For many years, exercise, along with diet and medication, has been considered 1 of the 3 cornerstones of diabetes therapy. Regular physical activity is recommended for patients with type 2 diabetes since it may have beneficial effects on metabolic risk factors for the development of diabetic complications. The low-cost, nonpharmacological nature of physical activity further enhances its therapeutic appeal.

Two of the major goals of diabetes therapy are to reduce hyperglycemia and body fat. Chronic hyperglycemia is associated with significant long-term complications, particularly damage to the kidneys, eyes, nerves, heart, and blood vessels. Obesity, especially abdominal obesity, is associated with insulin resistance, hyperinsulinemia, hyperglycemia, dyslipidemia, and hypertension; these abnormalities tend to cluster and are often referred to as the “metabolic syndrome.” Elements of the metabolic syndrome are strong risk factors for cardiovascular disease, and regular exercise in nondiabetic subjects has beneficial effects on virtually all aspects of the syndrome.

Although there have been numerous small studies on the effects of exercise in patients with type 2 diabetes, their findings have varied. There have been no large studies with adequate statistical power to guide practitioners in recommending exercise plans for their patients with diabetes. Exercise interventions reduced glycosylated hemoglobin (HbA1c) in some studies, but not in others. Meta-analysis may be especially useful in summarizing and quantifying the effects of exercise on glycemic control and body mass in patients with type 2 diabetes.

Context Exercise is widely perceived to be beneficial for glycemic control and weight loss in patients with type 2 diabetes. However, clinical trials on the effects of exercise in patients with type 2 diabetes have had small sample sizes and conflicting results.

Objective To systematically review and quantify the effect of exercise on glycosylated hemoglobin (HbA1c) and body mass in patients with type 2 diabetes.

Data Sources Database searches of MEDLINE, EMBASE, Sport Discuss, Health Star, Dissertation Abstracts, and the Cochrane Controlled Trials Register for the period up to and including December 2000. Additional data sources included bibliographies of textbooks and articles identified by the database searches.

Study Selection We selected studies that evaluated the effects of exercise interventions (duration ≥8 weeks) in adults with type 2 diabetes. Fourteen (11 randomized and 3 nonrandomized) controlled trials were included. Studies that included drug interventions were excluded.

Data Extraction Two reviewers independently extracted baseline and postintervention means and SDs for the intervention and control groups. The characteristics of the exercise interventions and the methodological quality of the trials were also extracted.

Data Synthesis Twelve aerobic training studies (mean [SD], 3.4 [0.9] times/week for 18 [15] weeks) and 2 resistance training studies (mean [SD], 10 [0.7] exercises, 2.5 [0.7] sets, 13 [0.7] repetitions, 2.5 [0.4] times/week for 15 [10] weeks) were included in the analyses. The weighted mean postintervention HbA1c was lower in the exercise groups compared with the control groups (7.65% vs 8.31%; weighted mean difference, −0.66%; P < .001). The difference in postintervention body mass between exercise groups and control groups was not significant (83.02 kg vs 82.48 kg; weighted mean difference, 0.54; P = .76).

Conclusion Exercise training reduces HbA1c by an amount that should decrease the risk of diabetic complications, but no significantly greater change in body mass was found when exercise groups were compared with control groups.
analyzing prior research when the number of subjects per study is small and the results are somewhat conflicting, as is the case for exercise interventions in patients with type 2 diabetes.

The main objective of this study was to systematically review the effect of exercise interventions on glycemic control as represented by HbA1c, and body mass, measured as body weight in kilograms or body mass index (calculated as weight in kilograms divided by the square height in meters) in adults with type 2 diabetes.

METHODS

Study Selection

Literature searches of computer databases were performed for the period up to and including December 2000 (MEDLINE 1966-2000, EMBASE 1980-2000, Sport Discuss 1949-2000, Health Star 1975-2000, Dissertation Abstracts 1861-2000, and the Cochrane Controlled Trials Register). The reference lists of major textbooks, review articles, and of all included articles identified by the search were hand searched to find other potentially eligible studies. Potential missing articles and unpublished literature were sought from experts. Non-English studies were included.

The computer-based search strategy included common text words and Medical Subject Headings related to exercise and type 2 diabetes. MEDLINE and EMBASE searches were limited to human subjects and used a validated and highly sensitive search filter for randomized controlled trials and nonrandomized controlled clinical trials (CCTs). If studies reported data for which it was impossible to discriminate between participants with type 2 diabetes and those with impaired glucose tolerance, we attempted to contact authors for the individual patient data.

We limited the analyses to exercise interventions lasting at least 8 weeks since our main outcome of interest, HbA1c, reflects average blood glucose concentration from the previous 8 to 12 weeks. An exercise intervention was defined as a predetermined program of physical activity described in terms of type, frequency, intensity, and duration. Studies in which the intervention consisted only of recommending increased physical activity were not included within the analyses since it would be impossible to quantify the exercise intervention and compliance. To be included, compliance with exercise interventions had to be verified by direct supervision or through exercise diaries. Studies that included drug interventions were excluded from the analysis.

Data Extraction

For the variables of interest, we extracted sample sizes as well as baseline and postintervention means and SDs for the intervention and control groups. The authors of potentially eligible studies were contacted when necessary to resolve ambiguities in reported methods or results and to seek additional information. In some cases, postintervention SDs were not available. In these instances, we imputed the baseline SD. This was assumed to be valid since the baseline and postintervention SDs were found to be similar within the other trials included in the meta-analysis (for example, the postintervention SDs were on average 0.14 units lower than the baseline SDs). Where necessary, means and measures of dispersion were approximated from figures in the manuscripts using an image scanner (RT615CTW [resolution 200 dpi], Compaq Computer Corp, Houston, Tex), as described previously.

The characteristics of the exercise interventions were extracted, including the type, frequency, duration, intensity, and energy cost. The Compendium of Physical Activities was used to estimate the exercise intensity in terms of metabolic equivalents (METs). Exercise volume (total energy expenditure on exercise, in METs per hour) was calculated by multiplying the intensity in METs by total time spent exercising (number of exercise sessions multiplied by duration of each exercise session). The methodological quality of each included trial was assessed using a validated 5-point scale as described by Jadad et al. The instrument assigned scores for reported randomization, blinding, and withdrawals. In addition to this quality scoring, we recorded separately whether allocation concealment was adequate, as described by Schulz et al.

Two of the authors (N.G.B. and E.H.) independently performed the literature search, quality assessment, and data extraction. Any disagreements on inclusion of trials or quality assessment were resolved by discussion with a third author (R.J.S.).

Statistical Analysis

Statistical analysis was performed with Review Manager Software (RevMan 4.1, Cochrane Collaboration, Oxford, England) and JMP Software (Version 3.1.6.2, SAS Institute Inc, Cary, NC). In each study, the effect size for the intervention was calculated by the difference between the means of the exercise and control groups at the end of the intervention. Each mean difference was weighted according to the inverse of its variance, and the average was taken (weighted mean difference [WMD]). When the same outcome was measured by different scales (ie, body mass represented by body weight in some studies and body mass index in others), the mean difference was standardized by dividing it by the within-group SD; the results were then weighted and the average taken (standardized mean difference [SMD]). The WMD or SMD in each study was pooled with a fixed-effects model. The χ² test for heterogeneity was performed, and when significant heterogeneity was found, the analysis was redone with a random-effects model. The funnel plot technique was used to detect publication bias.

We performed a meta-regression analysis to explore whether effects of the exercise interventions on HbA1c were mediated by effects on body mass, by the exercise intensity, or by exercise volume. In all meta-regression
EFFECTS OF EXERCISE IN TYPE 2 DIABETES

models, studies were weighted by sample size. In the first model, the mean difference in end-of-study HbA1c for individual studies was regressed on the corresponding mean difference in body mass at the same point in time. In the second model, we corrected for baseline values by regressing the difference between exercise and control groups’ change from baseline in HbA1c, on the corresponding values for body mass change. In the third model, the mean difference in end-of-study HbA1c was regressed on the exercise intensity (METs). In the fourth model, exercise volume was used (total METs per hour). In the fifth model, body mass, exercise intensity, and exercise volume were entered simultaneously.

RESULTS

Participants, Study Design, and Exercise Interventions

The computer searches yielded approximately 2700 potential articles. After the application of the filter for CCTs, the number of potential studies was 1487. The most common reasons for exclusion were: review article only, nonhuman subjects, lack of type 2 diabetic control group, lack of an exercise training intervention, duration of intervention less than 8 weeks, and/or absence of exercise supervision or exercise diaries. Eventually, 14 trials were deemed appropriate for inclusion, but in some cases there were multiple publications from the same trial.12-40

Two of the 14 trials presented data for 2 comparisons, therefore 16 comparisons were included (Table). One of these trials12 had a 2×2 factorial design in which participants were assigned to 4 groups (exercise, diet, exercise and diet, and control). For this trial, we were able to analyze 2 comparisons: exercise and diet vs diet alone; and exercise alone vs control. The second trial, Vanninen et al,21 had data analyzed separately for men and women. In the article by Wing et al,22 the results of 2 separate studies were presented.

Of the studies otherwise meeting inclusion criteria, one study41 was excluded because the exercise intervention alternating between 3 months of exercise and 3 months without exercise, and another study42 was excluded because program participation was not associated with a significant increase in physical activity. Two studies43,44 were excluded because we were unable to differentiate between participants with and without diabetes and 3 others45-47 were excluded because postintervention HbA1c and body mass values were not available. In the study by Kaplan et al,18 the combined exercise and diet group was excluded from the analysis because only the last 5 of the 10 weeks included exercise.

A total of 504 participants were included in the 14 trials. The mean (SD) age of participants in studies for which this information was available was 55.0 (7.2) years, duration of diabetes was 4.3 (4.6) years, and 50% of participants were women (Table). The quality of the trials according to the scale described by Jadad et al28 was moderate to low. The mean (SD) score was 1.6 (0.5) out of a possible 5 points. The quality assessment criterion that permitted the greatest discrimination between studies was randomization since the studies obtained similar scores on other methodological quality characteristics. Of the 14 trials, 11 were randomized controlled trials and 3 were CCTs (Table). None of the trials was double blind or had adequate allocation concealment. Nine trials had adequately described dropouts;11-16,18,20 there were no dropouts in 2 of the studies,17,25 while 3 studies did not comment on dropouts.21,22

The compliance to the exercise interventions was relatively high. In 9 studies,11,14,18,20-22 the mean participation rate was above 80%, 2 articles13,19 indicated that compliance was good, and 3 studies16,17,23 did not comment on compliance. Dietary compliance was assessed in all but 1 study21 that prescribed dietary cointerventions, using food diaries or weekly meetings with a dietician. Medication was altered for a small number of participants during 1 study.21 In this study, 6 participants started taking glybenclamide and it was not stated how many of these participants had been assigned to the exercise group. More details on the medications taken by participants and dietary cointerventions are provided in the Table.

The exercise interventions in each study are described in the Table. The exercise interventions typically prescribed 3 workouts per week, each lasting a mean (SD) of 53 (17) minutes (including 10 minutes of warm-up and cool-down) for 18 (15) weeks. The intensity of the aerobic exercise was moderate and typically consisted of walking or cycling. Two studies16,17 used resistance exercise training as an intervention and 1 study20 added resistance training with elastic bands to its aerobic training program. Resistance training was composed of 2 to 3 sets ranging from 10 to 20 repetitions. One study16 described the initial resistance to be at 50% to 55% of the participants’ repetition maximum, while the other did not specify the intensity.17 Both studies stated that the resistance was progressively increased.16,17

The results are presented for 2 types of comparisons. The exercise vs nonexercise control comparisons included studies in which there was no diet cointervention or in which the same diet cointervention was given to both the exercise and control groups. The second set of comparisons was between combined exercise and diet interventions vs nondieting/nonexercising control groups.

Effect of Exercise on Glycemic Control

Baseline and postintervention HbA1c values were described in 12 studies (14 comparisons). For the 11 comparisons between exercise and nonexercise control groups there were no significant baseline differences in HbA1c (WMD, 0.08%; P=.65). As shown in Figure 1, when the postintervention results were pooled, HbA1c was significantly lower in the exercise groups compared with the control groups (7.65% vs 8.31%; WMD, -0.66%; P<.001). Figure 1 also illustrates the effects on HbA1c of interventions combining exercise and diet compared with nonexercise, nondiet
controls. When diet and exercise were combined, the effect on HbA1c was similar to the effect of exercise alone (WMD, −0.76%; P = .008).

A sensitivity analysis identified no significant differences between the results from randomized controlled trials and CCTs. The postintervention WMD between exercise and control groups for the 9 randomized comparisons was −0.63% (95% confidence interval [CI], −1.01% to −0.25%; P= .001), whereas the corresponding WMD for the 2 CCTs was −0.75% (95% CI, −1.36% to −0.14%; P= .02). Further subgroup analysis comparing aerobic or resistance training groups with the control group revealed no significant difference. The WMD for aerobic training vs control was −0.67% (95% CI, −1.04% to −0.30%; P< .001) and was −0.64% (95% CI, −1.29% to 0.01%; P= .05) for resistance training vs control.

There was only 1 study20 in which participation was limited to participants with diabetes who were older than 65 years. The age of the participants in this study was much higher than the overall mean (SD) age of the participants in this meta-analysis (69.4 [4.7] years vs 55.0 [7.2] years, respectively). The intervention in this study was not successful in reducing HbA1c. If this study were excluded, the overall WMD for HbA1c would have been −0.74% (95% CI, −1.09% to −0.39%).

**Effect of Exercise on Body Mass**

In all but 2 of 14 trials, the details on the changes in body mass were given in kilograms (Raz et al14 and Van Ginneken et al26 only presented body mass index values). In the body mass comparisons for the 13 exercise groups vs nonexercise control groups, no significant postintervention differences were found (SMD, 0.06; P = .60; FIGURE 2). The effect of exercise vs nonexercise control was similar when only the 12 studies that measured body mass in kilograms were considered separately (83.02 kg vs 82.48 kg; WMD, 0.54 [95% CI, −2.91 to 3.99]; P = .76). There were no significant differences between the 2 groups when randomized controlled trials, CCTs, aerobic training studies, and resistance training studies were considered separately. In the studies comparing combined exercise and diet interventions vs control (Figure 2), the postintervention body mass difference also did not reach statistical significance (SMD, −0.20; P = .25).

The average baseline to postintervention changes in body weight were approximately −0.9 kg (P=.70) in the exercise groups, −3.4 kg (P=.11) in the combined exercise and diet groups, −2.5 kg (P=.29) in the diet groups, and 0.8 kg (P=.73) in the control groups.

Abdominal obesity was represented by waist-to-hip ratio or waist circumference. This information was available in 4 studies.12,13,16,19 The postintervention WMDs were −0.02 U (P=.05) for waist-to-hip ratio and −4.53 cm (P<.001) for waist circumference. However, much of this difference could be accounted for by baseline differences in abdominal adiposity favoring the exercise groups (waist-to-hip ratio, −0.01; P=.40; waist circumference, −3.52 cm; P<.001). Only 1 study13 in our meta-analysis directly measured abdominal obesity by magnetic resonance imaging. The aerobic training program in that study (55 minutes, 3 times/week, 10 weeks) resulted in a significant reduction in both abdominal subcutaneous adipose tissue (227.3 cm² to 186.7 cm²; P<.05) and visceral adipose tissue (156.1 cm² to 80.4 cm²; P<.05) while no significant reductions were found in the control group. In the same study, waist circumference and waist-to-hip ratio were not significantly reduced (98.4 cm to 97.4 cm and 0.97 to 0.94 U, respectively). Only 2 studies, 1 of aerobic training13 and 1 of resistance training,16 presented data on the sum of skinfolds and neither study found a significant exercise effect on this outcome. There were no significant changes in body fat percentage within the 2 aerobic training studies13,19 that measured this variable. In the study by Moulier et al,11 magnetic resonance imaging indicated that the mid-thigh muscle cross-sectional area was significantly increased after aerobic training (149.3 cm² to 183.5 cm²; P<.05).

**Meta-Regression Analysis**

The postintervention mean difference in body weight did not predict the postintervention mean difference in HbA1c (r²=.03; P=.84 for model 1). Even after correcting for baseline values, no significant association between these variables was found (r²=.09; P=.31 for model 2). Exercise intensity (METs) was not associated with the postintervention mean difference in HbA1c (r²=.04; P=.51 for model 4). When body mass (SMD), exercise intensity (METs), and exercise volume (total MET hours) were entered simultaneously as independent variables (model 5), a nonsignificant 8% of the variance in HbA1c was explained (P=.79).

**Evaluation of Potential Bias**

The funnel plot technique31 was used to evaluate publication bias. The postintervention WMDs in HbA1c were plotted against the sample size of the study. The plot did not show any asymmetry, an indication that significant publication bias was not likely. We did not find an unpublished study meeting the inclusion criteria. To statistically pool results from different studies using a fixed-effects model, the values must be relatively homogenous between studies. The results from the various analyses were consistent and homogeneous, however, there was 1 exception. The χ² tests suggested that there was heterogeneity in the baseline HbA1c values for the combined exercise and diet vs control comparison (Figure 2). This analysis was repeated with a random-effects model; the baseline WMD was reduced to 0.02% (P>.99) and the postintervention WMD was not changed (WMD, −0.76% [95% CI, −1.32 to −0.20]; P=.008).

**COMMENT**

Postintervention HbA1c values were significantly reduced in the exercise groups compared with control groups while body mass was not. The postintervention HbA1c values were 0.66%
<table>
<thead>
<tr>
<th>Source, y</th>
<th>Study Location</th>
<th>Age, y†</th>
<th>Women, %</th>
<th>Duration of Type 2 Diabetes Mellitus, y†</th>
<th>Prestudy vs Poststudy Medication</th>
<th>Exercise Group</th>
<th>Control</th>
<th>No. of Subjects</th>
<th>Medication Use</th>
<th>No. of Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunstan et al, 1997</td>
<td>Australia</td>
<td>53.3 (7.7)</td>
<td>23</td>
<td>5.4 (4.3)</td>
<td>No change</td>
<td>Exercise vs Nonexercise</td>
<td>14</td>
<td>11 Taking oral hypoglycemic agent</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Fujii et al, 1982</td>
<td>Japan</td>
<td>39.5 (6.3)</td>
<td>40</td>
<td>ND</td>
<td>No change</td>
<td>10</td>
<td>No medication</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaplan et al, 1987</td>
<td>United States</td>
<td>54.1 (8.4)</td>
<td>58</td>
<td>NA</td>
<td>19 Taking insulin and 29 taking oral hypoglycemic agent prestudy</td>
<td>18</td>
<td>NA</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lehmann et al, 1995</td>
<td>Switzerland</td>
<td>55.5 (9.8)</td>
<td>48</td>
<td>7.8 [1-25]</td>
<td>No change</td>
<td>16</td>
<td>10 Taking oral hypoglycemic agent</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maurer et al, 1997</td>
<td>France</td>
<td>45.5 (8.5)</td>
<td>17</td>
<td>4.9 (2.0)</td>
<td>20 Taking oral hypoglycemic agent (3 sulfonylureas; 14 metformin) for &gt;3 mo prestudy</td>
<td>10</td>
<td>NA</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raz et al, 1994</td>
<td>Israel</td>
<td>56.6 (6.5)</td>
<td>65</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>19 Glibenclamide and metformin</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ronnemaa et al, 1986</td>
<td>Finland</td>
<td>52.5 [45-60]</td>
<td>33</td>
<td>7.1 [1-13]</td>
<td>18 Taking sulfonylureas and 10 taking sulfonylureas and metformin combined prestudy</td>
<td>13</td>
<td>NA</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing et al, 1988</td>
<td>United States</td>
<td>54.2 (8.3)</td>
<td>84</td>
<td>4.6 (5.0)</td>
<td>10</td>
<td>6 Taking oral hypoglycemic agent</td>
<td>12</td>
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<td></td>
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</tr>
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<td>Agurs-Collins et al, 1997</td>
<td>Australia</td>
<td>50.7 (6.8)</td>
<td>37</td>
<td>5.2 (4.2)</td>
<td>No change</td>
<td>Exercise vs Nonexercise Control</td>
<td>11</td>
<td>7 Taking oral hypoglycemic agent</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Honkola et al, 1997</td>
<td>Finland</td>
<td>64.7 (8.7)</td>
<td>55</td>
<td>8.0 (8.5)</td>
<td>NA</td>
<td>Exercise and Diet vs Control</td>
<td>18</td>
<td>4 Taking oral hypoglycemic agent and 5 taking insulin</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Agurs-Collins et al, 1997</td>
<td>United States</td>
<td>61.7 (5.8)</td>
<td>77</td>
<td>NA</td>
<td>NA</td>
<td>Exercise and Diet vs Control</td>
<td>31</td>
<td>15 Taking oral hypoglycemic agent and 16 taking insulin</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Vanninen et al, 1992</td>
<td>Finland</td>
<td>53.0 (7.0)</td>
<td>0</td>
<td>ND</td>
<td>1 Taking glibenclamide prestudy and 7 taking glibenclamide poststudy</td>
<td>For men</td>
<td>21</td>
<td>NA</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>54.0 (6.0)</td>
<td>100</td>
<td>ND</td>
<td>17</td>
<td>NA</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
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<td></td>
<td></td>
<td>251</td>
<td></td>
<td>253</td>
<td></td>
</tr>
</tbody>
</table>

Average 55.0 (7.2) 50 4.3 (4.6)

*RCT indicates randomized controlled trial; VO2max, maximum oxygen consumption; VO2peak, peak oxygen consumption; ND, newly diagnosed; CCT, nonrandomized controlled trial; and NA, data not available.
†Values are expressed as mean (SD) or median [range].
<table>
<thead>
<tr>
<th>Group</th>
<th>Medication Use</th>
<th>Type of Trial</th>
<th>Diet Cointervention</th>
<th>Exercise Intervention</th>
<th>Type</th>
<th>No. of Times/wk</th>
<th>No. of Weeks</th>
<th>Length, min</th>
<th>Intensity</th>
<th>Metabolic Equivalent, h/wk‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (Aerobic Training)</td>
<td></td>
<td>RCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Taking oral hypoglycemic agent</td>
<td></td>
<td></td>
<td>&lt;30% kcal/d as fat (&lt;10% saturated fat, &lt;100 mmol/d sodium, and 1 fish meal/d (3.6 g of omega-3 fatty acids/d)</td>
<td>Cycling</td>
<td>3</td>
<td>8</td>
<td>40</td>
<td>50%-65% VO2max</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>8 Taking oral hypoglycemic agent</td>
<td></td>
<td></td>
<td>Same as other group but no fish</td>
<td>Cycling</td>
<td>3</td>
<td>8</td>
<td>40</td>
<td>50%-65% VO2max</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>No medication</td>
<td></td>
<td>CCT</td>
<td>Caloric restriction: 30-35 kcal/kg of ideal body weight</td>
<td>Jogging</td>
<td>5</td>
<td>26</td>
<td>30</td>
<td>Approximately 40% VO2max</td>
<td>10.0</td>
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</tr>
<tr>
<td>NA</td>
<td></td>
<td>RCT</td>
<td>1200 kcal/d (50% as carbohydrates, 30% as fat, 20% as protein)</td>
<td>Walking</td>
<td>3</td>
<td>10</td>
<td>80</td>
<td>60%-70% VO2max</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>6 Taking oral hypoglycemic agent</td>
<td></td>
<td>CCT</td>
<td>1664 kcal/d (39% as carbohydrates, 44% as fat, and 17% as protein)</td>
<td>Walking, cycling, jogging, rowing, star climbing</td>
<td>3</td>
<td>13</td>
<td>90</td>
<td>50%-70% VO2max</td>
<td>16.9</td>
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<tr>
<td>NA</td>
<td></td>
<td>RCT</td>
<td>Half of each group took branched-chain amino acid supplements, the other half took placebo</td>
<td>Cycling</td>
<td>3</td>
<td>10</td>
<td>55</td>
<td>75% VO2peak intervals</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Glibenclamide and metformin</td>
<td></td>
<td>RCT</td>
<td>None</td>
<td>Cycling, rowing, swimming, treadmill</td>
<td>3</td>
<td>12</td>
<td>55</td>
<td>65%VO2peak</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>NA</td>
<td></td>
<td>RCT</td>
<td>None</td>
<td>Walking, jogging, skiing</td>
<td>6</td>
<td>17.5</td>
<td>45</td>
<td>70% VO2max</td>
<td>24.8</td>
<td></td>
</tr>
<tr>
<td>6 Taking oral hypoglycemic agent</td>
<td></td>
<td>RCT</td>
<td>Goal: lose 1 kg/wk (prebody weight [kg] × 26-100 kcal/d); increase complex carbohydrates and decrease fat</td>
<td>Walking</td>
<td>3</td>
<td>10</td>
<td>60</td>
<td>4.8 km/session</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>9 Taking oral hypoglycemic agent and 5 taking insulin</td>
<td></td>
<td>RCT</td>
<td>Same as study 1</td>
<td>Walking</td>
<td>3</td>
<td>10</td>
<td>60</td>
<td>4.8 km/session</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>12 Taking glyburide and 15 taking metformin</td>
<td></td>
<td>RCT</td>
<td>None</td>
<td>Walking, cycling, weight training</td>
<td>3</td>
<td>16</td>
<td>60</td>
<td>Aerobic: 60%-79% VO2max; resistance training: 2 sets, 20 repetitions, 9 exercises</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>(Resistance Training)</td>
<td></td>
<td></td>
<td></td>
<td>Reminded not to alter diet</td>
<td>Cycling, weight training</td>
<td>3</td>
<td>8</td>
<td>60</td>
<td>2-3 sets, 10-15 repetitions, 10 exercises, 50%-55% repetition maximum (adjusted at wk 4)</td>
<td>11.4</td>
</tr>
<tr>
<td>6 Taking oral hypoglycemic agent and 7 taking insulin</td>
<td></td>
<td>CCT</td>
<td>Prestudy diet</td>
<td>Cycling, weight training</td>
<td>2</td>
<td>22</td>
<td>45</td>
<td>2 sets, 12-15 repetitions, 8-10 exercises (progressively increased intensity)</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>(Aerobic Training)</td>
<td></td>
<td>RCT</td>
<td>Exercise group: 55%-60% as carbohydrates, 12%-20% as protein, and &lt;30% fat; goal: lose 4.5 kg over 6 mo</td>
<td>Cycling, rowing, aerobics (low impact), treadmill</td>
<td>3</td>
<td>13</td>
<td>30</td>
<td>Low-impact aerobic activity</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>NA</td>
<td></td>
<td>RCT</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>11§</td>
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</tbody>
</table>

‡Amount of energy expenditure per week during programmed exercise (1 metabolic equivalent equals 210 mL of oxygen per kilogram).
§Total number of RCTs.
The finding that exercise does not need to reduce body weight to have a beneficial impact on glycemic control is clinically significant and close to the difference between conventional and intensive glucose-lowering therapy in the United Kingdom Prospective Diabetes Study (UKPDS). In the UKPDS, subjects receiving intensive treatment with insulin or sulfonylureas had HbA1c averaging 0.9% below the conventional treatment (7.0% vs 7.9%; P<.001) and had significant reduction in diabetes-related clinical end points (40.9 vs 46 events per 1000 patient-years; P=.03). In UKPDS, subjects randomized to intensified glycemic control with metformin, HbA1c was only 0.6% lower than with conventional treatment but there were risk reductions of 32% (P=.002) for diabetes-related clinical end points and 42% for diabetes-related deaths (P=.02). The potential importance of good glycemic control for the reduction of cardiovascular disease risk was supported in a recent meta-regression study, which demonstrated an exponential relationship between fasting glucose concentrations and the incidence of cardiovascular events. We speculate that a greater reduction in cardiovascular complications might be anticipated with exercise than with insulin or sulfonylureas in the UKPDS since, unlike these medications, exercise is associated with other cardioprotective benefits and does not cause weight gain.

The meta-regression results suggest that the differences in HbA1c found between the exercise groups and control groups after the intervention were not mediated by differences in weight loss, exercise intensity, or exercise volume. The finding that exercise does not need to reduce body weight to have a beneficial impact on glycemic control is clinically important. Exercise training decreases hepatic and muscle insulin resistance and increases glucose disposal through a number of mechanisms that would not necessarily be associated with body weight changes. The mechanisms were extensively re-

### Table: Differences in Glycosylated Hemoglobin (HbA1c) From Baseline to Postintervention

<table>
<thead>
<tr>
<th>Source, y</th>
<th>Period</th>
<th>Exercise Group</th>
<th>Control Group</th>
<th>Weight, %</th>
<th>WMD, % (95% CI)</th>
<th>Favours Treatment</th>
<th>Favours Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunstan et al, 1998</td>
<td>Baseline</td>
<td>11/8.2 (1.7)</td>
<td>10/8.1 (1.9)</td>
<td>5.8</td>
<td>0.1 (-1.43 to 1.63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>11/8.0 (1.7)</td>
<td>10/8.3 (2.2)</td>
<td>3.7</td>
<td>-0.3 (-1.98 to 0.38)</td>
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<td></td>
</tr>
<tr>
<td>Honkola et al, 1997</td>
<td>Baseline</td>
<td>18/7.5 (1.3)</td>
<td>20/7.7 (1.3)</td>
<td>19.9</td>
<td>-0.2 (-1.03 to 0.63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>18/7.4 (0.9)</td>
<td>20/8.1 (1.3)</td>
<td>20.9</td>
<td>-0.7 (-1.41 to 0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing et al, 1997</td>
<td>Study 1</td>
<td>Baseline</td>
<td>10/9.7 (1.6)</td>
<td>12/9.4 (1.7)</td>
<td>7.1</td>
<td>0.3 (-1.08 to 1.68)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>10/8.0 (1.3)</td>
<td>12/7.9 (1.7)</td>
<td>6.7</td>
<td>0.1 (-1.15 to 1.35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tassler et al, 2000</td>
<td>Baseline</td>
<td>19/7.5 (1.2)</td>
<td>20/7.3 (1.7)</td>
<td>16.2</td>
<td>0.2 (-0.72 to 1.12)</td>
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</tr>
<tr>
<td></td>
<td>Post</td>
<td>19/7.6 (1.2)</td>
<td>20/7.8 (1.5)</td>
<td>14.4</td>
<td>-0.2 (-1.05 to 0.65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dunstan et al, 1997</td>
<td>Exercise and Diet vs Diet Alone</td>
<td>Baseline</td>
<td>14/8.3 (1.5)</td>
<td>12/8.0 (1.5)</td>
<td>10.2</td>
<td>0.3 (-0.86 to 1.46)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>14/7.7 (1.5)</td>
<td>12/7.9 (1.5)</td>
<td>7.8</td>
<td>-0.2 (-1.36 to 0.96)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lehmann et al, 1995</td>
<td>Baseline</td>
<td>16/7.5 (1.6)</td>
<td>13/7.8 (1.7)</td>
<td>9.3</td>
<td>-0.3 (-1.51 to 0.91)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>16/7.5 (1.6)</td>
<td>13/8.4 (1.7)</td>
<td>7.1</td>
<td>-0.9 (-2.11 to 0.31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raz et al, 1994</td>
<td>Baseline</td>
<td>19/12.5 (2.9)</td>
<td>19/12.4 (4.0)</td>
<td>2.8</td>
<td>0.1 (-2.12 to 2.32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>19/11.7 (2.6)</td>
<td>19/12.9 (4.2)</td>
<td>2.1</td>
<td>1.2 (-3.42 to 1.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ronnemaa et al, 1996</td>
<td>Baseline</td>
<td>13/9.6 (1.6)</td>
<td>12/10.0 (1.5)</td>
<td>9.3</td>
<td>-0.4 (-1.62 to 0.82)</td>
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</tr>
<tr>
<td></td>
<td>Post</td>
<td>13/8.6 (1.9)</td>
<td>12/9.9 (1.7)</td>
<td>5.2</td>
<td>-1.3 (-2.71 to 0.11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mourier et al, 1997</td>
<td>Baseline</td>
<td>10/8.5 (1.9)</td>
<td>11/7.4 (1.0)</td>
<td>7.9</td>
<td>1.1 (-0.21 to 2.41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>10/6.2 (0.6)</td>
<td>11/7.7 (1.3)</td>
<td>13.6</td>
<td>-1.5 (-3.28 to -0.62)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>Baseline</td>
<td>154</td>
<td>156</td>
<td>100</td>
<td>0.08 (-0.29 to 0.45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>154</td>
<td>156</td>
<td>100</td>
<td>-0.66 (-0.98 to -0.34)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WMD indicates weighted mean difference; CI, confidence interval. Studies are placed in ascending order of the intensity of the exercise intervention and represent the mean difference and the 95% CI for baseline and postintervention measurements. Exercise vs nonexercise control: baseline values, the chi-square test for heterogeneity was 4.78 (P=.39) and the z score for overall effect was 0.45 (P=.65); postintervention values, the chi-square test for heterogeneity was 9.76 (P=.46) and the z score for overall effect was 4.01 (P<.001). Exercise and diet vs control: baseline values, the chi-square test for heterogeneity was 6.77 (P=.03) and the z score for overall effect was 0.60 (P=.55); postintervention values, the chi-square test for heterogeneity was 0.74 (P=.69) and the z score for overall effect was 2.66 (P=.008).
Figure 2. Differences in Body Mass From Baseline to Postintervention

<table>
<thead>
<tr>
<th>Source, y</th>
<th>Period</th>
<th>Exercise Group</th>
<th>Control Group</th>
<th>Weight, %</th>
<th>SMD, % (95% CI)</th>
<th>Favors Treatment</th>
<th>Favors Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunstan et al14</td>
<td>1997</td>
<td>Exercise and Diet vs Diet Alone</td>
<td>14/85.7 (15.0)</td>
<td>12/89.4 (13.6)</td>
<td>7.0</td>
<td>-0.25 (-1.02 to 0.53)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>14/83.3 (15.0)</td>
<td>12/88.0 (13.6)</td>
<td>7.0</td>
<td>-0.32 (-1.09 to 0.46)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Exercise Alone vs Control</td>
<td>11/85.6 (10.6)</td>
<td>12/88.4 (16.2)</td>
<td>6.2</td>
<td>-0.20 (-1.02 to 0.63)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>11/83.5 (10.6)</td>
<td>12/87.8 (16.2)</td>
<td>6.2</td>
<td>-0.30 (-1.12 to 0.52)</td>
<td></td>
</tr>
<tr>
<td>Dunstan et al18</td>
<td>1998</td>
<td>Baseline</td>
<td>11/83.6 (12.3)</td>
<td>10/82.7 (11.7)</td>
<td>5.7</td>
<td>0.07 (-0.78 to 0.93)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>11/83.2 (12.3)</td>
<td>10/83.7 (12.0)</td>
<td>5.8</td>
<td>-0.04 (-0.90 to 0.82)</td>
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<tr>
<td>Kaplan et al18</td>
<td>1987</td>
<td>Baseline</td>
<td>19/89.2 (21.1)</td>
<td>19/92.2 (21.8)</td>
<td>10.3</td>
<td>-0.13 (-0.77 to 0.50)</td>
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<tr>
<td></td>
<td></td>
<td>Post</td>
<td>18/88.0 (21.1)</td>
<td>15/92.3 (21.8)</td>
<td>9.0</td>
<td>-0.20 (-0.80 to 0.49)</td>
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</tr>
<tr>
<td>Wing et al18</td>
<td>1988</td>
<td>Study 1</td>
<td>10/106.9 (16.8)</td>
<td>12/97.4 (13.2)</td>
<td>5.6</td>
<td>0.61 (-0.25 to 1.48)</td>
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<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>10/98.4 (16.8)</td>
<td>12/90.1 (15.5)</td>
<td>5.8</td>
<td>0.50 (-0.36 to 1.35)</td>
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<tr>
<td></td>
<td></td>
<td>Post</td>
<td>13/104.1 (21.6)</td>
<td>15/102.0 (19.4)</td>
<td>7.6</td>
<td>0.10 (-0.64 to 0.84)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Exercise</td>
<td>13/94.8 (20.9)</td>
<td>15/96.4 (19.8)</td>
<td>7.7</td>
<td>-0.08 (-0.82 to 0.67)</td>
<td></td>
</tr>
<tr>
<td>Mouier et al19</td>
<td>1997</td>
<td>Baseline</td>
<td>10/85.3 (12.3)</td>
<td>11/84.4 (14.9)</td>
<td>5.7</td>
<td>0.06 (-0.79 to 0.92)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>10/83.8 (12.3)</td>
<td>11/84.2 (15.3)</td>
<td>5.8</td>
<td>-0.03 (-0.88 to 0.83)</td>
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</tr>
<tr>
<td>Raz et al19</td>
<td>1994</td>
<td>Baseline</td>
<td>19/31.8 (4.6)</td>
<td>19/30.2 (4.7)</td>
<td>10.2</td>
<td>0.34 (-0.30 to 0.98)</td>
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<tr>
<td></td>
<td></td>
<td>Post</td>
<td>19/31.5 (4.3)</td>
<td>19/30.6 (4.2)</td>
<td>10.4</td>
<td>0.21 (-0.43 to 0.85)</td>
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<tr>
<td>Lehmann et al19</td>
<td>1995</td>
<td>Baseline</td>
<td>16/87.3 (22.3)</td>
<td>13/86.8 (13.1)</td>
<td>7.8</td>
<td>0.03 (-0.71 to 0.76)</td>
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<tr>
<td></td>
<td></td>
<td>Post</td>
<td>16/86.6 (22.2)</td>
<td>13/86.8 (12.5)</td>
<td>7.9</td>
<td>-0.01 (-0.74 to 0.72)</td>
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<tr>
<td>Tessier et al20</td>
<td>2000</td>
<td>Baseline</td>
<td>19/83.1 (18.0)</td>
<td>20/79.4 (14.3)</td>
<td>10.6</td>
<td>0.22 (-0.41 to 0.85)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>19/83.0 (17.6)</td>
<td>20/79.5 (14.6)</td>
<td>10.7</td>
<td>0.21 (-0.42 to 0.84)</td>
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</tr>
<tr>
<td>Ronnemaa et al21</td>
<td>1998</td>
<td>Baseline</td>
<td>13/85.2 (21.6)</td>
<td>12/82.8 (44.3)</td>
<td>6.8</td>
<td>0.07 (-0.72 to 0.85)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>13/83.2 (19.5)</td>
<td>12/83.3 (43.0)</td>
<td>6.9</td>
<td>0.00 (-0.79 to 0.78)</td>
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</tr>
<tr>
<td>Honkola et al22</td>
<td>1997</td>
<td>Baseline</td>
<td>18/87.3 (20.8)</td>
<td>20/77.1 (12.5)</td>
<td>9.9</td>
<td>0.59 (-0.06 to 1.24)</td>
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<td></td>
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<td>Post</td>
<td>18/86.6 (20.4)</td>
<td>20/78.8 (13.4)</td>
<td>10.2</td>
<td>0.45 (-0.20 to 1.09)</td>
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</tr>
<tr>
<td>Fuji et al22</td>
<td>1982</td>
<td>Baseline</td>
<td>10/67.3 (10.8)</td>
<td>15/64.6 (12.8)</td>
<td>6.5</td>
<td>0.22 (-0.59 to 1.02)</td>
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<tr>
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<td></td>
<td>Post</td>
<td>10/63.9 (10.8)</td>
<td>15/63.8 (12.8)</td>
<td>6.6</td>
<td>0.09 (-0.71 to 0.89)</td>
<td></td>
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<tr>
<td>Overall</td>
<td></td>
<td>Baseline</td>
<td>183</td>
<td>190</td>
<td>100</td>
<td>0.14 (-0.06 to 0.30)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post</td>
<td>182</td>
<td>186</td>
<td>100</td>
<td>0.06 (-0.15 to 0.26)</td>
<td></td>
</tr>
</tbody>
</table>

Exercise and Diet vs Nonexercise, Nondiet Controls

Agurs-Collins et al23 1997 Baseline 32/93.3 (18.6) 32/94.9 (20.1) 45.3 -0.08 (-0.57 to 0.41) 0.22 (-0.78 to 0.26) 0.06 (-0.15 to 0.26)

Vanninen et al24 1992 Men Baseline 21/31.1 (3.7) 24/30.1 (3.1) 31.3 0.29 (-0.30 to 0.88) 0.06 (-0.70 to 0.47)

Women Baseline 17/33.4 (6.7) 16/34.2 (6.2) 23.3 -0.12 (-0.80 to 0.56) -0.22 (-0.90 to 0.47)

Overall Baseline 70 72 100 0.03 (-0.30 to 0.36) -0.20 (-0.54 to 0.14)

SMD indicates standardized mean difference; CI, confidence interval. Studies are placed in ascending order of the duration of the exercise intervention and represent the mean difference and the 95% CI for baseline and postintervention measurements. Body mass was measured in kilograms except for the studies by Raz et al14 and Vanninen et al21 in which body mass index was measured in kilograms divided by meters squared. Exercise vs nonexercise control: baseline values, the χ² test for heterogeneity was 5.97 (P = .92) and the z score for overall effect was 1.37 (P = .17); postintervention values, the χ² test for heterogeneity was 5.28 (P = .95) and the z score for overall effect was 0.52 (P = .60). Exercise and diet vs control: baseline values, the χ² test for heterogeneity was 1.13 (P = .57) and the z score for overall effect was 0.15 (P = .88); postintervention values, the χ² test for heterogeneity was 0.13 (P = .94) and the z score for overall effect was 1.16 (P = .24).

In the present meta-analysis, the exercise interventions produced no statistically significant reduction in body weight. There are several possible explanations for this. First, the exercise interventions were of relatively short duration and involved only moderate amounts of exercise. Second, exercise participants might have reduced their daily physical activities, partially counterbalancing the increased energy expenditure from the exercise intervention. Third, exercise group subjects might have increased their food intake, or decreased it less than control subjects. However, the studies’ dietary intake records did not support this possibility. Fourth, in relatively inactive people, increasing physical activity can result in an increase in lean body mass. Therefore, it is certainly possible that the amount of weight loss did not fully reflect the amount of fat loss. More accurate measures of body composition, such as computed tomography, magnetic resonance imaging, or
EFFECTS OF EXERCISE IN TYPE 2 DIABETES

hydrostatic weighing, would be desirable in future studies to precisely measure changes in body composition.

The effect of exercise on HbA1c and body mass was estimated from data obtained across different ethnicities (Northern Europeans, Southern Europeans, blacks, Asian, Middle Easterners), medication status (no medication, oral hypoglycemic agents, insulin therapy), age groups, and dietary interventions. The results are therefore widely generalizable to middle-aged patients with type 2 diabetes. Because only 1 study included many participants who were older than 65 years, we cannot be certain that the overall results are generalizable to people older than 65 years. Adherence rates to the exercise programs were relatively high in most studies (mean >80%, where reported). Adherence rates lower than these would presumably result in a lesser impact on HbA1c.

There is little research on the effects of resistance training (such as weight lifting) in patients with type 2 diabetes; only 2 resistance exercise studies met inclusion criteria for this analysis. Several relevant resistance training studies were excluded from the present analysis because of the absence of an appropriate control group or the inclusion of nondiabetic participants. In the present meta-analysis, the postintervention WMD for HbA1c in the resistance training groups vs nonexercise control groups was similar to aerobic training groups vs nonexercise control groups (−0.64% [95% CI, −1.29% to 0.01%] and −0.67% [95% CI, −1.04% to −0.30%], respectively). Well-designed studies on the effects of resistance training and aerobic training are needed to better understand the impact of increasing muscle mass and reducing fat mass (especially visceral fat) on glycemic control and other metabolic abnormalities.

In conclusion, although the individual trials on the effects of exercise in patients with type 2 diabetes have had partially conflicting results, the current meta-analysis suggests that exercise training reduces HbA1c by approximately 0.66%, an amount that would be expected to reduce the risk of diabetic complications significantly. The studies reviewed in this meta-analysis did not find significantly greater weight loss in the exercise groups compared with the control groups. Therefore, exercise should be viewed as beneficial on its own, not merely as an avenue to weight loss. Future research should include longer interventions with better quantification of body composition changes. In the interim, our analysis using an evidence-based approach adds support to the idea that exercise is a cornerstone of diabetes therapy.

Author Contributions: Study concept and design: Boulé, Kenny, Wells, Sigal. Acquisition of data: Boulé, Haddad. Analysis and interpretation of data: Boulé, Haddad, Kenny, Wells, Sigal. Drafting of the manuscript: Boulé, Kenny, Sigal. Critical revision of the manuscript for important intellectual content: Boulé, Haddad, Kenny, Wells, Sigal. Statistical expertise: Wells. Administrative, technical, or material support: Boulé, Sigal.

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REFERENCES

quality of reports of randomized clinical trials: is blind-

Empirical evidence of bias: dimensions of method-


Oxford, England: Cochrane Collaboration; 1997:

section 8.

30. Mulrow CD, Oxman AD. Analysing and present-

31. Cooper H, Hedges LV. The Handbook of Re-

32. Dunstan DW, Mori TA, Puddey IB, et al. A ran-

33. Mori TA, Dunstan DW, Burke V, et al. Effect of
dietary fish and exercise training on urinary F2-

34. Kaplan RM, Wilson DK, Hartwell SL, Merino KL,

35. Ronnemaa T, Mamiemi J, Puukka P, Kiusi T. Ef-

36. Ronnemaa T, Mattila K, Lehtonen A, Kallio V. Fac-

37. Vanninen E, Uusitupa M, Lansimies E, Siitonen O,

38. Dunstan DW, Bjortorp P, Grimby G. Physical training in
ebese women: effects of muscle morphology, bio-

chemistry and function. Eur J Appl Physiol. 1984;52:

39. Saltin B, Henriksson J, Nygaard E, Andersen P, Jans-

40. Fiber types and metabolic potentials of skel-

tal muscles in sedentary man and endurance run-


41. Andersson A, Sjodin A, Olsson R, Vessby B. Ef-

42. Effects of physical exercise on phospholipid fatty acid


274:E432-E438.

43. Krótkiewski M, Bjortorp P. Muscle tissue in obe-

sity with different distribution of adipose tissue: ef-

fects of physical training. Int J Obes Relat Metab Dis-


44. Brooks GA, Falvey TD. White TP. Exercise Physi-

ology: Human Bioenergetics and Its Applications. 2nd ed.

Mountain View, Calif.: Mayfield Publishing Company;

1995.


46. Eriksson J, Taimela S, Eriksson K, Parviainen S, Pel-

tonen J, Kujala U. Resistance training in the treat-


47. Fluckey JD, Hickey MS, Brambrink JK, Hart KK,

Alexander K, Craig BW. Effects of exercise resistance

glucose tolerance in normal and glucose-

intolerant subjects. J Appl Physiol. 1994;77:1087-

1092.


50- to 65-y-old men. J Appl Physiol. 1994;77:

1122-1127.

49. Ryan AS, Pratley RE, Goldberg AP, Elahi D. Re-

sistance training increases insulin action in postmeno-


durance exercise or circuit-type resistance training for individuals with impaired glucose tolerance? Horm Metab Res. 1998;30:37-41.


157.

glucose tolerance test-derived glucose effectiveness in

strength-trained humans. Metabolism. 1998;47:

874-877.


1170-1175.

54. Miller WJ, Sherman WM, Ivy JL. Effect of strength training on glucose tolerance and post-glucose insu-


543.

55. Zachwieja JJ, Toffolo G, Cobelli C, Bier DM,

Yarasheski KE. Resistance exercise and growth hor-

mone administration in older men: effects on insulin

sensitivity and secretion during a stable-label intra-

venous glucose tolerance test. Metabolism. 1996;45:

254-260.