High-Intensity Resistance Training Improves Glycemic Control in Older Patients With Type 2 Diabetes

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OBJECTIVE — To examine the effect of high-intensity progressive resistance training combined with moderate weight loss on glycemic control and body composition in older patients with type 2 diabetes.

RESEARCH DESIGN AND METHODS — Sedentary, overweight men and women with type 2 diabetes, aged 60–80 years ($n = 36$), were randomized to high-intensity progressive resistance training plus moderate weight loss (RT & WL group) or moderate weight loss plus a control program (WL group). Clinical and laboratory measurements were assessed at 0, 3, and 6 months.

RESULTS — HbA_{1c} fell significantly more in RT & WL than WL at 3 months (0.6 ± 0.7 vs. 0.07 ± 0.8%, $P < 0.05$) and 6 months (1.2 ± 1.0 vs. 0.4 ± 0.8%, $P < 0.05$). Similar reductions in body weight (RT & WL 2.5 ± 2.9 vs. WL 3.1 ± 2.1 kg) and fat mass (RT & WL 2.4 ± 2.7 vs. WL 2.7 ± 2.5 kg) were observed after 6 months. In contrast, lean body mass (LBM) increased in the RT & WL group (0.5 ± 1.1 kg) and decreased in the WL group (0.4 ± 1.0) after 6 months ($P < 0.05$). There were no between-group differences for fasting glucose, insulin, serum lipids and lipoproteins, or resting blood pressure.

CONCLUSIONS — High-intensity progressive resistance training, in combination with moderate weight loss, was effective in improving glycemic control in older patients with type 2 diabetes. Additional benefits of improved muscular strength and LBM identify high-intensity resistance training as a feasible and effective component in the management program for older patients with type 2 diabetes.

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Exercise, along with diet and medication, plays an important role in the management of type 2 diabetes. However, whereas the therapeutic benefits of exercise have been studied extensively in middle-aged men and women with type 2 diabetes (1–3), little is known about the impact of exercise training in older people with this condition. Aerobic or endurance exercise programs have been traditionally recommended for older patients with type 2 diabetes and have been associated with weight loss, improved glucose tolerance, and cardiovascular fitness (4–6). Recent position statements from both the American Diabetes Association (7) and the American College of Sports Medicine (8) also recommend the use of resistance training as part of a well-rounded exercise program for older individuals. However, the role of progressive resistance training as a treatment regimen for improving the metabolic profile of older patients with type 2 diabetes has received little attention. Given that the prevalence of type 2 diabetes increases with age (9) and that aging is associated with a reduction in muscle strength and metabolic control, both of which are influenced by the progressive age-related decline in muscle mass (sarcopenia) (10), resistance training may represent an effective exercise alternative for older adults. Furthermore, several studies in older patients without diabetes have demonstrated that resistance training can improve muscular strength and may be an effective tool for the prevention of age-related sarcopenia (11–13).

Due to the limited information on the role of resistance training for older patients with type 2 diabetes, it has been recommended that resistance training programs use moderate weights and high repetitions (7). However, it appears that the impact of progressive resistance training on muscle mass and muscle strength in both young and older individuals is more pronounced if higher training intensities (70 and 90% of the one-repetition maximum strength [1-RM]) are used (14). In older adults without diabetes, high-intensity progressive resistance training programs have been reported to have significant effects on daily energy expenditure (15), body composition (16), and insulin sensitivity (17,18). To date, no study has examined the long-term effects of high-intensity progressive resistance training in combination with moderate weight loss in subjects with type 2 diabetes. The absence of such data has precluded specific recommendations by the American Diabetes Association with respect to the merits of high-intensity resistance training for older individuals with type 2 diabetes (7). The aim of this randomized controlled trial was to examine the effects of a 6-month high-intensity progressive resistance

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Abbreviations: 1-RM, one-repetition maximum strength; HOMA, homeostasis model assessment; LBM, lean body mass; RT & WL group, high-intensity progressive resistance training plus moderate weight loss group; WL group, moderate weight loss plus a control program group.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

training program, combined with healthy eating designed to elicit moderate weight loss, on HbA_{1c} and body composition in older adults with type 2 diabetes. More specifically, we asked the following questions: *1*) is a high-intensity progressive resistance training program feasible for previously sedentary, overweight older patients with type 2 diabetes? and 2) does high-intensity progressive resistance training combined with moderate weight loss reduce HbA_{1c}, increase muscle strength and lean body mass (LBM), and decrease fat mass in older patients with type 2 diabetes compared with a control program (flexibility exercise) plus moderate weight loss?

RESEARCH DESIGN AND METHODS

— Men and women, aged between 60 and 80 years, with treated (diet and/or medication) type 2 diabetes were recruited from the clinics of the International Diabetes Institute and by a local media campaign. Subjects were overweight (BMI >27 kg/m^2 and ≤40 kg/m^2), were sedentary (no strength training and <150 min of brisk walking/moderate exercise per week and <60 min of vigorous exercise per week in the preceding 6 months), had established (>6 months) but not optimally controlled type 2 diabetes (HbA_{1c} range 7–10%), were not taking insulin, and were nonsmokers. After telephone screening, 110 potential volunteers were invited to attend a more detailed screening visit involving a comprehensive medical examination, including medical history, physical examination, resting blood pressure, resting 12-lead electrocardiogram, and HbA_{1c} measurement. Of these, 47 (24 men and 23 women) met the full entry criteria, and 36 agreed to participate in the study. Reasons for exclusion included history or physical findings suggestive of ischemic heart disease, systemic diseases, uncontrolled hypertension (>160/90 mmHg), and advanced diabetic neuropathy or retinopathy. Subjects with severe orthopedic, cardiovascular, or respiratory conditions that would preclude participation in an exercise program or those with a medical condition listed in the American College of Sports Medicine absolute exercise contraindications (19) were excluded. Of the 36 subjects who agreed to participate, 20 had a history of hypertension, 3 had a history of neuropathy, 1 had a history of retinopathy, and 7 reported a history of arthritis. Antidiabetic and antihypertensive medications were continued during the study. The study was approved by the International Diabetes Institute and Deakin University Human Research Ethics Committees, and written consent was obtained from all subjects.

The study was a 6-month randomized controlled clinical trial, with repeated measurements performed at 3-month intervals. Subjects were randomly assigned to either a high-intensity progressive resistance training plus moderate weight loss group (RT & WL, $n = 19$) or a 2) moderate weight loss group plus control program (flexibility exercise) (WL, $n = 17$). Two subjects from the RT & WL group and four subjects from the WL group withdrew from the study during the first 8 weeks. The reasons for withdrawal included health problems not related to the intervention ($n = 2$) or other commitments that precluded ongoing participation ($n = 4$). One participant from the RT & WL group was placed on insulin treatment within the first 6 weeks of the trial and was not included in any analysis. Therefore, of the 36 who began the study, 29 subjects (16 [84%] RT & WL and 13 [76%] WL) successfully completed the intervention, yielding a dropout rate of 19%.

Healthy eating plan

For the initial 4-week baseline period, all subjects were placed on a healthy eating plan, supplying ≤30% of total energy intake from fat and <10% from saturated fat), with the remainder distributed between carbohydrates and protein. The healthy eating plan was designed to elicit a moderate weight loss of 0.25 kg/week over the course of the intervention and was individually prescribed by a dietitian using two separate 3-day food records performed during the baseline. Compliance with the healthy eating plan was assessed by interviews every 2 weeks with the dietitian and by completion of a weekly food checklist. A 3-day food record was obtained at 3 and 6 months to assess changes in nutrient intake. All nutritional information obtained from food records was analyzed by a dietitian using the Foodworks nutrient analysis software program (Xyris Software, Brisbane, Queensland, Australia).

Exercise intervention

During the 6-month intervention, all subjects attended the exercise laboratory on 3 nonconsecutive days per week. Resistance training consisted of a 5-min warm-up and 5-min cool-down period of low-intensity stationary cycling and ~45 min of high-intensity resistance training (dynamic exercise involving concentric and eccentric contractions). During the first and second weeks of training, the resistance was set at 50–60% of each individual's 1-RM. The 1-RM was defined as the maximum amount of resistance that could be moved through the full range of motion of an exercise for no more than one repetition. Thereafter, the goal was to achieve between 75 and 85% of the current 1-RM. Subjects followed an individually monitored progressive resistance training program using free weights and a multiple-station weight machine. Nine exercises were used for training: bench press, leg extension, upright row, lateral pull-down, standing leg curl (ankle weights), dumbbell seated shoulder press, dumbbell seated biceps curl, dumbbell triceps kickback, and abdominal curls. All subjects were required to perform each repetition in a slow, controlled manner, with a rest of 90–120 s between sets. Three sets of 8–10 repetitions were performed for all exercises (except abdominal curls) at each training session. All sessions were supervised to ensure correct technique and to monitor the appropriate amount of exercise and rest intervals. Training workload was increased regularly as tolerated for each muscle group after subjects had successfully achieved three sets of 10 repetitions with appropriate technique. 1-RM testing was repeated every 12 weeks to establish a new baseline.

The control program (WL) was designed to provide participative involvement but not to elicit change in muscle strength or cardiovascular fitness. Each session involved stationary cycling with no workload for 5 min, followed by a series of static stretching exercises (~30 min). Subjects were not blinded to treatment and were informed that improved flexibility was an expected outcome.

Testing procedures

Anthropometry and body composition. Height (cm) was measured using a Holtain stadiometer (Holtain, Crosswell, Wales). Body weight (kg) was assessed us-

ing SECA electronic scales to the nearest 0.1 kg. Waist circumference was measured using a nonelastic measuring tape at the midpoint between the lower border of the ribcage and the iliac crest. Fat mass and LBM were measured by dual-energy X-ray absorptiometry using a DPX-L densitometer (Lunar, Madison, WI). All scanning and analyses were performed by the same operator. The coefficient of variation for repeated measurement was 1.2% for fat mass and 1.7% for LBM.

Muscle strength. Before the determination of their initial 1-RM, subjects attended two separate familiarization sessions, where they were shown proper exercise techniques by a trained instructor and given the opportunity to become accustomed to the selected exercises. To determine the 1-RM, each participant initially performed a warm-up set of eight repetitions with a light weight. After the successful completion of a further three to five repetitions at a moderate to heavy weight selected by the instructor, and after a brief rest (1–2 min), the workload was incrementally increased until only one repetition with correct technique could be completed. The 1-RM testing on the bench press and leg extension exercises was used to document the respective changes in upper body and lower body strength.

Habitual physical activity. Habitual physical activity was estimated using a 7-day physical activity recall questionnaire (20) to measure changes in physical activity patterns. The questionnaire was interviewer administered and the total hours spent sleeping and performing moderate, hard, and very hard activity were used to calculate daily energy expenditure (20,21). The resistance training activity that the RT & WL group participated in as part of the intervention was not included in the final analysis of the habitual physical activity data.

Clinical and laboratory measurements. Resting supine blood pressure was assessed using the Dinamap automatic blood pressure monitor (Critikon, Tampa, FL). Four separate readings were taken at one-minute intervals, and the mean of the final three readings was recorded. All blood pressure measurements were performed at least 24 h postexercise.

Blood samples were obtained from each participant's antecubital vein after an overnight fast for the determination of plasma glucose, serum insulin, lipids and lipoproteins, and HbA_{1c}. All samples were collected at least 48 h postexercise. Serum samples for insulin were stored at −80°C until assayed. HbA_{1c} was measured with the Roche Unimate 5HbA_{1c} kit using the Olympus AU600 automated analyzer. Plasma glucose levels were measured enzymatically (glucose oxidase) within 12 h of collection using the Olympus AU600 automated analyzer. Serum total cholesterol, HDL cholesterol, and triglycerides were determined enzymatically on the Olympus AU600 analyzer. LDL cholesterol was calculated from the Friedewald formula (22). Serum insulin was measured using a human insulin–specific radioimmuoassay kit (Linco Research, St Charles, MO). Homeostasis model assessment (HOMA) was used to estimate insulin sensitivity from fasting insulin and glucose concentrations (23).

Table 1—*Descriptive characteristics of the RT & WL and WL groups*

	RT & WL	WL
n	16	13
Age (years)	67.6 ± 5.2	66.9 ± 5.3
Sex (M/F)	10/6	6/7
Duration of diabetes (years)	7.6 ± 5.4	8.8 ± 7.9
Oral hypoglycemic medication use (*n*)	15	10
Anthropometry		
Height (cm)	167.8 ± 8.7	166.0 ± 9.1
Weight (kg)	88.7 ± 10.9	89.5 ± 12.1
BMI (kg/m^2)	31.5 ± 3.7	32.5 ± 3.8
Waist circumference (cm)	105.3 ± 7.5	103.3 ± 11.4
Body composition		
Fat mass (kg)	33.1 ± 7.4	35.6 ± 6.8
LBM (kg)	51.8 ± 8.1	49.7 ± 9.5
Blood pressure		
Systolic (mmHg)	145 ± 17.8	147 ± 15.5
Diastolic (mmHg)	78 ± 8.8	75 ± 6.4
Serum glucose and insulin		
Fasting glucose (mmol/l)	9.5 ± 2.3	9.4 ± 2.1
Fasting insulin (pmol/l)	132.9 ± 63.0	101.9 ± 25.8
Insulin sensitivity (HOMA)	17.7 ± 6.5	20.8 ± 6.2
HbA_{1c} (%)	8.1 ± 1.0	7.5 ± 1.1
Serum lipids		
Total cholesterol (mmol/l)	5.1 ± 0.8	5.7 ± 1.2
HDL cholesterol (mmol/l)	1.2 ± 0.2	1.4 ± 0.3
LDL cholesterol (mmol/l)	3.1 ± 0.8	3.5 ± 0.9
Triglycerides (mmol/l)	1.8 ± 0.8	1.8 ± 0.8
Total energy intake (kcal/day)	1,783 ± 349	1,815 ± 431
Estimated energy expenditure (kcal/day)*	3,022 ± 413	3,109 ± 428

Data are means ± SD. *Calculated from 7-day recall.

Statistical analysis

Statistical analysis was conducted using SPSS version 10.0.5 for Windows (SPSS, Chicago). Independent *t* tests were used to assess between-group comparisons at baseline. Net differences at 3 and 6 months were calculated by subtracting the within-group changes from baseline for the WL group from the within-group changes for the RT & WL group. Time, group, and interaction effects were examined using a two-way ANOVA or ANCOVA with repeated measures on one factor (time). Fasting plasma insulin levels were log transformed to yield a normal distribution before parametric analysis. All other data were normally distributed.

RESULTS

Subject characteristics

There were no differences in the baseline characteristics of the subjects in the RT & WL or WL groups (Table 1). During the 6-month intervention, four subjects (three RT & WL and one WL) decreased their oral hypoglycemic medication dos-

Table 2—*Absolute changes in fasting glucose, insulin, lipids, and HbA_{1c} from baseline for the RT & WL and WL groups, and the net difference between groups*

	3-month change from baseline			6-month change from baseline		
	RT & WL	WL	Net difference (95% CI)	RT & WL	WL	Net difference (95% CI)
Fasting plasma glucose (mmol/l)	−0.5 ± 2.3	0.09 ± 2.5	−0.6 (−2.4 to 1.3)	−1.4 ± 2.7	−0.6 ± 2.4	−0.8 (−2.8 to 1.2)
Fasting serum insulin (pmol/l)	7.1 ± 43.3	16.4 ± 60.3	−9.3 (−48.8 to 30.2)	10.5 ± 46.3	−4.7 ± 27.2	15.2 (−14.7 to 45.1)
Insulin sensitivity (HOMA) (%)	−1.3 ± 4.6	−0.3 ± 6.1	−1.0 (−5.2 to 3.1)	0.03 ± 5.2	0.8 ± 6.5	−0.8 (−5.2 to 3.7)
HbA_{1c} (%)	−0.6 ± 0.7*	−0.07 ± 0.8	−0.5 (−1.1 to −0.01)†	−1.2 ± 1.0*	−0.4 ± 0.8	−0.8 (−1.5 to −0.1)†
Serum lipids (mmol/l)						
Total cholesterol	−0.03 ± 0.6	−0.2 ± 0.9	0.2 (−0.4 to 0.7)	−0.09 ± 0.8	−0.5 ± 0.8	0.4 (−0.3 to 1.1)
HDL cholesterol	0.02 ± 0.1	0.07 ± 0.2	−0.05 (−0.1 to 0.05)	0.06 ± 0.1	0.07 ± 0.2	−0.01 (−0.1 to 0.1)
LDL cholesterol	0.03 ± 0.4	−0.2 ± 0.9	0.2 (−0.3 to 0.7)	−0.06 ± 0.7	−0.5 ± 0.9	0.4 (−0.2 to 1.0)
Triglycerides	−0.2 ± 0.7	−0.05 ± 0.9	−0.2 (−0.8 to 0.4)	−0.2 ± 0.7	−0.08 ± 0.6	−0.1 (−0.7 to 0.4)

Data are means ± SD or means (95% CI). Net difference refers to the within-group change from baseline in the RT & WL group minus the within-group change from baseline in the WL group. *$P < 0.01$ within-group difference from baseline; †$P < 0.05$ between-group difference from baseline.

age and two subjects from each groups had their medication increased.

Adherence to the interventions

One-hundred percent adherence to the exercise sessions was set at 72 training sessions (three times per week for 24 weeks). Adherence to the exercise sessions among the 29 subjects averaged 88% (95% CI 81.7–94.1) for the RT & WL group and 85% (95% CI 77.9–92.4) for the WL group. Other than transient musculoskeletal soreness, no major complications or injuries were reported from either the RT & WL group or the WL group.

Changes in metabolic variables

HbA_{1c}. The net and percent change in HbA_{1c} from baseline for both groups are shown in Table 2 and Fig. 1. The RT & WL program was associated with a significant reduction in HbA_{1c} at both 3 months (0.6 ± 0.7%, $P < 0.01$) and 6 months (1.2 ± 0.9%, $P < 0.01$). No detectable changes were observed in HbA_{1c} for the WL group. There was a significant group-by-time interaction ($P < 0.05$), with the magnitude of the decrease in HbA_{1c} being greater in the RT & WL group than in the WL group. The overall net difference between groups in mean HbA_{1c} from baseline was −0.5% ($P < 0.05$) at 3 months and −0.8% ($P < 0.05$) at 6 months. The results remained unchanged after adjustment for age, sex, duration of diabetes, use of oral hypoglycemic medication, medication change, baseline HbA_{1c} levels, and change in waist circumference.

Fasting insulin and glucose. Fasting plasma insulin levels remained unchanged throughout the 6-month intervention for both the RT & WL and WL groups (Table 2). For fasting plasma glucose, no changes were detected in either group after 3 months, but a 1.4-mmol/l decrease ($P = 0.06$) was observed in the RT & WL group after 6 months (Table 2). However, there were no differences between the groups for either serum insulin or plasma glucose at any time point. Furthermore, insulin sensitivity (HOMA) remained unchanged in both groups.

Changes in anthropometric and body composition

In both the RT & WL and WL groups, there was a significant reduction in body weight and waist circumference after 3 and 6 months (Table 3). Fat mass also decreased in both groups after 6 months. However, there were no between-group differences in the net change from baseline for any of these variables at any time. LBM increased in the RT & WL group after 6 months' training (0.5 ± 1.2 kg, $P = 0.09$), but decreased in the WL group (0.4 ± 1.0 kg), which led to a significant group-by-time interaction ($P < 0.05$). The overall net percentage change from baseline for LBM in the RT & WL group relative to the WL group was 1.9% (95% CI 0.16–3.55).

Changes in muscle strength

As expected, resistance training and weight loss resulted in significant in-

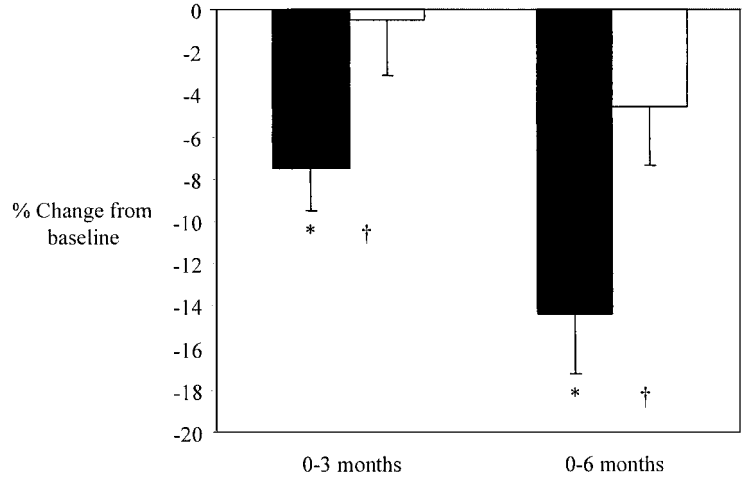

Figure 1—*Relative changes (percent) in HbA_{1c} from baseline in the RT & WL and WL groups after 3 and 6 months. *P < 0.01 within-group difference from baseline; †P < 0.05 between-group difference for the change from baseline. Values are means ± SE.*

Table 3—*Absolute changes in anthropometry, body composition, muscle strength, blood pressure, energy expenditure, and energy intake from baseline for the RT & WL and WL groups, and the net difference between groups*

	3-month change from baseline			6-month change from baseline		
	RT & WL	WL	Net difference (95% CI)	RT & WL	WL	Net difference (95% CI)
Anthropometry						
Body mass (kg)	−1.8 ± 2.0*	−2.0 ± 1.5*	0.2 (−1.2 to 1.6)	−2.5 ± 2.9*	−3.1 ± 2.1*	0.6 (−1.3 to 2.6)
Waist circumference (cm)	−3.8 ± 3.5*	−3.1 ± 3.2*	−0.7 (−3.3 to 2.0)	−6.9 ± 5.7*	−6.7 ± 6.1*	−0.2 (−4.8 to 4.2)
Body Composition						
Fat mass (kg)	—	—	—	−2.4 ± 2.8*	−2.1 ± 2.5*	0.3 (−2.4 to 1.8)
LBM (kg)	—	—	—	0.5 ± 1.2	−0.4 ± 1.0	0.9 (0.05–1.8)§
Muscle strength						
Upper body (% change)	30.5 ± 18.8*	7.6 ± 15.7	22.9 (7.6–38.2)‡	43.2 ± 34.2*	1.5 ± 17.7	41.7 (14.4–69.0)‡
Lower body (% change)	8.0 ± 17.1	2.1 ± 18.4	5.9 (−8.9 to 20.6)	33.0 ± 21.7*	5.0 ± 16.9	28.0 (9.1–46.9)‡
Resting blood pressure (mmHg)						
Systolic	−4.9 ± 13.9	−3.8 ± 13.6	−1.1 (−11.7 to 9.4)	−6.7 ± 10.0†	−2.5 ± 15.8	−4.2 (−14.1 to 5.7)
Diastolic	−3.6 ± 7.4	−0.9 ± 6.8	−2.7 (−8.1 to 2.8)	−4.4 ± 6.9†	−0.9 ± 10.1	−3.5 (−10.0 to 3.0)
Energy expenditure (kcal/day)	−38 ± 209	−80 ± 207	42 (−117 to 202)	−97 ± 204	−55 ± 253	−42 (−216 to 131)
Total energy intake (kcal/day)	−275 ± 343†	−241 ± 311†	−34 (−309 to 241)	−281 ± 418†	−391 ± 251*	110 (−193 to 413)

Data are means ± SD or means (95% CI). Net difference refers to the within-group change from baseline in the RT & WL group minus the within-group change from baseline in the WL group. *$P < 0.01$, †$P < 0.05$ within-group differences from baseline; ‡$P < 0.01$, §$P < 0.05$ between-group difference from baseline.

creases in upper and lower body muscle strength throughout the intervention (Table 3). There were no changes in muscle strength in the WL group. The overall net percentage change from baseline in upper body strength in the RT & WL group was 22.9% (95% CI 7.6–38.2, $P < 0.01$) at 3 months and 41.7% (95% CI 14.4–69.0, $P < 0.01$) at 6 months. For lower body strength, the net percentage change from baseline in the RT & WL group was 5.8% (95% CI −8.9 to 20.6, $P = 0.6$) at 3 months and 28.0% (95% CI 9.1–46.9, $P < 0.01$) at 6 months.

Changes in blood pressure and serum lipids

Resting blood pressure did not change from baseline in either group after 3 months (Table 3). After 6 months, a significant reduction was observed in both systolic (6.7 ± 10.0 mmHg, $P < 0.05$) and diastolic (4.4 ± 6.9, $P < 0.05$) blood pressure in the RT & WL group. However, no between-group differences were observed for the net change in either systolic or diastolic blood pressure at any time. Serum lipids and lipoproteins were unchanged from baseline in both groups (Table 2).

Changes in energy intake and habitual physical activity

Analysis of the dietary records indicated that the mean total energy intake at 3 and 6 months was decreased from baseline in both the RT & WL and WL groups (Table 3). However, no differences were observed between the groups at any time. Furthermore, habitual physical activity (estimated energy expenditure, kilocalories per day) did not change from baseline in either group (Table 3).

CONCLUSIONS — This study has demonstrated that a supervised progressive high-intensity resistance training program performed 3 days/week for 6 months was safe and well tolerated by older patients with type 2 diabetes and was effective in improving glycemic control and muscle strength. The combination of resistance training and moderate weight loss was associated with a threefold greater decrease in HbA_{1c} levels after 6 months compared with moderate weight loss without resistance exercise, and this was not mediated by concomitant reductions in body weight, waist circumference, and fat mass. The addition of resistance training also contributed to the maintenance of LBM despite moderate weight loss.

Traditionally, aerobic activities have been recommended for people with type 2 diabetes because of the known benefits on insulin sensitivity and glucose tolerance (7). However, for many older patients with type 2 diabetes, the presence of diabetic complications or coexisting conditions, such as obesity, degenerative arthritis, or cardiovascular disease, may preclude participation in aerobic activities that involve prolonged periods of weight bearing, such as walking. In the present study, we found that a high-intensity (75–85% of maximum strength) progressive resistance training program involving nine upper and lower body exercises (three sets of 8–10 repetitions) performed 3 days/week led to a significant reduction in HbA_{1c} after 3 months, which was decreased further after 6 months of training. Data from the U.K. Prospective Diabetes Study show that for every percentage point reduction in HbA_{1c}, there is a 35% reduction in microvascular complications (24). Furthermore, recent data from the EPIC (European Prospective Investigation of Cancer and Nutrition)-Norfolk prospective population study show that HbA_{1c} concentration explains most of the excess mortality risk of diabetes, with an increase of one percentage point in HbA_{1c} associated with a 28% increase in risk of death, independent of other well-established cardiovascular risk factors (25). In light of these findings, it seems plausible to suggest that the mean 1.2% reduction in HbA_{1c} after resistance training is likely to offer a prognostic advantage in older patients with type 2 diabetes.

In recognition of the potential to improve muscular strength, endurance, and

muscle mass, recent guidelines have supported the inclusion of resistance exercise as part of a well-rounded program for the lifestyle management of patients with type 2 diabetes (7,8). However, of the few studies that have assessed the impact of resistance training on glycemic control in this population (26–30), none have investigated the long-term effects of high-intensity progressive resistance training combined with moderate weight loss in older adults with type 2 diabetes. Recent studies in middle-aged subjects with type 2 diabetes have reported improved insulin sensitivity using the hyperinsulinemic-euglycemic clamp (29) and improved glucose tolerance (28) after short-term moderate-intensity resistance training, although most (28,29), but not all (30), have failed to detect an improvement in HbA_{1c}. However, in all of these studies, the resistance training period was restricted to <8 weeks and, in contrast to the high-intensity (75–85% of maximum strength) resistance training program used in the present study, all used moderate intensity (40–50% of maximum strength) training protocols, including circuit weight training, which has both aerobic and resistance exercise components.

The mechanisms for the improvement in glycemic control observed after resistance training in the present study are unclear. It is unlikely that differences in the magnitude of the changes in body weight and total fat mass accounted for the improved glycemic control, because both groups experienced similar changes throughout the study duration. Since improved insulin action has been positively associated with an exercise-induced increase in LBM in healthy young women (31), older men (17), and postmenopausal women (18) after resistance training, it is possible that the small increase in LBM observed in the resistance-trained individuals may be an important mediator of the improved glycemic control seen in the resistance-trained subjects. It has been suggested that the improved insulin sensitivity after resistance training occurs via different mechanisms from endurance training, with resistance training probably inducing a mass effect without altering the intrinsic capacity of the muscle to respond to insulin (31). However, it has also been proposed that improved insulin sensitivity after resistance training may be mediated by concomitant decreases in visceral and abdominal subcutaneous adipose tissue or abdominal obesity (32). In the present study, although abdominal fat mass was not directly assessed, waist circumference, which is a very robust predictor of abdominal visceral fat (33), was decreased to a similar extent in both the RT & WL and WL groups, implying that mechanisms other than abdominal obesity changes may have been involved in the more pronounced effect on HbA_{1c} observed after resistance training.

Because improved glucose disposal and metabolism may last for several hours, or perhaps days, after the cessation of acute exercise (34), it is uncertain whether the improved insulin sensitivity observed after exercise training in patients with type 2 diabetes is due to the cumulative effects of the individual acute exercise bouts or a specific training-induced adaptation (35). To avoid the possible residual effects of the last exercise bout on fasting glucose and insulin levels, all blood samples were assessed at least 48 h after the last exercise session. This interval may explain the absence of significant differences between the RT & WL and WL groups with respect to both of these variables as well as insulin sensitivity estimated using the HOMA model. Other explanations may relate to the sample size being inadequate to detect a significant fall in fasting glucose and insulin levels or the possibility that the major effect of the resistance training program was on postprandial glucose and postprandial insulin sensitivity, which are dependent on muscle insulin sensitivity. Nevertheless, regardless of whether the changes detected in HbA_{1c} reflect the summation of acute training or a chronic effect of training, our findings provide strong support for the notion that resistance training performed on a regular basis has significant therapeutic value and should be incorporated into initiatives designed to manage glycemic control in older patients with type 2 diabetes.

In agreement with previous studies in middle-aged patients with type 2 diabetes (28,30) and middle-aged men at high risk for coronary heart disease (36,37), in this study, resistance training did not induce changes in the lipid profile. Common to all these studies, resistance training has either not altered body weight or led to relatively small weight loss during the intervention period. Since it appears that there is a positive association between exercise-induced changes in lipid profiles and weight loss (38), our findings, along with previous studies (28,30,36,37), suggest that a greater change in body weight and fat mass may be necessary to have a significant effect on the lipid profile after resistance training. Similarly, although there was a trend for blood pressure to be reduced from baseline levels in the resistance-trained subjects, no differences were observed between the groups at either 3 or 6 months in the present study. This finding is consistent with other studies in patients with type 2 diabetes (3,30) and in men with an increased risk of coronary heart disease (37) after resistance training and may be influenced by the initial baseline levels of the subjects and the magnitude of change in body weight and fat mass (37,39–41). Nonetheless, our findings support earlier investigations in both normotensive and hypertensive subjects suggesting that long-term resistance training does not stimulate elevations in blood pressure, thereby supporting the appropriateness of this form of exercise for individuals with an elevated risk of hypertension.

Maintenance of both upper and lower body muscle strength is important for older people to accomplish many of the tasks of daily living requiring static or dynamic efforts as well as for the prevention of falls (42). Previous studies in middle-aged and older patients with type 2 diabetes that have used moderate training intensities have also observed muscular strength changes (28–30), but our findings suggest that high-intensity resistance training may be more effective, since the magnitude of the improved muscular strength was considerably higher in our program than that previously reported. In addition to improved muscle strength, our findings concur with previous studies that have demonstrated that combining resistance training with moderate energy restriction preserves LBM during diet-induced weight loss while contributing to loss in fat mass (43,44). Collectively, these results provide evidence to support the inclusion of high-intensity resistance training within lifestyle management strategies designed to reduce fat mass in older patients with type 2 diabetes. Furthermore, the high compliance and adherence to the high-intensity resistance training program observed in the present study indicates that this type of exercise training was well tolerated, feasible, and

safe for older patients with type 2 diabetes. Nevertheless, further long-term studies are needed to examine whether the benefits can be maintained or even enhanced beyond the 6-month intensive training period and to determine whether similar programs conducted outside the intensive laboratory-based setting can improve glycemic control. Additional work is also required to assess the appropriateness of such programs for patients with type 2 diabetes who also have ischemic heart disease or the presence of advanced diabetes complications such as neuropathy and retinopathy.

In conclusion, the results of this study demonstrate that a 6-month supervised high-intensity resistance training program was safe and well tolerated by older patients with type 2 diabetes. When combined with moderate weight loss, resistance training was more effective for improving HbA_{1c} than moderate weight loss without resistance training, and this observation could not be explained by differences in body weight, waist circumference, and fat mass changes during the intervention. Furthermore, the addition of resistance training contributed to the preservation of LBM during moderate weight loss. These findings provide strong support for the recommendation of this form of exercise in the therapeutic management of glycemic control of older patients with type 2 diabetes.

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