unadjusted 95% CI are presented in the tables and figures. The level of significance was set at an overall \(\alpha\) level of 0.05; however, we used Bonferroni adjustments to account for multiple comparisons. Thus, the \(P\) values for intergroup comparisons were considered significant when \(P < 0.0083\) (0.05 divided by six possible comparisons for each variable) and \(<0.0125\) for within-group comparisons (0.05 divided by four possible within-group changes). We used SAS version 9.1 (Cary, NC) for all analyses.

RESULTS

After the run-in phase, 60, 64, 64, and 63 participants were randomly allocated to aerobic exercise training, resistance exercise training, combined exercise training, and a control group, respectively. Thirty participants withdrew from the study between randomization and after 6 months: 12 participants from the aerobic training, 7 participants from the resistance training, 8 participants from the combined training, and 3 participants from the control group. Several other participants did not have complete sets of data. As such, 48 participants from the aerobic exercise training group, 54 participants from the resistance exercise training group, 54 participants from the combined exercise training group, and 60 participants from the control group were included in the analyses. Reasons for not completing the study included medical conditions, loss of interest, and other personal or time commitments that interfered with the ability to participate or continue with the study.

General Exercise Outcomes

Cardiorespiratory fitness. \(\dot{V}O_2^{\text{peak}}\) relative to body mass (mL \(O_2\) kg\(^{-1}\) min\(^{-1}\)) was significantly improved at 6 months with aerobic training and combined training \((P < 0.001)\), and the changes were significant compared with those of the resistance training group (aerobic training, \(P = 0.007; A + R, P = 0.001)\) and control group \((P < 0.001; Fig. 1)\). No differences were observed between the aerobic training and the combined training groups \((P = 0.638)\) as well as between the resistance training and control groups \((P = 0.243)\) for changes in \(\dot{V}O_2^{\text{peak}}\). The same results were observed when \(\dot{V}O_2^{\text{peak}}\) were adjusted for lean body mass (LBM) (data not shown). Maximal workload and treadmill times were significantly increased at 6 months with aerobic training and combined exercise training \((P < 0.001\); Table 3). Improvements in workload were also significant relative to the control group \((P < 0.001)\) after aerobic training and combined training as well as compared with the resistance training
training group after aerobic training only ($P = 0.006$). Treadmill time improved significantly in the aerobic training and combined training groups compared with those in the resistance exercise training ($P = 0.001$) and control groups ($P < 0.001$). Maximal HR decreased significantly over time only in the aerobic exercise training group (from 161.42 ± 2.04 to 157.57 ± 2.26 bpm, $P = 0.007$). No significant difference was observed for changes in maximal HR among the exercise training groups. Although a tendency toward greater improvements in $V\text{O}_{2}\text{peak}$ was observed in older versus younger participants after combined exercise training (Fig. 2), the effect of training group did not significantly vary according to age or sex for changes in $V\text{O}_{2}\text{peak}$ (age, $P = 0.300$; sex, $P = 0.859$), workload (age, $P = 0.200$; sex, $P = 0.924$), and treadmill time (age, $P = 0.445$; sex, $P = 0.939$).

**Submaximal exercise response.** $V\text{O}_{2}$ relative to body mass (mL O$_2$·kg$^{-1}$·min$^{-1}$) at the ventilatory threshold improved at 6 months with aerobic training and combined training ($P < 0.001$) as well as compared with the control group ($P < 0.001$; Fig. 3). After adjusting for multiples comparisons, improvements in $V\text{O}_2$ at the ventilatory threshold were not significantly greater with aerobic training and combined training than with resistance training ($A, P = 0.021; A + R, P = 0.013$). No differences were observed between the aerobic training and combined training groups ($P = 0.928$) as well as between the resistance training and control groups ($P = 0.138$) for changes in $V\text{O}_2$ at the ventilatory threshold. Workload at the ventilatory threshold significantly increased after 6 months for all training groups ($P < 0.001$). Relative to the control group, workload increased more in the aerobic and combined training groups ($A, P < 0.001; A + R, P = 0.002$) and also in the aerobic

![FIGURE 2—Mean ± SD changes in $V\text{O}_{2}\text{peak}$ (mL O$_2$·kg$^{-1}$·min$^{-1}$) between younger (39–54 yr) and older participants (55–70 yr) in the four study groups from baseline to 6 months.](image-url)
training group compared with the resistance training group ($P = 0.008$). The effect of training on changes in submaximal aerobic responses did not differ according to age or sex.

**Muscular strength.** Leg press, bench press, and seated row performance increased significantly in all exercise groups ($P < 0.001$; Fig. 4). A significant within-group change over time was also found in the control group for the leg press ($P = 0.002$). In comparison with the control group, changes in leg press, bench press, and seated row performances were greater in the resistance and combined exercise training groups ($P < 0.001$). Relative to the aerobic training group, greater strength improvements were found with resistance training on the bench press ($P = 0.005$) and with both resistance and combined training on the seated row ($R, P = 0.001; A + R, P = 0.005$). Strength improvements in the resistance training group were not significantly different from those obtained with combined training in any of the strength exercises. The effects of training group did not vary according to age or sex for changes in strength.

**DISCUSSION**

We compared the effects of aerobic exercise training, resistance exercise training, and the combination of aerobic and resistance exercise training with a nonexercising control group on cardiorespiratory fitness and muscular strength in previously sedentary individuals with T2DM. After 6 months of exercise training, the aerobic and combined exercise training groups significantly increased VO$_{2\text{peak}}$, maximal workload, treadmill time, as well as VO$_2$ and workload at the ventilatory threshold compared with the control group. In addition, relative to the control group, muscular strength as measured on the seated row, bench press, and leg press significantly increased in the resistance and combined exercise training groups. Strength performance was also significantly improved in the aerobic exercise training group, although the improvements were not significantly greater than those of the control group after adjusting for multiple comparisons. Our hypothesis that improvements in cardiorespiratory fitness and strength in the combined exercise training group would be similar to those derived from aerobic exercise training alone and resistance exercise training alone, respectively, was supported.

Previous studies have reported improvement in cardiorespiratory fitness as measured by VO$_{2\text{peak}}$, treadmill time, or workload ($6,8,12,20,23,28,32,33,36$). Notably, Cauza et al. (8) showed that 4 months of endurance training three times per week at 60% of VO$_{2\text{peak}}$ significantly improved VO$_{2\text{peak}}$ by 1.49 mL O$_2$ kg$^{-1}$ min$^{-1}$, which was paralleled by an increase in maximal workload (+12 W) in 17 individuals with T2DM. Kadogloua et al. (20) reported that 4 d/wk$^{-1}$ of aerobic training for 6 months between 50% and 75% of VO$_{2\text{peak}}$ improved VO$_{2\text{peak}}$ by 3.66 mL O$_2$ kg$^{-1}$ min$^{-1}$ and treadmill test duration by 0.79 min in 30 individuals with diabetes assigned to the exercise group. The responses were similar to those observed in the present study. We show that the aerobic exercise training group increased VO$_{2\text{peak}}$ by 1.73 mL O$_2$ kg$^{-1}$ min$^{-1}$, which was paralleled by increments in workload (+23.6 W) and treadmill time (+1.19 min) in comparison to the control group. The results from our study also support that improvements in cardiorespiratory fitness after combined aerobic and resistance exercise training are similar to those derived from aerobic training alone. Specifically, VO$_{2\text{peak}}$ increased by 1.93 mL O$_2$ kg$^{-1}$ min$^{-1}$, maximal workload by 19.8 W, and treadmill time by 1.14 min in the combined exercise group versus the control group. To our knowledge, Cuff et al. (10) published the only other study reporting similar improvements in VO$_{2\text{peak}}$ between aerobic training alone (13.1%) and combined aerobic and resistance training (10.2%) in T2DM.

In parallel to the improvements in maximal aerobic performance, submaximal exercise performance was also significantly improved after exercise training. Oxygen consumption at the ventilatory threshold was increased.
by 1.33 mL O₂·kg⁻¹·min⁻¹ with aerobic training and by 1.36 mL O₂·kg⁻¹·min⁻¹ after combined exercise training compared with controls. This is in contrast to a study by Vanninen et al. (35) where VO₂ at the ventilatory threshold remained unchanged in men and women who were encouraged to increase their level of physical activity for 12 months. Ventilatory threshold as a percentage of VO₂peak, however, remained unchanged between 0 and 6 months after aerobic training (50.8% ± 5.7% vs 51% ± 5.1%) and combined training (50.1% ± 5.5% vs 51.2% ± 5.1%). However, workload at the ventilatory threshold significantly increased by 14.8 W with aerobic training and by 9.9 W with combined training relative to controls, which, to our knowledge, has also not been previously reported in individuals with T2DM.

Several small studies previously found significant changes in strength after resistance exercise training in individuals with T2DM. Dunstan et al. (11), for example, reported a 42% and 28% increase in upper and lower body strength after 6 months of progressive resistance training, whereas Castaneda et al. (7) reported a 33% improvement in whole body strength after 16 wk of high-intensity resistance training. In the present study, strength performance on the seated row, bench press, and leg press increased by 41%, 57%, and 65%, respectively, in the resistance exercise training group, suggesting that the training stimulus provided in the exercise program was sufficient to elicit improvements in strength in older individuals with T2DM. Strength gains with combined training were comparable to those obtained from resistance training alone; notably, seated row, bench press, and leg press performance improved by 33%, 38%, and 48%, respectively. This is in contrast to previous studies among younger healthy individuals where strength development was attenuated with a combined training program versus resistance training alone (17). To date, no other study has compared strength gains after combined exercise training with those obtained with resistance exercise training alone in individuals with diabetes. Consistent with the results reported by Wood et al. (39) among older healthy individuals, the present study suggests that a combined exercise program does not alter strength development in adults with T2DM and that strength improvements are similar between resistance exercise training alone and combined aerobic and resistance training. Significant strength gains of 21%, 25%, and 42% on the seated row, bench press, and leg press, respectively, were also observed after aerobic exercise training, and small strength improvements in the leg press were seen in the control group. The improvement in strength at 6 months in the control group could result from participants becoming familiar with lifting techniques and equipment and/or as a residual effect from the run-in phase where all participants performed both aerobic and resistance exercise training for a period of 4 wk. In support of this, Staron et al. (31) previously trained 24 young women twice per week for a period of 20 wk after which they underwent a detraining phase of 30–32 wk. These women performed 1RM tests on the leg press, leg extension, and squat after the period of detraining. Although 1RM values had decreased from the previous training period, all detraining values remained significantly greater than pretraining values, suggesting that some adaptations to strength training may be retained for long periods after the cessation of training.

Regular aerobic activity is important to delay or attenuate age-related decreases in cardiorespiratory fitness. Moreover, resistance exercise training can prevent and/or delay the development of sarcopenia, osteoporosis, and improve functional capacity in tasks of daily living among older individuals with diabetes. Higher levels of aerobic fitness can also reduce the risk of cardiovascular and overall mortality (38). A consensus statement published by the American Diabetes Association (29) indicates that individuals with T2DM should accumulate at least 150 min·wk⁻¹ of moderate-intensity aerobic physical activity (40%–60% of VO₂max) or 50%–70% of maximum HR) or at least 90 min·wk⁻¹ of vigorous-intensity aerobic exercise (60% of VO₂max, or 70% of maximum HR). In addition, people with diabetes are encouraged to perform at least three sessions per week of resistance exercise training, targeting all major muscle groups, progressing to three sets of 8–10 repetitions at a weight that cannot be lifted more than 8–10 times. These exercise guidelines are based on programs shown to improve glycemic control, assist with weight maintenance, and reduce the risk of cardiovascular disease (29).

In the present study, aerobic exercise training was performed three times per week, and the intensity and duration progressed to a maximum of 45 min at 75% of maximum HR. Resistance exercise training progressed to three weekly sessions, targeting seven major muscle groups for three sets of eight repetitions at the maximum amount of weight that could be lifted eight times. In addition to providing important reductions in HbA₁c, the aerobic exercise program elicited improvements in cardiorespiratory fitness, whereas resistance exercise training improved muscular strength among younger and older participants. Combined exercise training, however, led to significantly greater reductions in HbA₁c, albeit similar improvements in aerobic fitness and muscular strength compared with aerobic and resistance training alone. Moreover, although no statistically significant effect of age on fitness change was found between the training groups, older participants tended to increase cardiorespiratory fitness more with combined training (+1.5 mL O₂·kg⁻¹·min⁻¹) than with only aerobic training (+0.7 mL O₂·kg⁻¹·min⁻¹; Fig. 4). The older participants are likely to have had a greater degree of sarcopenia, and the increased muscular fitness from resistance training may have helped to maximize the benefits of aerobic training. Nonetheless, our results are consistent with the recommendations from the American College of Sports Medicine position stand on exercise and physical activity for older adults as well as the 2008 Physical Activity Guidelines Advisory Committee Report (27,34), which suggest that older adults (≥65 yr) could gain substantial health benefits from performing...
regular resistance training in addition to aerobic training. Hence, individuals with T2DM, and especially older adults with diabetes, would be well advised to perform a combined training program to promote the development of two aspects of fitness, notably aerobic fitness and muscular strength.

In summary, combined exercise training did not seem to provide additional benefits nor did it mitigate changes in physical fitness in younger participants compared with the effects of aerobic training alone on aerobic fitness or resistance training alone on muscular fitness. In older subjects, there was a trend to greater aerobic fitness gains with combined training versus aerobic training alone. These findings provide further evidence supporting the additional health benefits of combined aerobic and resistance exercise training especially for older people with T2DM.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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