Home-Based Resistance Training Is Not Sufficient to Maintain Improved Glycemic Control Following Supervised Training in Older Individuals With Type 2 Diabetes

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OBJECTIVE — To examine whether improvements in glycemic control and body composition resulting from 6 months of supervised high-intensity progressive resistance training could be maintained after an additional 6 months of home-based resistance training.

RESEARCH DESIGN AND METHODS — We performed a 12-month randomized controlled trial in 36 sedentary, overweight men and women with type 2 diabetes (aged 60–80 years) who were randomly assigned to moderate weight loss plus high-intensity progressive resistance training (RT&WL group) or moderate weight loss plus a control program (WL group). Supervised gymnasium-based training for 6 months was followed by an additional 6 months of home-based training. Glycemic control (HbA_{1c}), body composition, muscle strength, and metabolic syndrome abnormalities were assessed at 0, 3, 6, 9, and 12 months.

RESULTS — Compared with the WL group, HbA_{1c} decreased significantly more in the RT&WL group (−0.8%) during 6 months of supervised gymnasium-based training; however, this effect was not maintained after an additional 6 months of home-based training. In contrast, the greater increase in lean body mass (LBM) observed in the RT&WL group compared with the WL group (0.9 kg, $P < 0.05$) after the gymnasium-based training tended to be maintained after the home-based training (0.8 kg, $P = 0.08$). Similarly, the gymnasium-based increases in upper body and lower body muscle strength in the RT&WL group were maintained over the 12 months ($P < 0.001$). There were no between-group differences for changes in body weight, fat mass, fasting glucose, or insulin at 6 or 12 months.

CONCLUSIONS — In older adults with type 2 diabetes, home-based progressive resistance training was effective for maintaining the gymnasium-based improvements in muscle strength and LBM but not glycemic control. Reductions in adherence and exercise training volume and intensity seem to impede the effectiveness of home-based training for maintaining improved glycemic control.

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Physical activity recommendations for older patients with type 2 diabetes have traditionally focused on aerobic-based activities such as walking programs. However, resistance or strength training has been considered a viable alternative to aerobic exercise because of its effectiveness in improving muscular strength and its role in the prevention of age-related sarcopenia (1). Recently, we have reported improved HbA_{1c} in sedentary, overweight, older men and women (60–80 years of age) with type 2 diabetes after 6 months of supervised progressive resistance training (2). Other controlled trials have also demonstrated improved glycemic control in patients with type 2 diabetes after supervised resistance training for 2–4 months (3,4).

Although these findings support the use of resistance training for the management of glycemic control in older adults with type 2 diabetes, it is unclear whether improved glycemic control can be maintained after supervised exercise is withdrawn. Most trials have used supervised exercise sessions in laboratories or exercise facilities to assess the effectiveness of resistance training on metabolic parameters and functional capacity. Because maintenance of good glycemic control is a long-term consideration, strategies to facilitate regular long-term participation in resistance training are needed.

One potential maintenance strategy could be home-based resistance training, because this may foster long-term adherence through greater convenience and flexibility (5). In cardiac patients, home-based maintenance programs after center-based cardiac rehabilitation have been shown effective in improving or maintaining functional capacity, blood lipid profiles, and body weight (6). Additionally, studies in older adults have reported that home-based resistance training can be an effective way to elicit strength gains,

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Abbreviations: HOMA, homeostasis model assessment; LBM, lean body mass; 1RM, one-repetition maximum.

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

although the effect on metabolic risk markers such as glycemic control, lipids, and blood pressure is unknown (7,8).

We examined the feasibility and effectiveness of a long-term (6-month) home-based resistance-training program in older overweight adults with type 2 diabetes who had completed an initial 6-month period of supervised gymnasium-based resistance training. Specifically, we aimed to determine whether beneficial effects of supervised gymnasium-based resistance training on glycemic control and body composition could be maintained following a home-based maintenance program.

RESEARCH DESIGN AND METHODS

Baseline characteristics of participants and the screening and testing procedures for this study have been described in detail previously (2). In summary, 21 men and 15 women aged 60–80 years with treated (diet and/or medication) type 2 diabetes were recruited into the study and were randomly assigned to moderate weight loss plus high-intensity progressive resistance training (RT&WL group) or moderate weight loss plus a control program (WL group). All participants were overweight (BMI >27 and ≤ 40 kg/m^2) and sedentary, had established (>6 months) but not optimally controlled type 2 diabetes (HbA$_{1c}$ range 7–10%), were not taking insulin, were nonsmokers, and consumed on average fewer than two alcoholic beverages per day. Four women had a history of hormone replacement therapy, but none was a current user. Antidiabetic and antihypertensive medications were continued during the study. The study was approved by the International Diabetes Institute and Deakin University Human Research Ethics Committee, and written consent was obtained from all participants.

The study was a 12-month randomized controlled clinical trial with repeated measurements performed at 3-month intervals. The intervention was divided into two distinct phases. Phase 1 (gymnasium based), which consisted of 6 months of supervised training, has been described in detail previously (2). The present study reports the results from phase 2 (home based), which consisted of an additional 6 months of training in the home setting. During the home-based phase, an additional three participants withdrew from the study (two from the RT&WL group and one from the WL group). All withdrawals occurred within the first 2 weeks of the home-based training. Reasons for withdrawal included overseas travel, continued pain associated with osteoarthritis of the knee, and personal problems unrelated to the study. Therefore, 72% of the 36 originally randomized participants completed the 12 month intervention: 14 (74%) of the RT&WL group and 12 (71%) of the WL group.

Intervention

Phase 1: Supervised gymnasium-based training. Details of the prescribed healthy eating plan and the supervised gymnasium-based training (progressive resistance training program and control flexibility program) have been previously reported (2). All exercise sessions were conducted in a research laboratory and were supervised to ensure correct technique and to monitor the appropriate amount (and progression) of exercise and rest intervals.

Phase 2: Home-based training. At the completion of gymnasium-based training, all participants were provided with individualized instructions, training, and appropriate equipment (dumbbells/ankle weights or a flexibility wall chart) to perform the resistance training or light flexibility training 3 days per week at home or at commercial/community facilities. However, none of the participants in the RT&WL group continued their training program within commercial/community facilities during the home-based phase of the study. To accommodate the transition to home-based training, participants in the RT&WL group completed the home-based exercise program within the supervised gymnasium-based setting during the final 4 weeks of phase 1. The home-based exercises were similar to those used in the gymnasium-based program, with the exception that dumbbells and ankle weights replaced the exercises performed on the multistation weight machines. The nine home-based exercises included lying dumbbell flies, seated single-leg extension (ankle weights), dumbbell shoulder press, dumbbell bent-over row, standing leg curl (ankle weights), dumbbell upright row, dumbbell bicep curls, dumbbell triceps kickbacks, and abdominal curls. Participants were also provided with detailed instruction booklets describing each resistance training exercise and were asked to follow an individually prescribed training program (three sets of 8–10 repetitions with the goal to exercise at an intensity corresponding to ~60–80% of the current one-repetition maximum [1RM]).

During the first week of the home-based training, home visits were conducted to ensure that the home training environment was appropriate and safe. The home-training dumbbells provided capacity for workloads between 2.5 and 30 kg, and the ankle weights provided workloads between 0.5 and 20 kg. Additional weights were provided periodically to facilitate progression. The subjects in the control flexibility group were given stretching wall charts and were asked to continue the flexibility program at home. Participants were telephoned weekly for the first 4 weeks and every 2 weeks thereafter to monitor compliance, answer questions, and provide individualized feedback. Participants also completed weekly training diaries and were required to attend the gymnasium monthly to perform the home-based training so that technique and progression could be monitored. During the home-based training, participants were not required to follow the healthy eating plan and were not provided with dietary advice from the dietitian.

Measurements

Blood samples were obtained from each participant's antecubital vein at baseline and every 3 months after an overnight fast for the determination of plasma glucose, serum insulin, and HbA$_{1c}$. All samples were collected at least 48 h after exercise. Serum samples for insulin were stored at −80°C until assayed. GHb was measured with the Roche Unimate 5 HbA$_{1c}$ kit (Roche, Montclair, NJ) using the Olympus AU600 automated analyzer (Olympus, Tokyo, Japan). Plasma glucose levels were measured enzymatically (glucose oxidase) within 12 h of collection using the Olympus AU600 automated analyzer. Serum insulin was measured using a human insulin-specific radioimmunoassay kit (Linco Research, St. Charles, MO). Homeostasis model assessment (HOMA) was used to estimate insulin sensitivity from fasting insulin and glucose concentrations (2,4).

Procedures used for the measurement of height, weight, waist circumference, habitual physical activity, and 1RM have been described previously (2). Total body fat and lean body mass (LBM) were as-

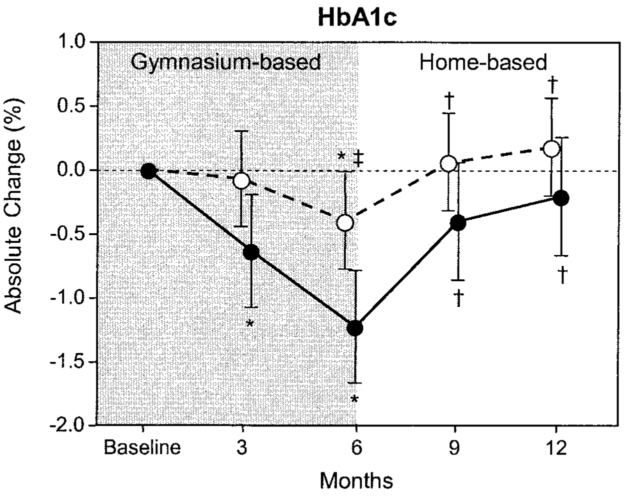

Figure 1—*Absolute change in HbA$_{1c}$ from baseline in RT&WL (●) and WL (○) groups after 3, 6, 9, and 12 months.* $^*P < 0.05$ *within-group difference for the change from baseline;* †$P < 0.05$ *within-group difference for the change from 6 months;* ‡$P < 0.05$ *between-group difference for the change from baseline. Values are means and 95% CI.*

sessed by dual-energy X-ray absorptiometry (DPX-L; Lunar, Madison, WI) at baseline, 6 months, and 12 months. All scanning and analyses were performed by the same operator. The coefficient of variation for repeated measurement was 1.2% for total body fat and 1.7% for LBM.

Statistical analyses

Statistical analysis was conducted using Stata Statistical Software release 8.0 (Stata, College Station, TX) (9). Independent Student's t tests were used for between-group comparisons at baseline. Net between-group differences were calculated by subtracting the within-group changes from baseline for the WL group from the within-group changes for the RT&WL group for each time point (6, 9, and 12 months). Time, group, and interaction effects during the 12-month period were examined using pooled time series regression analysis for longitudinal data with random effects models. Fasting plasma insulin levels and HOMA values were log transformed to yield a normal distribution before parametric analysis. All other data were close to normally distributed.

RESULTS— Baseline characteristics for the 29 participants have been previously reported (2). There were no differences between the RT&WL and WL groups, respectively, for HbA$_{1c}$ (8.1 ± 1.0 vs. 7.5 ± 1.1%), weight (88.7 ± 10.9 vs. 89.5 ± 12.1 kg), total body fat (33.1 ± 7.4 vs. 35.6 ± 6.8 kg), or LBM (51.8 ± 8.1 vs. 49.7 ± 9.5 kg).

During the home-based training (6–12 months), in the RT&WL group, one participant decreased his oral hypoglycemic medication dosage and one participant had her medication increased. Another subject in this group was started on insulin treatment during the home-based training.

Changes in HbA$_{1c}$ from baseline to 12 months

The change in HbA$_{1c}$ in both groups after the supervised gymnasium-based and home-based training is shown in Fig. 1. As previously reported, there was a greater reduction in HbA$_{1c}$ in the RT&WL group compared with the WL group after the gymnasium-based training (interaction, $P < 0.05$). In contrast, a significant and similar increase in HbA$_{1c}$ was observed in both groups during home-based training (6–9 months and 6–12 months, respectively; $P < 0.05$). Figure 1 and Table 1 show that the statistically significant between-group difference for the net change after gymnasium-based training (−0.8%; $P < 0.05$) was not maintained during home-based training. These results remained unchanged after adjustment for age, sex, duration of diabetes, use of oral hypoglycemic medication, insulin use, medication change, change in waist circumference, and change in total energy intake and estimated energy expenditure.

Changes in physiological outcomes

Anthropometric and body composition measures. The net and percent change in body weight, total body fat, and LBM from baseline in both groups is shown in Table 1 and Fig. 2. Both groups experienced a similar decrease in body weight and total body fat after the supervised gymnasium-based training ($P < 0.01$). In contrast, LBM increased in the RT&WL group compared with the WL group during this period (interaction, $P < 0.05$). At the completion of home-based training, both groups had experienced a similar increase in body weight and total body fat (P ranging from <0.05 to <0.01); however, body weight remained significantly lower than baseline levels in both groups after 12 months. LBM did not change significantly in either group after home-based training, but a significant 0.6-kg ($P < 0.05$) decrease from baseline levels was observed in the WL group at 12 months (Fig. 2). Therefore, the significant between-group difference in LBM observed after gymnasium-based training tended to be maintained through home-based training (group-by-time interaction; $P = 0.08$).

Muscle strength. As expected, significant increases from baseline in upper and lower body strength were observed in the RT&WL group compared with the WL group after gymnasium-based training (Table 1). The between-group difference was 30.7 kg (95% CI 14.3–47.2; $P = 0.0001$) for upper body strength and 8.3 kg (3.9–12.6; $P = 0.0001$) for lower body strength. These between-group differences were maintained at 9 and 12 months.

Changes in fasting glucose, serum insulin, and insulin sensitivity (HOMA). As previously reported, no significant within-group or between-group changes from baseline were observed in fasting glucose, serum insulin, or insulin sensitivity during gymnasium-based training. Similarly, no changes were detected for fasting glucose in either group during the home-based training (Table 1). However, the WL program was associated with a significant decrease in fasting serum insulin at 9 and 12 months and an increase in insulin sensitivity (HOMA) at 9 and 12 months, although these changes were no longer significant after adjustment for the major confounders. No detectable changes were observed in fasting serum insulin or insulin sensitivity in the

Table 1—*Absolute changes from baseline in fasting glucose, insulin, waist circumference, muscle strength, energy expenditure, and energy intake during home-based training (9 months, 12 months) for the RT&WL and WL groups and the net difference between groups*

	9-month change from baseline			12-month change from baseline		
	RT&WL	WL	Net difference (95% CI)	RT&WL	WL	Net difference (95% CI)
Fasting plasma glucose (mmol/l)	−0.8 ± 2.2	−0.7 ± 2.1	−0.1 (−1.7 to 1.5)	0.3 ± 2.2	−0.5 ± 2.1	0.8 (−0.8 to 2.4)
Fasting serum insulin (pmol/l)*	1.6 ± 45.6	−16.5 ± 47.2†	18.1 (−16.0 to 52.1)	−0.1 ± 46.8	−19.3 ± 50.1†	19.2 (−16.3 to 54.7)
Insulin sensitivity (HOMA) (%)*	−0.6 ± 5.4	4.1 ± 6.1†	−4.7 (−8.9 to −0.5)	0.04 ± 5.5	5.4 ± 6.5†	−5.4 (−9.8 to −1.0)
Waist circumference (cm)	−6.9 ± 4.7†	−6.1 ± 4.3†	−0.8 (−4.1 to 2.5)	−3.4 ± 4.7†	−2.0 ± 4.3	−1.4 (−4.8 to 1.8)
Muscle strength						
Upper body (kg)	26.3 ± 22.8†	−2.5 ± 19.1	28.8 (12.0–45.2)‡	26.4 ± 22.8†	−0.2 ± 19.1	26.6 (9.6–42.9)‡
Lower body (kg)	7.1 ± 6.1†	0.7 ± 5.4	6.4 (2.1–10.6)‡	4.9 ± 6.4†	−0.1 ± 5.4	5.0 (0.5–9.3)‡
Energy expenditure (kcal/day)	−65 ± 195	−187 ± 244†	122 (−38 to 281)	−132 ± 195†	−192 ± 244†	60 (−99 to 220)
Total energy intake (kcal/day)	−208 ± 573	−166 ± 399	−42 (−426 to 329)	−262 ± 532§	−229 ± 401§	−33 (−389 to 342)

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. *Data log-transformed for statistical analysis; †$P < 0.05$ for within-group differences from baseline; ‡$P < 0.05$ for between-group difference from baseline; §significant from baseline.

RT&WL group at any time point. As shown in Table 1, no between-group differences from baseline were observed for fasting plasma glucose, serum insulin, and insulin sensitivity (HOMA) during the home-based training.

Changes in energy intake and habitual physical activity. Analysis of the dietary records showed no between-group differences from baseline for total energy and fat intake at any time point during the intervention (Table 1). Similarly, no between-group differences were observed for habitual physical activity (estimated energy expenditure, kcal/day).

Adherence and training volume. Adherence to the exercise sessions during gymnasium-based training was 88% (81.7–94.1%) for the RT&WL group and 85% (77.9–92.4%) for the WL group. Compared with gymnasium-based training, both groups experienced a similar significant decrease in adherence during home-based training ($P < 0.05$); the mean adherence reported was 72.6% (56.8–88.5%) for the RT&WL group and 78.1% (65.3–90.9) for the WL group. Similarly, the frequency of exercise (days/week) decreased in both the RT&WL group during home-based training (2.8 [2.6–2.9] vs. 2.2 [1.7–2.7]; $P < 0.05$) and the WL group (2.7 [2.5–2.8] vs. 2.2 [2.0–2.7]; $P < 0.05$).

For the RT&WL group, the training volume (calculated as the total amount of weight lifted multiplied by the amount of repetitions completed) was assessed during the final week of gymnasium-based training and the first week of home-based training using self-completed activity logs. Relative to gymnasium-based training, there was a 51.8% (24.8–78.9; $P = 0.001$) decrease in training volume during the home-based training. This observation was largely attributed to a 62.6% (54.0–71.3; $P = 0.001$) reduction in the amount of weight lifted. Insufficient return of activity logs precluded calculation of training volume in the final week of home-based training. No major complications or injuries were reported from either group during both the gymnasium-based and home-based training.

CONCLUSIONS

— The home-based resistance training maintenance program was well tolerated by older adults with type 2 diabetes but did not maintain improvements in glycemic control seen after supervised resistance training. However, home-based training was effective for maintaining improvements in muscle strength and LBM.

As reported earlier, the decrease in HbA_{1c} was significantly greater in resistance-trained subjects during the initial 6-month supervised period (2). However, after 12 months, HbA_{1c} levels were no longer significantly different from baseline values in either group. There are several plausible explanations that may account for these findings. In contrast to the 6-month gymnasium-based program, home-based training was not combined with a healthy eating plan designed to elicit moderate weight loss. Although significant gains in weight and total body fat were observed in both groups after home-based training, we did not observe any between-group differences in self-reported energy intake between the respective periods. However, estimation of dietary intake using self-reported dietary assessments can be subject to inaccuracy due to under-reporting, especially in overweight subjects (10). Nevertheless, it is unlikely that the magnitude of the changes in body weight, total body fat, and energy balance accounted for the changes in glycemic control throughout the study because the impact of resistance training on glycemic control in the supervised setting was independent of changes in all of these variables.

The reduced adherence to exercise and the reduction in the volume and intensity of training during home-based training may have lessened the impact of resistance training on glycemic control.

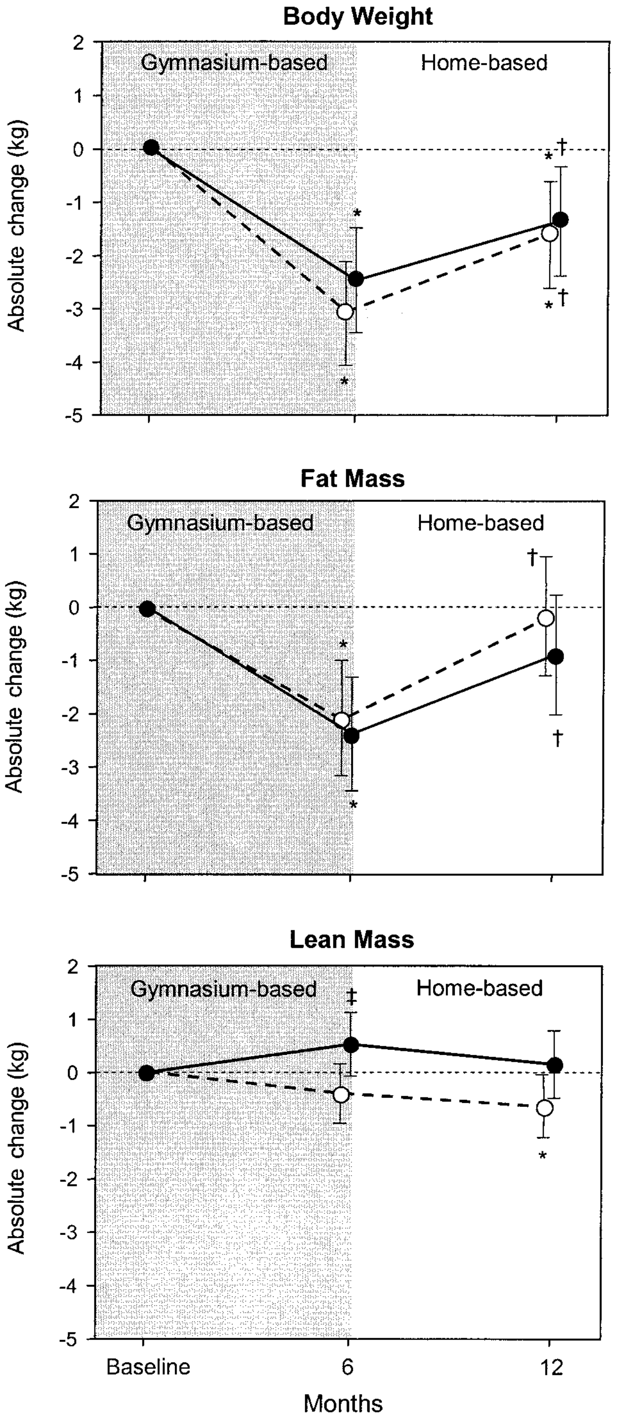

Figure 2—*Absolute change in body weight, total body fat, and LBM from baseline in RT&WL (●) and WL (○) groups after 6 and 12 months.* *$P < 0.05$ *within-group difference for the change from baseline;* †$P < 0.05$ *within-group difference for the change from 6 months;* ‡$P < 0.05$ *between-group difference for the change from baseline. Values are means and 95% CI.*

We estimated that training volume decreased initially by 52% from the gymnasium-based to home-based training, which was largely due to a reduction in training workloads or the amount of weight lifted. During the home-based training, the absolute workload could not be maintained because various exercises performed using machine weights in the supervised setting have greater workload capacity than hand or leg weights. Therefore, it is likely that the training intensity during home-based training was below the level (70–90% 1RM) generally considered to be optimal for affecting change in muscle mass and glycemic control in older adults with type 2 diabetes (11). Previous studies in patients with type 2 diabetes using low to moderate intensity resistance training protocols (40–50% 1RM) have failed to detect any improvement or only modest effects on HbA_{1c} levels (3,12). Our findings also support the results from a recent study in older patients with type 2 diabetes (4), which indicate that high-intensity resistance training, similar to what was used during gymnasium-based training in the present study, may be necessary to induce a stronger stimulus for glucose uptake.

Resistance training contributed to the preservation of LBM during diet-induced weight loss in the initial 6-month supervised training and tended to attenuate the continued decline in LBM observed in subjects in the WL group during home-based training. Schmitz et al. (13) found that increases in LBM after a 15-week supervised strength-training program in middle-aged women could be maintained over 6 months through an unsupervised program in an exercise facility. In addition, the observation that muscle strength increases from a supervised resistance training program were maintained after 6 months of home-based training is consistent with recent findings in overweight middle-aged women (13). However, the finding that home-based training did not induce further strength gains from those observed during supervised training is most likely due to the reduced training volume during this period. This further supports our argument that home-based training did not provide a sufficient training stimulus to induce changes in muscle glucose uptake. Because skeletal muscle is the largest mass of insulin-sensitive tissue in the body, it is possible that the small increase and decrease in LBM observed in resistance-trained subjects after the gymnasium and home-based training, respectively, may have been an important mediator of the changes in glycemic control seen in the resistance-trained subjects (14). However, a recent study by Holten et al. (15) suggests that resistance training enhances insulin action in people with type 2 diabetes through mechanisms that may be independent of increases in muscle mass, such as local contraction-mediated mechanisms involving key proteins in the insulin-signaling cascade. The training volume used by Holten et al. (15) was similar to that used during the supervised gymnasium-based training in the present study, further supporting our suggestion that the reduced training volume during home-based training was not sufficient to stimulate changes in glucose uptake in the resistance-trained subjects.

Few studies have assessed the long-term efficacy of home-based progressive resistance training using free weights in older adults (16). In the absence of any major injuries or adverse events and a reasonable retention rate, our findings demonstrate that progressive resistance training using hand and leg weights in the home setting is safe and feasible in older adults with type 2 diabetes. Our study design does not permit the direct comparison of home-based versus facility-based training, because the home-based training was applied to the respective intervention groups in a chronological sequence. Therefore, participants were exposed to a considerable period of supervised training preceding the home-based training. Furthermore, participants received contact on a regular basis from the research staff and also attended monthly supervised sessions at the exercise laboratory. Although our study design cannot elucidate whether reduced adherence might have also occurred if participants had continued training in the exercise laboratory, a more intensive approach involving more frequent contact, as demonstrated in recent diabetes prevention trials in the U.S. (17) and Finland (18), could have improved adherence and consequently enhanced the impact of home-based resistance training on glycemic control. Our finding that home-based resistance training was not effective for maintaining improved glycemic control indicates that ongoing supervision and perhaps, more importantly, access to more specialized exercise training equipment such as machines, may be necessary to facilitate the benefits of progressive resistance programs in older adults with type 2 diabetes. Additional work is required to examine the efficacy and long-term compliance to progressive resistance training programs within other supervised community settings such as local gymnasiums, community centers, aged residences, or a combined home/supervised center-based approach.

In conclusion, we have demonstrated that a 6-month home-based progressive resistance training program 3 days per week following supervised gymnasium-based training was safe and well tolerated by older adults with type 2 diabetes. Whereas home-based resistance training was effective for maintaining the gymnasium-based improvements in muscle strength and LBM, the improved glycemic control associated with supervised resistance training in combination with moderate weight loss was not maintained after the home-based training. The apparent ineffectiveness of home-based training to maintain the improvements in glycemic control was most likely due to a reduction in adherence and exercise training volume and intensity during the home-based training. Because maintenance of optimal glycemic control is one of the cornerstones in the management of type 2 diabetes, more studies involving other types of approaches to initiate and maintain effective progressive resistance training in community settings are warranted.

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