Effect of Resistance Training With or Without Chromium Picolinate Supplementation on Glucose Metabolism in Older Men and Women

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The effect of 12 weeks of resistance training (RT) with or without chromium picolinate (Cr-pic) supplementation on glucose tolerance was assessed in moderately overweight older men and women (age, 62 ± 4 years; body mass index [BMI], 29.1 ± 2.5 kg/m^2). Seventeen men and 15 women were randomized to groups that consumed either 17.8 μmol chromium per day (924 μg Cr/d) as Cr-pic or a placebo (<0.1 μg Cr/d) while performing RT twice weekly. For all 32 subjects combined, fasting glucose increased but there were no changes in insulin or C-peptide concentrations after 12 weeks of RT. In response to an oral glucose challenge, the glucose and C-peptide areas under the curve (AUCs) were unchanged, whereas there was a 19% decrease in the insulin AUC (from 68 ± 53 to 55 ± 29 × 10^3 pmol/L/180 min, $P = .045$). The RT responses for the fasting concentration or AUC for glucose, insulin, or C-peptide were not influenced by Cr-pic. The decrease in the insulin AUC without any change in insulin secretion, as evidenced by a lack of change in the C-peptide AUC, suggests enhanced insulin clearance from the circulation with RT. Collectively, these data suggest that RT decreases the insulin response following an oral glucose challenge in older moderately overweight men and women without affecting glucose tolerance. The data also suggest that the decrease in circulating insulin may result from an increase in insulin clearance, not a decrease in insulin secretion. High-dose Cr-pic supplementation had no effect on any measure of glucose metabolism during RT.

IT IS OFTEN REPORTED that advancing age is associated with a progressive development of glucose intolerance, due to increased peripheral tissue resistance to the action of insulin.[1] However, this deterioration in glucose homeostasis and increase in insulin resistance may be attributed more to a decrease in physical activity and an increase in body fatness.[2,3] Both factors are common in older individuals and therefore may significantly contribute to the abnormal glucose metabolism in this age group.

Resistance training (RT), with or without changes in body weight, increases insulin sensitivity in older men and women.[4,5] Using the oral glucose tolerance test (OGTT) to stimulate the pancreas, other studies have reported a decrease in the insulin area under the curve (AUC) with[6,7] and without[8-10] change in glucose tolerance in older men.

Trivalent chromium, an essential trace mineral, is involved in glucose, lipid, and amino acid metabolism and potentiates the action of insulin.[11-13] Some[14-17] but not all[18-20] controlled clinical trials provide evidence that chromium supplementation improves glucose tolerance. Since chromium is thought to be an effective dietary supplement to improve glucose metabolism, it is important to establish whether older individuals, those at greatest risk to develop hyperinsulinemia, hyperglycemia, or non–insulin-dependent diabetes mellitus (NIDDM), may benefit from this proposed method of improving glucose metabolism.

To our knowledge, there are no published data on the combined effects of RT and chromium supplementation on glucose metabolism in older individuals. Therefore, the objective of this study was to determine whether RT combined with high-dose chromium picolinate (Cr-pic) supplementation would significantly alter glucose metabolism in weight-stable, moderately overweight sedentary older men and women. It was hypothesized that after 12 weeks of RT, subjects who consumed a Cr-pic supplement would demonstrate a greater improvement in glucose metabolism compared with subjects who consumed a low-chromium placebo supplement.

SUBJECTS AND METHODS

Subjects

Thirty-five men and women (age, 54 to 71 years; body mass index [BMI], 26 to 36 kg/m^2) who were not actively involved in any physical training volunteered to participate in this 13-week study. A medical history questionnaire, resting and resistance exercise electrocardiogram, routine blood and urine analyses, 75-g dextrose OGTT, and physician-administered physical examination were completed to exclude subjects with any metabolic or cardiac abnormalities. When this study was performed, the 1979 recommendations of the National Diabetes Data Group (NDDG)[21] were used to exclude diabetics at screening. Potential subjects with fasting plasma glucose greater than 7.77 mmol/L or 2-hour OGTT plasma glucose greater than 11.1 mmol/L and one additional 0 to 120-minute plasma glucose sample greater than 11.1 mmol/L were deemed diabetic and excluded from the study. After being cleared for the study, each subject signed an informed-consent form in accordance with The Pennsylvania State University Institutional Review Board and the General Clinical Research Center (GCRC) Advisory Committee.

More recently, the NDDG criteria have been revised with stricter guidelines for the diagnosis of NIDDM.[22] Using the new criteria and based on baseline OGTT data, the 35 men and women studied were classified as follows: fasting plasma glucose, 15 men and 12 women normal (<6.10 mmol/L), three men and four women impaired (6.11 to 7.00 mmol/L), and one woman diabetic (>7.00 mmol/L); 2-hour plasma glucose during OGTT, 16 men and 10 women normal (<7.76

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mmol/L), one man and six women impaired (7.77 to 11.09 mmol/L), and one man and one woman diabetic (>11.10 mmol/L). To maintain the original objective to study nondiabetics, data from one man and two women judged to be diabetic by updated NDDG[22] criteria were excluded from the analyses. Thus, the data presented are from a total of 17 men and 15 women.

Experimental Design

The study period was 13 weeks. All baseline testing was completed during study week 1, at which time each subject did not consume any supplement and remained sedentary. This was then followed by a 12-week period in which the men and women were randomly assigned in a double-blind fashion (separate randomization for men and women) to either a chromium plus RT group ([Cr-RT] n = 17, nine men and eight women) or placebo plus RT group ([P-RT] n = 15, eight men and seven women). All tests and evaluations were repeated at study week 13.

Each subject received commercially prepared capsules reported to contain either 9.62 μmol Cr/capsule (500 μg Cr/capsule) as Cr-pic or a placebo (Nutrition 21, San Diego, CA) twice daily. The men and women were instructed to consume one capsule in the morning and one capsule in the evening without food. The capsules were distributed weekly in 7-day medication dispensers, and compliance was monitored by counting any returned capsules and by weekly interview. Compliance was also confirmed by an approximate 50-fold increase in 24-hour urinary chromium excretion at study weeks 7 and 13 for the Cr-RT group.[23] Chemical analysis found the Cr-pic capsules to contain 8 88 ± 0.21 μmol Cr/capsule (462 μg Cr/capsule) and the placebo less than 0.002 μmol Cr/capsule (<0.1 μg Cr/capsule). The Cr-pic and placebo capsules were analyzed for chromium using a graphite furnace atomic absorption spectrophotometer (model HGA 500; Perkin-Elmer, Norwalk, CT) as previously described by Anderson et al.[24] All subjects were encouraged to maintain their normal lifestyle and not to begin any other exercise training programs except the one prescribed for this study. The use of all nutritional supplements, other than those used for the study was discontinued 3 weeks before and throughout the investigation.

RT Protocol

The training program consisted of 12 weeks of progressive RT twice weekly with a minimum of 2 days' rest between training sessions. The following five exercises were performed using Keiser pneumatic variable-resistance machines (Keiser pneumatic resistance equipment; Keiser Sports Health Equipment, Fresno, CA): (1) unilateral knee extension, (2) unilateral knee flexion for men and bilateral knee flexion for women, (3) double leg press, (4) seated chest press, and (5) seated arm pull. The first two sets consisted of eight repetitions at 80% of the one-repetition maximum (1 RM), and the third set was continued until voluntary muscular fatigue or until 12 repetitions were completed. If 12 repetitions were completed for a given exercise, the resistance was increased by 5% for the next RT session. RT sessions were preceded and concluded by 10 minutes of easy cycling (heart rate < 100 beats/min) and 10 minutes of stretching. Sixteen men completed 23 RT sessions (100% compliance), and one man completed 22 RT sessions. All of the women completed 23 RT sessions (100% compliance).

Each subject's maximal strength was measured for each exercise on Keiser pneumatic resistance equipment as the maximal amount of resistance that could be moved through the full range of motion one time only, ie, 1 RM. Baseline maximal strength for each exercise was set as the greater of two 1 RMs obtained during the first two RT sessions. 1 RM assessments were repeated at study week 13. Total body strength is reported as the sum of 1 RM measurements for right and left unilateral leg extension, double leg press, chest press, and arm pull.

Diet

To standardize the diets before performing glucose metabolism assessments, all subjects consumed foods and beverages (except water) prepared and provided by the Metabolic Research Kitchen at the GCRC for 5 days during study weeks 1 and 13 of the intervention. The controlled diet consisted of 2-day rotating menus both designed to provide 13%, 57%, and 30% of total energy as protein, carbohydrate, and fat, respectively.[23] The chromium content of these menus was about 77 μg Cr/d.[23-25] Each subject's total energy intake was estimated to be 1.5 times the basal energy requirement as predicted from the sex-specific Harris-Benedict equation.[26] Total energy intake was calculated using Nutritionist IV software (version 4.0, N-Squared Computing: First Data Bank, San Bruno, CA) assuming metabolizable energy values for protein, carbohydrate, and fat of 16.7, 16.7, and 37.7 kJ/g, respectively. During study weeks 2 to 6 and 8 to 12, the subjects consumed their habitual diet prepared by themselves.

OGTT

For the OGTTs, the subjects reported to the laboratory in the morning in the postabsorptive state after an overnight 12-hour fast. At study week 13, the OGTT was performed 72 hours after the last exercise session. A catheter was inserted into an antecubital vein, and fasting blood was drawn for analysis of plasma glucose, insulin, and C-peptide concentrations. After the fasting blood sample, a 75-g glucose solution (Fisher Scientific, Pittsburgh, PA) was consumed within 5 minutes and venous blood samples were taken at 30, 60, 90, 120, 150, and 180 minutes. The integrated AUCs for glucose, insulin, and C-peptide were calculated using the trapezoidal method.[8]

Blood samples collected into heparanized tubes were centrifuged at 3,000 × *g* and 4°C for 10 minutes. A portion of the supernatant was removed and analyzed for glucose using an oxidase method standard for the glucose analyzer (Beckman Glucose Analyzer 2, model 6517; Beckman Instruments, Brea, CA). The remainder of the sample was stored at −20°C and used for insulin and C-peptide analyses via double-antibody radioimmunologic procedures as described by Engdahl et al.[27] Due to the large number of samples, it was impossible to test all samples in one assay. However, all samples for each subject were analyzed in the same assay.

Body Composition Measurements

All body composition measurements were performed in the postabsorptive state after a 12-hour overnight fast. The subjects were encouraged to maintain their initial baseline weight for the duration of the intervention period, since the objective of this study was to assess the effects of RT and chromium supplementation on glucose and insulin metabolism independent of changes in body weight. Fasting body weight was measured each weekday during study weeks 1 and 13, and twice weekly during the other study weeks (model 2181; Toledo Scale, Toledo, OH). Weight was measured to the nearest 0.1 kg with the subject wearing underwear, socks, a T-shirt, and gym shorts. Nude body weight was calculated as total body weight minus the weight of the socks, T-shirt, and gym shorts. Body height without shoes was measured to the nearest 0.1 cm with a wall-mounted stadiometer one morning during week 1, and was assumed to remain constant throughout the study.

Body density was determined in the fasting state using hydrostatic weighing,[28] with residual volume measured in the hydrostatic weighing tank via the nitrogen dilution technique.[29] Percent body fat (%BF), fat mass (FM), and fat-free mass (FFM) were estimated from body density using the two-compartment model of Siri.[30]

The waist circumference was obtained by placing a Gulick tape

around the waist at the umbilicus, and the hip circumference was obtained by placing the tape around the hips at the greatest protrusion of the buttocks. All circumferences were measured by the same technician.

Statistical Methods

Values are reported as the mean ± SD. The difference between the Cr-RT group (n = 17) and P-RT group (n = 15) for each of the independent variables was determined at baseline using one-way ANOVA. The difference between men (n = 17) and women (n = 15) for each independent variable was also determined at baseline using one-way ANOVA. The main effects of RT, Cr-pic supplementation, and sex, and the interactions between these independent variables on each of the dependent variables were determined using three-way repeated-measures ANOVA. Pearson product-moment correlations were used to determine if any relationship existed between the changes in measured variables. Statistical significance was assigned for a P value of .05 or less. All data processing and calculations were performed using JMP Statistical Discovery Software (SAS Institute, Cary, NC).

RESULTS

Group Characteristics and Body Composition

At baseline, there were no significant differences in the height, weight, FM, FFM, %BF, waist circumference, waist to hip ratio, and BMI between P-RT and Cr-RT groups. The Cr-RT group was older than the P-RT group. As expected, the men were taller and heavier and had a higher absolute FFM than the women. The women had a higher %BF compared with the men. With RT, the body composition changes in men and women were different. The differences in the response for these weight-stable men and women were evident for %BF (delta, 0.2 ± 2.0 for women *v* −1.7 ± 1.8 for men, $P = .007$), FM (delta, 0.5 ± 1.7 kg for women *v* −1.6 ± 2.1 kg for men, $P = .005$), and FFM (delta, 0.1 ± 1.4 kg for women *v* 1.8 ± 1.5 kg for men; $P = .002$). Cr-pic did not influence any effects of RT on these measurements for men or women. The BMI, body weight, waist circumference, and waist to hip ratio remained stable throughout the intervention period in both men and women, independently of Cr-pic (Table 1).

Strength Indices

There was no difference in baseline total body strength between P-RT and Cr-RT groups. As expected, the men were stronger than the women in total body strength at baseline (355 ± 53 *v* 211 ± 37 kg, $P < .001$). P-RT (19% ± 9%) and Cr-RT (21% ± 12%) groups had similar relative gains in total body strength. The men (18% ± 8%) and women (22% ± 13%) also had similar increases in strength, independently of Cr-pic.

Glucose Response

At baseline, there were no differences in the fasting glucose or integrated glucose AUC between P-RT and Cr-RT groups or between men and women. Fasting glucose increased following RT for both groups combined. Cr-pic did not have any effect on fasting glucose. In response to the oral glucose challenge, repeated-measures ANOVA showed no significant main effects of time (ie, RT) or sex and no interactions among time, Cr-pic, and/or sex on the glucose AUC (Table 2 and Figs 1 and 2).

Insulin Response

There was no difference in fasting or integrated AUC plasma insulin concentrations between P-RT and Cr-PT groups or between men and women at baseline. RT with or without Cr-pic supplementation had no effect on fasting insulin. Repeated-measures ANOVA showed no significant sex effect or interaction between RT, chromium, or sex following the intervention. However, when the data from all 32 subjects were combined, RT resulted in a 19% decrease in the insulin AUC (from 68 ± 53 to 55 ± 29 × 10^3 pmol/L/180 min, $P = .045$), (Table 2 and Figs 3 and 4).

C-Peptide Response

Fasting C-peptide concentrations at baseline were not different between Cr-RT and P-RT groups or between men and women. The incremental C-peptide AUC following oral glucose ingestion was not different between P-RT and Cr-RT groups, whereas men had a higher C-peptide AUC compared with women (420 ± 199 *v* 196 ± 61 × 10^3 pmol/L/180 min). The fasting C-peptide concentration was unchanged in the groups after RT. Twelve weeks of RT with or without Cr-pic had no effect on the C-peptide AUC after an oral glucose challenge (Table 2 and Figs 5 and 6).

Correlation

The change in the glucose AUC was highly correlated with the baseline glucose AUC ($r = -.468$, $P = .007$), indicating that subjects with the highest baseline glucose AUC had the largest decrease in the glucose AUC following RT. The change in the insulin AUC was also highly correlated with the baseline insulin AUC ($r = -.869$, $P < .0001$), indicating that the higher the baseline insulin AUC, the greater the change in postexercise integrated insulin AUC. In addition, correlation analyses were performed to determine whether there were any relationships between the changes in body composition and changes in insulin or glucose AUCs for all 32 subjects. There was no relationship between the change in the insulin or glucose AUC due to training and the change in %BF, FM, or FFM.

DISCUSSION

The results of this study demonstrate that 12 weeks of high-intensity RT significantly decreases the plasma insulin AUC without changing the glucose AUC after an oral glucose challenge. This response is similar to some reports in the literature,[8-10] whereas others have reported a decrease in the glucose AUC using a comparable protocol.[6,7] The reduction in circulating plasma insulin may be mainly due to a training-induced diminished insulin secretion and/or enhanced clearance from the circulation.[31] Therefore, measuring plasma insulin and C-peptide concentrations simultaneously allows for less ambiguity in the interpretation of changes in the plasma insulin AUC. Insulin and C-peptide are secreted in equimolar amounts from the pancreas.[32] However, only insulin is extracted by the liver,[33] making the plasma C-peptide concentration an indirect indicator of in vivo β-cell activity. In the present study, the decrease in the insulin AUC was not accompanied by a change in the C-peptide AUC. The reduction in the insulin AUC coupled with no change in the C-peptide AUC suggests an

Table 1. Subject Characteristics and Body Composition Before and After 12 Weeks of Cr-RT or P-RT

Characteristic	Cr-RT		P-RT	
	Baseline	Final	Baseline	Final
Age* (yr)				
All subjects	63 ± 5		60 ± 3	
Men	63 ± 4 (59-69)		60 ± 3 (56-66)	
Women	63 ± 6 (54-71)		60 ± 3 (54-63)	
Height (cm)†				
All subjects	170.7 ± 10.2		169.3 ± 7.5	
Men	178.2 ± 7.3		174.3 ± 5.3	
Women	162.4 ± 5.1		163.5 ± 5.1	
Weight (kg)‡				
All subjects	85.0 ± 15.5	85.0 ± 14.8	84.2 ± 9.9	84.9 ± 10.0
Men	96.2 ± 13.1	96.0 ± 11.7	89.3 ± 8.7	89.9 ± 8.7
Women	72.4 ± 3.4	72.6 ± 74.2	78.3 ± 8.1	79.2 ± 8.4
BMI (kg/m^2)				
All subjects	28.9 ± 2.5	28.9 ± 2.3	29.3 ± 2.4	29.6 ± 2.4
Men	30.2 ± 2.6	30.2 ± 2.3	29.4 ± 2.6	29.6 ± 2.7
Women	27.5 ± 1.3	27.6 ± 1.3	29.3 ± 2.3	29.6 ± 2.3
% BF§				
All subjects	39.7 ± 6.5	38.7 ± 6 9	38.6 ± 7.5	38 0 ± 8.7
Men	35.2 ± 5.5	33.7 ± 4.5	32.6 ± 4.2	30.6 ± 3.8
Women	44.9 ± 2.7†	44.3 ± 4.4	45.5 ± 2.7†	46.5 ± 2.3
FM (kg)§				
All subjects	33.3 ± 6.0	32.3 ± 5.2	32.2 ± 5.6	31.9 ± 6.5
Men	34.0 ± 7.9	32.4 ± 5.9	29.2 ± 5.1	27.6 ± 4.6
Women	32.5 ± 3.1	32.3 ± 4.7	35.6 ± 4.1	36.8 ± 4.6
FFM (kg)§				
All subjects	51.6 ± 13.0	52.6 ± 13.5	52.0 ± 10.6	53 0 ± 11.8
Men	62.1 ± 8.6	63.5 ± 8.7	60.2 ± 6.4	62.3 ± 6.8
Women	39.9 ± 2.2	40.4 ± 2.8	42.7 ± 5.0	42.3 ± 4.6
Waist circumference (cm)				
All subjects	101.5 ± 6.2	101.6 ± 6.2	100.4 ± 7.9	102.1 ± 7.7
Men	101.5 ± 7.1	101.2 ± 7.1	97.3 ± 6.9	99.7 ± 7.9
Women	101.4 ± 5.6	102.2 ± 5.6	104.0 ± 8.0	104.7 ± 6.9
Waist to hip ratio				
All subjects	0.94 ± 0.04	0.95 ± 0.04	0.94 ± 0.05	0.95 ± 0.06
Men	0.94 ± 0.03	0.95 ± 0.05	0.95 ± 0.05	0.95 ± 0.05
Women	0.95 ± 0.04	0.95 ± 0.04	0.93 ± 0.04	0.95 ± 0.07

Values are the mean ± SD. Numbers in parentheses are the range.
*Cr-RT group older than P-RT group, $P < .05$ by ANOVA.
†Men were different than women at baseline, $P < .05$ by ANOVA.
‡Women *v* men at baseline, $P < .05$ by ANOVA.
§Significant time × sex interaction by repeated-measures ANOVA, $P < .05$.

increase of insulin clearance in response to RT. However, without any direct measurement of insulin clearance under steady-state glucose and insulin concentrations, we can only speculate that RT may influence insulin clearance. To assert that the decrease in insulin in response to RT resulted from an increase in insulin clearance, more research must be conducted using more direct methods to calculate insulin clearance.

This is the first study to report that RT may increase insulin clearance following a 12-week program. Fluckey et al[8] reported a significant decrease in the insulin AUC with no change in the C-peptide AUC 18 hours after an acute RT session and concluded that there was increased insulin clearance from the circulation. In the present study, glucose tolerance was determined 72 hours after the last exercise session, suggesting that the response was more likely due to a training effect rather than an acute response to a previous bout of exercise.

Since the euglycemic-hyperinsulinemic clamp was not used to measure insulin sensitivity, we can only deduce from the present data that the results are consistent with an increase in insulin sensitivity. A disadvantage of the glucose tolerance test is that since the test is performed in a non–steady state, the final results may be influenced by factors other than insulin secretion, insulin clearance, and insulin sensitivity. To this end, a reduction in the insulin AUC resulting from an increase in the insulin clearance rate does not directly translate to an increase in insulin sensitivity as a cause and effect, because the glucose tolerance test does not provide any information with regard to peripheral insulin metabolism.

Another important finding of this study is that Cr-pic supplementation had no effect to improve glucose tolerance despite the large dose of chromium used (924 μg Cr/d). In addition, Cr-pic did not augment the effect of RT on circulating insulin concentrations in this group of older healthy weight-stable men and women. These results are in agreement with

Table 2. Effects of Chromium Supplementation on OGTT Results After 12 Weeks of Cr-RT or P-RT

	Cr-RT		P-RT	
Parameter	Baseline	Final	Baseline	Final
Fasting glucose (mmol/L)*				
All subjects	5.73 ± 0.43	6.01 ± 0.60	5.45 ± 0.47	5.78 ± 0.47
Men	5.72 ± 0.48	6.13 ± 0.44	5.37 ± 0.37	5.63 ± 0.45
Women	5.74 ± 0.41	5.86 ± 0.78	5.53 ± 0.58	5.95 ± 0.46
Fasting insulin (pmol/L)				
All subjects	82 ± 40	77 ± 34	71 ± 28	82 ± 42
Men	90 ± 38	85 ± 34	72 ± 31	82 ± 24
Women	73 ± 43	68 ± 34	70 ± 27	82 ± 59
Fasting C-peptide (pmol/L)				
All subjects	389 ± 203	397 ± 211	362 ± 244	435 ± 277
Men	363 ± 272	345 ± 272	284 ± 278	323 ± 325
Women	418 ± 90	455 ± 101	491 ± 109	563 ± 142
Glucose AUC (mmol/L 180 min)†				
All subjects	247 ± 104	269 ± 158	297 ± 117	283 ± 117
Men	227 ± 81	243 ± 122	327 ± 134	274 ± 106
Women	271 ± 126	298 ± 195	263 ± 94	293 ± 137
Insulin AUC (pmol/L 180 min)†‡				
All subjects	67 ± 50	52 ± 28	69 ± 57	59 ± 30
Men	67 ± 44	57 ± 31	90 ± 71	69 ± 35
Women	67 ± 59	47 ± 27	45 ± 20	47 ± 19
C-peptide AUC (pmol/L 180 min)†§				
All subjects	319 ± 165	343 ± 185	311 ± 208	334 ± 198
Men	414 ± 173	427 ± 206	426 ± 225	423 ± 232
Women	211 ± 58	247 ± 100	180 ± 64	232 ± 75

NOTE. Values are the mean ± SD.

*Significant increase as a result of RT (n = 32), $P < .05$ by ANOVA.

†AUC is incremental AUC × 10^3.

‡Significant decrease in insulin AUC as a result of RT (n = 32), $P < .05$ by ANOVA.

§Women *v* men at baseline, $P < .05$ by 1-way ANOVA.

other studies documenting no additional benefit of chromium supplementation for improving glucose homeostasis.[18-20,34] A recent study by Grant et al[34] reported that 400 μg Cr/d (7.7 μmol Cr/d) as Cr-pic had no effect on the glucose or insulin response in young obese women after 9 weeks of supplementation with or without RT. Abraham et al[18] also demonstrated that 16 months of supplementation (200 μg Cr/d, 3.85 μmol Cr/d as Cr-pic) was ineffective in producing long-term changes in fasting blood glucose in diabetic and nondiabetic subjects. The investigators did not report the fasting insulin concentration. Uusitupa et al[20] performed an OGTT after treating glucose-intolerant elderly subjects for 6 months with 160 μg Cr/d (3.07 μmol Cr/d) chromium-rich yeast. In agreement with the present study, they observed no significant change in oral glucose tolerance, and concluded that chromium was ineffective either to improve glucose tolerance or to decrease insulin concentrations. Offenbacher et al[19] also reported similar results following

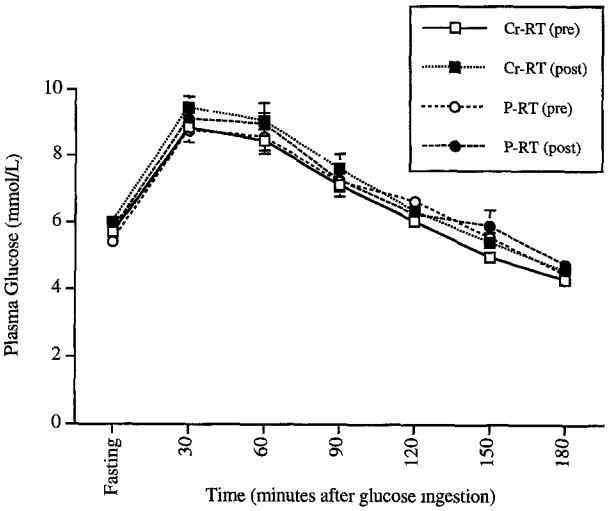

Fig 1. Plasma glucose before (fasting) and after glucose ingestion for Cr-RT and P-RT groups. Values are the mean ± SEM.

10 weeks of supplementation with 200 μg Cr/d (3.85 μmol Cr/d) as $CrCl_3$.

In contrast, some researchers have reported both improved glucose tolerance and increased insulin sensitivity[14-17] following chromium supplementation. A few differences in the experimental design of these studies could account for the disparity in results. Anderson et al[17] tested the hypothesis that 19.2 μmol (1,000 μg) supplemental Cr would improve glucose homeostasis in individuals treated for type 2 diabetes. They reported that hemoglobin A_{1c}, two-hour glucose, and fasting and two-hour insulin values were all decreased following 4 months of elevated intake of supplemental chromium. In another study, Anderson et al[14] fed glucose-intolerant men and women diets that contained 15 ± 0.6 μg Cr/d (0.29 ± 0.01 μmol Cr/d) and 11.4 ± 0.8 μg Cr/d (0.22 ± 0.02 μmol Cr/d), respectively, for 4 weeks before a 9-week supplementation period of 200 μg Cr/d as Cr-pic. These amounts were less than the minimum recommended daily allowance of 50 to 200 μg Cr/d (0.96 to 3.85 μmol Cr/d) and the reported intake in free-living individuals in the United States of 20 to 40 μg Cr/d (0.38 to 0.77 μmol Cr/d).

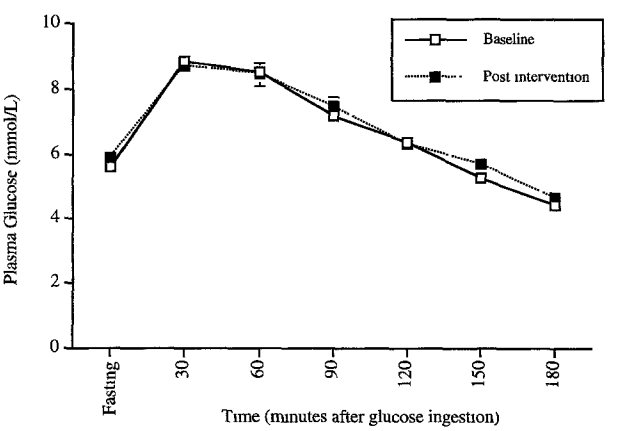

Fig 2. Plasma glucose before (fasting) and after glucose ingestion for P-RT and Cr-RT groups combined (*N* = 32). Values are the mean ± SEM.

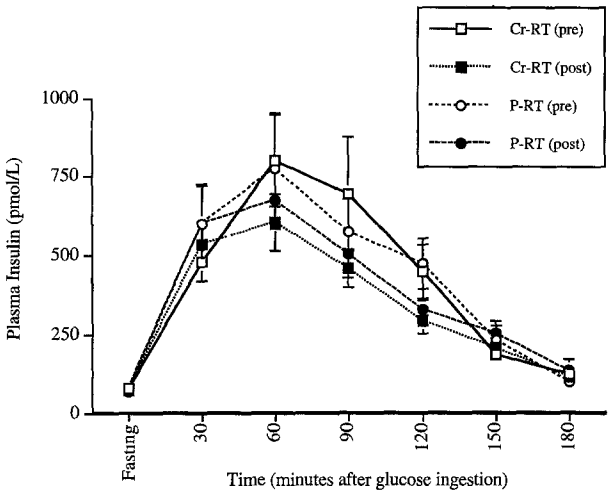

Fig 3. Plasma insulin before (fasting) and after glucose ingestion for Cr-RT and P-RT groups. Values are the mean ± SEM.

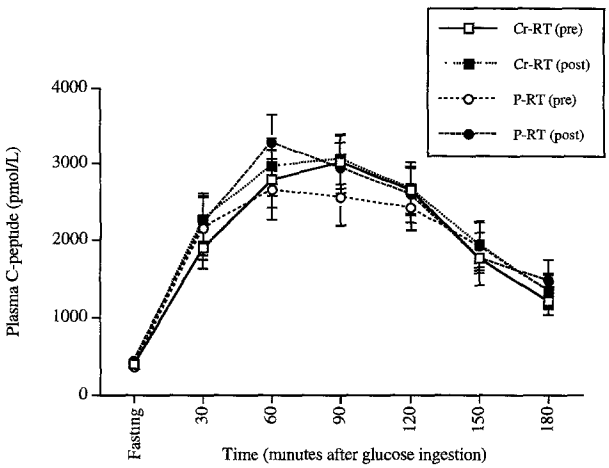

Fig 5. Plasma C-peptide before (fasting) and after glucose ingestion for Cr-RT and P-RT groups. Values are the mean ± SEM.

Therefore, the low intake in the study by Anderson et al[14] could induce a state of marginal chromium status, which, when combined with the existing hyperglycemia, increased the probability that supplementing the diet with chromium could result in an improvement in carbohydrate metabolism.

Potter et al[15] also concluded that 200 μg Cr/d (3.85 μmol Cr/d) as chromium chloride was instrumental in improving glucose homeostasis after glucose utilization increased during hyperglycemic clamps in elderly glucose-intolerant subjects. However, the mechanism by which this improved glucose homeostasis was possible does not agree with the hypothesized mechanism that chromium improves carbohydrate metabolism by increasing peripheral tissue sensitivity to insulin. Potter et al[15] reported an increase in insulin levels after the supplementation. Therefore, the mechanism in this case could be an increase in β-cell activity to increase insulin secretion in response to elevated glucose levels. In the present study, C-peptide concentrations did not change following the supplementation period. Since the C-peptide concentration is a good indicator of in vivo β-cell secretion of insulin, these data suggest that there was no change in the β-cell response to the glucose challenge after RT with or without chromium supplementation.

Besides the studies by Anderson et al[14,17] and Potter et al,[15] the only reports that have shown a relationship between chromium and abnormal glucose tolerance are clinical case reports of patients receiving total parenteral nutrition devoid of chromium who showed improved glucose homeostasis after supplementation.[35,36] Therefore, the relationship between chromium supplementation, glucose tolerance, and insulin action may indeed be complex. For example, the studies that report a benefit of chromium were performed in subjects with some combination of marginal chromium status and abnormal glucose metabolism, or diagnosed diabetes. This lends credence to the fact that chromium functions as a nutrient and not as a therapeutic agent, and that it will be of benefit only to those who exhibit some combination of abnormal glucose metabolism and low dietary chromium intake.

Riales and Albrink[16] reported that chromium supplementation significantly decreases the glucose AUC. However, they did not account for a significant change in body weight during the study period. This body weight change could be very

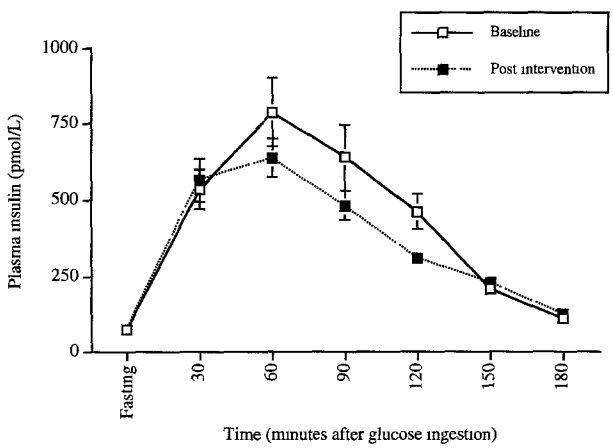

Fig 4. Plasma insulin before (fasting) and after glucose ingestion for P-RT and Cr-RT groups combined (N = 32). Values are the mean ± SEM.

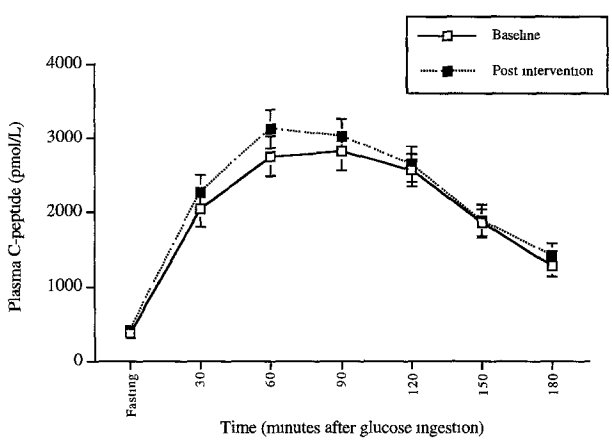

Fig 6. Plasma C-peptide before (fasting) and after glucose ingestion for P-RT and Cr-RT groups combined (N = 32). Values are the mean ± SEM.

important, since significant correlations between changes in body weight and changes in glucose tolerance and insulin action were previously reported.[37,38] It would be difficult to establish whether the improvement in glucose tolerance reported by Riales et al[16] was a result of the change in body weight or change in chromium status. In the present study, body weight remained stable throughout the intervention period. In addition, correlation analysis showed no relationship between changes in body composition and the change in any measure resulting from the OGTT.

The lack of a reliable nutrient reference database eliminates the opportunity for accurate estimation of habitual chromium intake from food records. The current assumption that a Western diet contains 15 μg Cr/1,000 cal[39] is a crude estimate and assumes that dietary patterns are similar across the United States. Duplicate composites of the subjects' habitual food intake were not collected for this study. However, duplicate composites of the menus provided to each subject were collected, and analysis of these controlled diets showed that the subjects were provided with approximately 77 μg Cr/d (1.49 μmol/d) 5 days before the OGTT.[23] This intake is unexpectedly high based on published results of the mean chromium content of self-selected diets.[39] The reasons for these higher levels are not readily apparent, but the methods used to process and package food for distribution to local grocery stores may account for the increase in the chromium content of the items. However, these menus were calculated based on total energy and macronutrient requirements and to ensure consistency in food intake before performing the glucose tolerance test. The menus were not prepared with chromium content in mind.

The significant increase in urinary chromium excretion with Cr-pic supplementation at RT weeks 6 and 12[23] is consistent with previous chromium supplementation studies in young men participating in a RT program.[40,41] In agreement with Hallmark et al,[41] we also report that the mean urinary chromium excretion of the placebo group was not significantly different from baseline at RT weeks 6 or 12. We also report that RT did not increase the mean urinary chromium excretion between weeks 6 and 12 in the chromium supplementation group. Therefore, under these experimental conditions, RT did not alter the urinary excretion or estimated absorption rate of chromium. The results of the present study are in contrast with the study by Rubin et al,[42] who reported increased urinary chromium excretion after acute and chronic RT. The measurement of urinary excretion of total dietary chromium intake as opposed to a single dose of ^{53}Cr as chromium chloride and the frequency (2 *v* 3 d/wk) and intensity (80% of 1 RM for five exercises *v* 90% of 3 RM for 14 exercises) might account for the difference in the results.

The increase in muscle strength in the present study is consistent with previous research in older individuals.[43,44] The 20% increase in total body strength is less than the 30% to 50% usually reported in previous studies. This difference is probably due to the lower total training stimulus, since five exercises were performed twice per week, in contrast to a more intense exercise protocol designed to target more muscle groups by using more exercises performed more frequently than twice per week. However, we are confident that the present exercise regimen did not in any way compromise our results, because other strength-training studies using a more intense exercise regimen reported that Cr-pic did not augment the increase in strength in young subjects following RT.[40,41]

In summary, the results of this study demonstrate that 12 weeks of RT reduces the insulin response without altering glucose tolerance in older moderately overweight men and women. This study also suggests, based on the indirect methodology of using the C-peptide concentration as an indicator of in vivo β-cell activity, that RT may influence insulin clearance from the circulation, since we observed no change in the C-peptide response. In addition, our data demonstrate that high-dose chromium supplementation is ineffective in improving glucose or insulin metabolism in a group of free-living sedentary older men and women during RT.

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