Randomized Crossover Study of Effect of Resistance Training on Glycemic Control, Muscular Strength, and Cholesterol in Type I Diabetic Men

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The goal of this study was to evaluate a program of resistance weight training on cardiovascular risk factors, blood glucose management, and overall strength in diabetic subjects. A randomized crossover design was performed on eight male type I (insulin-dependent) diabetic subjects (mean ± SD age 31 ± 3.5 yr, height 176 ± 5.6 cm, body wt 80 ± 15 kg, duration of diabetes 12.3 ± 9.8 yr, and insulin dose 24 U NPH/day and 21 U regular/day). The program consisted of heavy-resistance weight training 3 days/wk for 10 wk, concentrating on the strengthening of major muscle groups through progressive resistance. Blood tests included total cholesterol, triglycerides, very-low-density lipoprotein and high-density lipoprotein cholesterol, and HbA_{1c}. These tests were repeated at three time points during the program. Field-strength testing was performed before and after training. An improvement was seen in the squat (93.6% increase, $P < 0.0001$) and bench press (58% increase, $P < 0.005$). HbA_{1c} and triglyceride levels showed no change during the resting portion of the experiment but showed a significant change with the training program: HbA_{1c} 6.9 ± 1.4 vs. 5.8 ± 0.9% (P = 0.05) and triglyceride 5.044 ± 1.06 vs. 4.628 ± 0.88 mM (P = 0.01). Self-monitored glucose (taken pre- and postexercise) showed a decrease from 7.85 ± 3.13 to 7.05 ± 2.91 mM (P = 0.0001). Very-low-density lipoprotein cholesterol and triglycerides did not change after training. Analysis of variance showed no significant differences over time from the three time points with regard to reductions in cardiovascular risk factors or HbA_{1c}. Heavy-resistance strength training may be associated with a decrease in glycosylated hemoglobin and cholesterol in type I diabetic men after training, in addition to increasing overall strength. ***Diabetes Care*** **13:1039–43, 1990**

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The effects of strength training on the metabolic control and fitness capacity of type I (insulin-dependent) diabetic subjects are virtually unknown. In most cases, resistance training has been excluded from training programs because of acute responses associated with high-intensity–type training, e.g., hyperglycemia (1) and increased blood pressure response (2–4). Therefore, reviews and recommendations for exercise for diabetic individuals have emphasized aerobic programs (5).

In the past 5 yr, resistance-training programs have been studied to define their impact not only on fitness and cardiovascular function but also on cardiovascular risk factors (6,7). Glucose and insulin responses to weight-training (7a) and body-building programs have also been defined (8–10). However, none of these strength-training protocols were performed on type I diabetic subjects.

These studies open the way for the use of strength training as an alternative to aerobic training as the sole method of conditioning for people with type I diabetes mellitus. This study was undertaken to evaluate the effect of heavy-resistance strength training on strength and fitness levels, glycemic control, and blood lipid levels in men with type I diabetes mellitus.

RESEARCH DESIGN AND METHODS

Eight men with type I diabetes mellitus were recruited without regard to previous conditioning experience or years of disease. Informed witnessed consent was obtained from all subjects, and all protocols were approved by appropriate institutional review. Demographic data are shown in Table 1. Duration of diabetes was 12.3 ± 9.8 yr. Mean ± SD insulin levels were 24.1 ± 11.5 U NPH/day and 21 ± 11 U regular/day. One of the subjects had been successfully treated with laser surgery for diabetic retinopathy 3 yr previously. None of the other participants had any evidence of micro- or macrovascular complications or hypertension. Subjects did not visit a physician during their participation in the program. As part of their inclusion in the program, all participants agreed not to engage in any aerobic training during the course of the study. This was verified during the last blood draw by questionnaire.

An initial evaluation on each subject was performed at the start of the program. Resting measures included height, weight, resting heart rate, and body composition. Body-composition measures were performed by a combination of an electrical impedance assessment (Vallhalla, San Diego, CA) and a seven-site skin-fold assessment with Lange (Cambridge, MD) calipers, according to the protocol by Jackson and Pollack (11). There was no statistical difference between skin-fold and electrical impedance measurements ($P = 0.65$).

Initial strength measurements were performed with a two-repetition maximum lift performed on both the bench press and squat exercises with free-weight bars. Muscular endurance tests were performed with 50% initial body weight on the machine bench press and 100% body weight for the leg press exercise (Nautilus, Orlando, FL). Subjects performed as many repetitions as possible without breaking rhythm until they were unable to lift the designated weight. The same test was given after the training program with the use of the subject's final body weight. Performance was then calculated with the subject's weight multiplied by the number of repetitions completed divided by 10. These calculations appear in Fig. 1 and Table 3. Muscular endurance was also performed with a modified sit-up exercise with feet bent and arms crossed over the chest until the subjects could no longer perform a repetition >30° in elevation.

Training sessions took place after work hours (1700); thus, lunchtime injections and food intake were completed no later than 1200. Each strength session was divided into upper-body and lower-body training components. Subjects trained for 1 h 3 days/wk for 10 wk. A typical strength-training session is shown in Table 2. Training consisted of six upper-body exercises and four lower-body exercises. Subjects moved from major to minor muscle groups on progressive-resistance exercises

TABLE 1
Demographic data on subjects

	Group A	Group B
Age (yr)	31.5 ± 2	30.5 ± 5
Height (cm)	175.2 ± 10	176.5 ± 1.2
Weight (kg)	76.9 ± 18	82.7 ± 12
Body fat (%)*	18.8 ± 5.8	18.8 ± 4.2
Diabetes duration (yr)	15.5 ± 8.2	8.5 ± 9.9
Insulin dose (U/day)	42.2 ± 6	46 ± 2.2

Values are means ± SD. $n = 4$ for both groups.
*Percent body fat is the mean of 2 skin-fold formulas and 1 electrical impedance measurement.

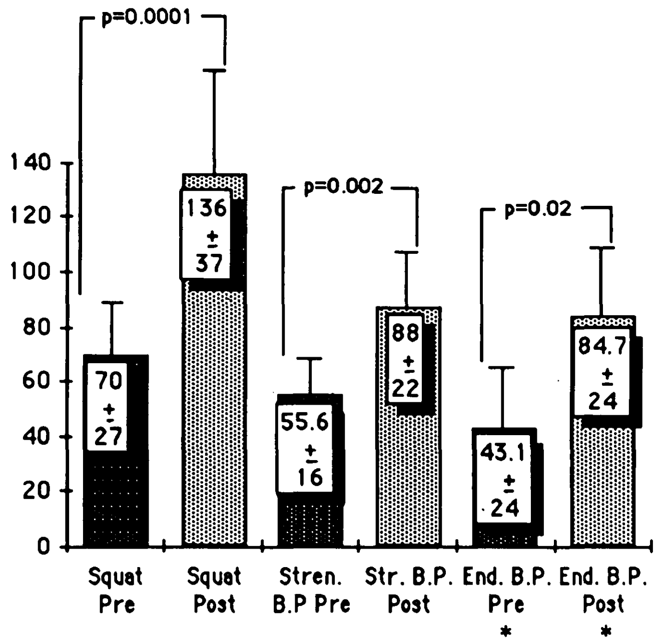

FIG. 1. Total strength and upper-body endurance changes in male type I (insulin-dependent) diabetic subjects before (Pre) and after (Post) 30-session training program. *Boxed figures*, mean value in kilograms for 8 subjects ± 1 SD. Str/Stren, strength; B.P., bench press; End., endurance. Values are means ± SD. *Weight × repetitions divided by 10.

TABLE 2
Typical strength-training session

Lower-body training	
Squats	(5–7 sets)
Nautilus leg presses	(3–4 sets)
Nautilus/Cybex leg extensions	(3–4 sets)
Nautilus calf raises	(3 sets)
Cybex leg extensions	(3–4 sets)
Upper-body training	
Free-weight bench presses	(4–6 sets)
Lat pulldowns	(3–5 sets)
Nautilus shoulder presses	(3–4 sets)
Incline dumbbell presses	(3–4 sets)
Shoulder flys	(3 sets)
Bent dumbbell rows, machine rows	(3–4 sets)
Dumbbell biceps curls	(3–4 sets)
Triceps extensions	(3–4 sets)
Crunches with resistance	(3–5 sets)
Cybex abdominals	(3–4 sets)
Postexercise flexibility	

consisting mainly of free weights and cable pully machines, with a modified pyramid-type training routine, until local muscular fatigue was reached in the latter sets near the end of each designated amount of repetitions. To minimize the aerobic effect in weight training, no more than 12 repetitions were performed at the beginning of any exercise station. A reduction of 2 repetitions occurred when weight was added to the exercise being performed. Subjects performed a total of 40–50 sets during their workout sessions. Rest intervals between each set ranged from 30 s to 2 min. Subjects used a weight-training belt for torso support during the squat exercises (Valeo, Waukeshau, WI).

To control for a sequential effect, subjects were randomized into two groups. Group A (n = 4) trained for ~30 sessions over 10 wk. After the training phase, blood was again drawn, and the group rested for 6 wk before their final blood draw. Group B (n = 40) trained in an opposite fashion, having an initial blood draw followed by a 6-wk rest period and a second blood draw followed by the exercise program, with a final blood draw after the 30 training sessions.

Analysis for total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, very-low-density lipoprotein (VLDL) cholesterol, and plasma glucose was performed during the study at the three time points mentioned above. Samples were chilled, spun, aliquoted, and frozen at −80°C until analysis. LDL and VLDL subfractions were precipitated with dextran sulfate, which allowed for the reading of HDL. All samples were run on an automated chemistry analyzer (Technicon RA 1000 analyzer, Tarrytown, NY). Serum glucose measurements were performed on an automated glucose analyzer (YSI 23 A, Yellow Springs, OH). Whole-blood determinations of glycosylated hemoglobin were performed as HbA_{1c} on site with an HbA_{1c} analyzer (DIC-Daiichi Analyzer, Kyoto, Japan).

Statistical analysis. Descriptive and Student's pairwise t test statistics were calculated with the Stat Works software program (Apple Computers, Cupertino, CA). Analysis of variance (ANOVA) was performed on an HSD ANOVA program (Human System Dynamics, Northridge, CA).

RESULTS

Changes in strength and endurance from exercise were measured before and after the training program. During the exercise phase, significant changes were documented in both the bench press and the squat. Data on

TABLE 3
Physiological changes resulting from strength training

	Pretraining	Posttraining	Rest	F	P
HbA_{1c} (%)	6.9 ± 1.4	5.8 ± 0.9			0.05
Blood glucose levels (self-monitored; mM)	7.84 ± 3.10	7.08 ± 2.90			0.0001
Strength and endurance change					
Machine leg presses (wt × repetitions/10)	58.1 ± 20.0	69.2 ± 15.0			
Abdominal crunches (total)	37.6 ± 14.0	40.0 ± 17.0			
Lipid profile change (mg/dl)					
High-density lipoprotein	49.6 ± 12.5	49.1 ± 8.6			
Low-density lipoprotein	115.0 ± 42.0	111 ± 29.0			
Very-low-density lipoprotein	29.9 ± 18.0	18.5 ± 7.7			
Triglycerides	149.7 ± 90.0	92.8 ± 38.0			
Insulin (total U/day)	46.2 ± 15.0	41.6 ± 16.0			
Body composition change					
Weight (kg)	79.5 ± 14.5	80.9 ± 16.0			
Body fat (%)	18.8 ± 4.6	17.8 ± 4.0			
Dietary intervention					
Total calories per day	2305 ± 330	2858 ± 656			
Carbohydrate (%)	60.0 ± 10.0	64.4 ± 8.4			
Protein (%)	25.2 ± 6.7	22.5 ± 4.2			
Saturated-unsaturated fat (%)	14.2 ± 6.9	14.5 ± 4.0			
Cholesterol intake (mM)	12.1 ± 8.7	10.3 ± 5.8			
Analysis of variance					
Total cholesterol (mM)	5.05 ± 1.08	4.64 ± 0.88	4.94 ± 1.10	0.32	0.68
High-density lipoprotein cholesterol (mM)	1.28 ± 0.32	1.27 ± 0.20	1.30 ± 0.34	0.02	0.21
Low-density lipoprotein cholesterol (mM)	2.99 ± 1.10	2.88 ± 0.74	3.00 ± 0.93	0.03	0.26
Very-low-density lipoprotein cholesterol (mM)	0.77 ± 0.50	0.48 ± 0.20	0.64 ± 0.40	1.26	0.30
Triglyceride (mM)	3.89 ± 2.30	2.41 ± 1.00	3.23 ± 1.90	1.26	0.31
Insulin (pM)	245.2 ± 90.6	246 ± 94	285 ± 93	0.48	0.61

Values are means ± SD.

these exercises are shown in Fig. 1. There was a 100% increase in strength with the squat and a 58% increase in upper-body strength, as tested by the free-weight two-repetition maximum lifts. In >200 total training sessions, there were no reports of injuries that prohibited participating in the workouts. Only minor soreness was reported. The endurance bench press test showed a significant change from prevalues ($P = 0.02$), but no other endurance test yielded significant changes with the strength-training routine (Table 3).

Total cholesterol decreased during training (5.044 ± 1.06 vs. 4.628 ± 0.88 mM, $P = 0.015$) (Fig. 2). LDL, VLDL, and triglycerides decreased, but these changes did not reach statistical significance; HDL remained unchanged.

ANOVA was applied to both groups of participants during their exercise training and resting periods when a total of three blood draws were performed. There were no significant interactions in risk factors over time (Table 3).

There was no significant change in weight during the experiment. A decrease of 1% body fat during the course of the study was also nonsignificant (Table 3).

There was no change in the dietary composition of the participants between the resting and exercising phases of the experiment. Although total calories per day differed by 553 (2305 ± 330 vs. 2858 ± 656 at rest), they did not reach statistical significance. Dietary components of percentage carbohydrate, protein, and fat did not vary by any appreciable degree during the resting versus exercise phases (Table 3).

Glycosylated hemoglobin level dropped significantly during the training program. A drop of 1.1% was observed during the duration of the exercise program ($P = 0.05$). Self-monitored blood glucose values taken before and after each training session changed during the exercise program in each subject from a mean prevalue of 7.84 ± 3.1 mM to a final value of 7.08 ± 2.9 mM ($P = 0.0001$). Table 3 shows the blood glucose levels before and after each training session during the duration of the exercise program for all participants. These data are based on the total number of sessions for each of the participants minus sessions where some carbohydrate was ingested. In sessions where pretraining blood glucose was <5.32 mM, subjects ingested 30 g glucose (GlucoTabs, Becton Dickinson, Franklin Lakes, NJ), and the data were excluded. Therefore, there was a total of 152 sessions. During the course of the study, there were 10 incidences of blood glucose levels <3.64 mM after exercise. Subjects were instructed to ingest 30- to 60-g glucose tablets and wait before leaving the training facility.

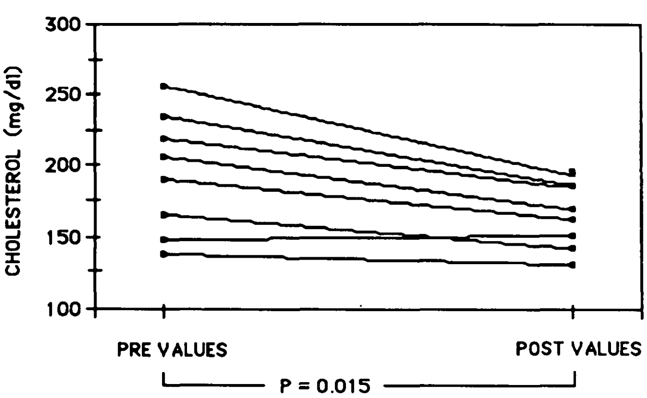

FIG. 2. Changes in total cholesterol before and after 30-session strength-training program. Mean values before (Pre) and after (Post) training program were 194 ± 41 vs. 178 ± 34 mg/dl, respectively (*n* = 8 subjects).

DISCUSSION

We report herein that a strength-training program for type I diabetic men can improve muscular strength, muscular endurance, glycosylated hemoglobin level, and total cholesterol. These changes are usually associated with aerobic exercise programs and, more recently, moderate strength programs with nondiabetic populations (6,7,10,12–14). Questions regarding the cholesterol-lowering effect of strength training need to be confirmed with larger sample-size studies to control for possible causes of variability not accounted for in this study. Goldberg et al. (6) showed favorable changes in lipid and lipoprotein levels after 16 wk of weight-training exercises in previously sedentary subjects. Miller et al. (8) showed a significant reduction in basal plasma insulin concentration, which was correlated with an increase in lean body mass in eight male subjects participating in a 10-wk strength-training program. Body builders show better glucose tolerance and lower insulin levels compared with untrained lean and obese subjects, suggesting that an increase in lean body mass mediated through training and a reduction in body fat may account for these effects (9). Hurley et al. (7) found that 18 wk of strength training was similar to aerobic activity in lowering the plasma glucose response to an oral glucose tolerance test and improved insulin sensitivity in untrained men. We cannot comment on potential hyperglycemia in response to exercise, because these reported effects have generally been observed at glucose values >14 mM at the initiation of a training session. Blood glucose values in our study did not approach this level before or after exercise.

Investigators who studied the effects of a combination of aerobic and strength-training programs have found favorable results with diabetic subjects. Peterson et al. (15) showed positive changes in HbA_{1c}, resting heart rate, blood pressure, and mean blood glucose levels during an 8-mo outpatient circuit strength- and aerobic-training and insulin and diet program in 10 type I diabetic subjects. Jovanovic-Peterson et al. (16) used the same type of training protocol to look at changes in metabolic and conditioning parameters in 9 type I diabetic subjects. They found significant changes in overall fitness and HbA_{1c} ($P < 0.005$) after 12 training sessions. Although the study by Miller et al. (8) was in nondiabetic men, because they reported a decrease in both the basal plasma insulin levels and post–glucose challenge insulin response, they suggested that high-resistance strength training may be a viable alternative to aerobic training for the control of blood glucose and insulin levels. Our data support this conclusion by showing reduced blood glucose and glycosylated hemoglobin levels with no change in insulin doses (Table 3) during resistance training. Thus, the often-prescribed avoidance of strength training for diabetic subjects (17) was not supported by our study results.

In conclusion, a supervised strength-training program with type I diabetic men was associated with no morbidity, increased strength, significant changes in glycemic control, and lower total cholesterol. It is hoped that these observations will stimulate other investigators to consider strength training and aerobic training as a potential therapeutic option for diabetic patients.

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