6.0 Results

The results provided in this section have been acquired from original studies from peer-reviewed journals. This section of the report is designed to provide data from reliable sources to answer the questions posed in the rationale for the study.

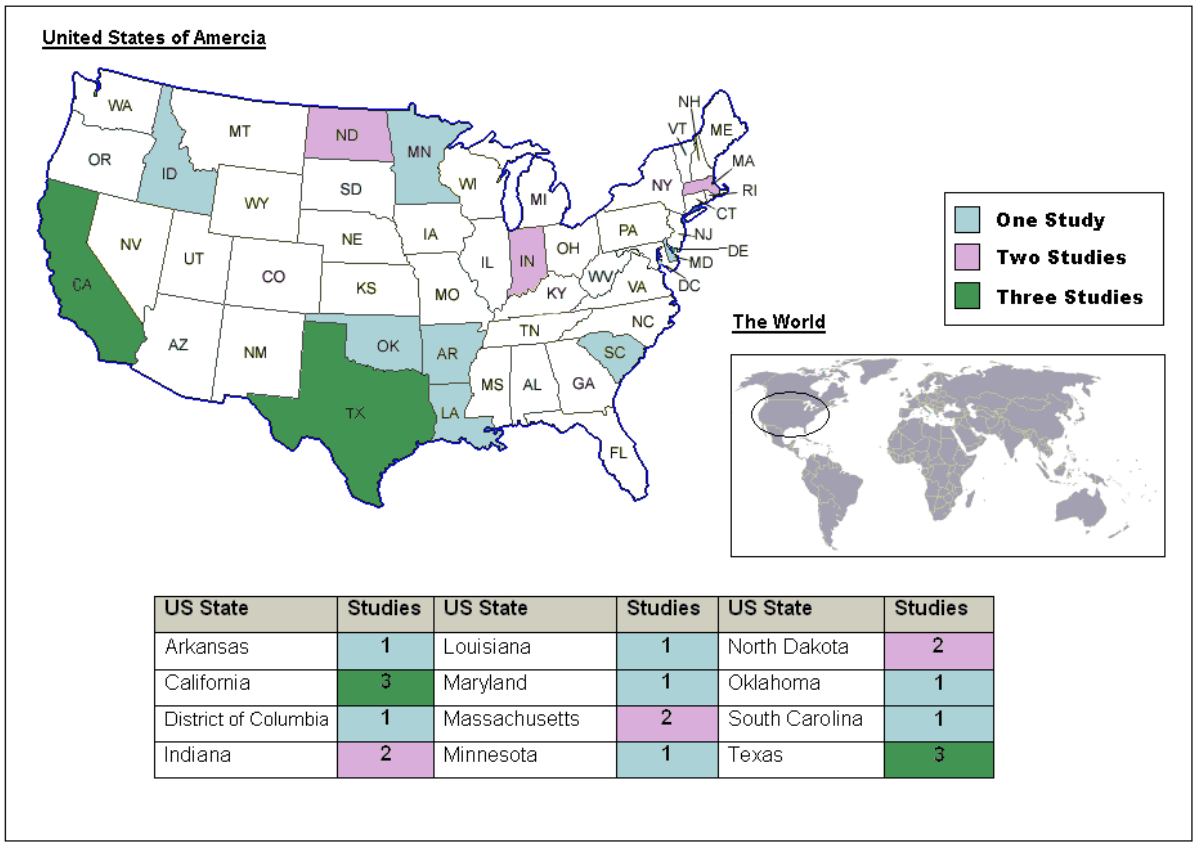
Further information regarding studies which have been used for analysis in this review are provided in Appendix A.

- Author, date, title
- Location and funding
- Study objective
- Number of subjects used (Gender, Age, Body Weight / Body Mass Index)
- Chromium type and dosage
- Duration of study
- Measures to control bias (Randomisation, double-blinding, compliance monitored, report of withdrawals)
- Variables measured (Analytical technique)
- Statistical analysis performed
- Results
- Conclusion

Following a comprehensive search using the protocols outlined in the methodology (section 3.0) a total of nineteen original research papers concerned with chromium supplementation and effect on body mass and composition were retrieved following the selection and exclusion procedure

previously described. Meta-analysis studies were not included, only original research material and only studies which focused on changes in body composition of human subjects. Three studies were excluded which did not comply with the selection criteria set out in section 3.5.

Of the nineteen-studies which were selected for use in the review, all (100%) were indicated to have been conducted in the United States of America. Location of the study was defined as main contact address of the study or the most prevalent contact address amongst multiple authors. Figure 1 illustrates the various locations where research into the effect of chromium supplementation on body composition has been performed.



US State	Studies	US State	Studies	US State	Studies
Arkansas	1	Louisiana	1	North Dakota	2
California	3	Maryland	1	Oklahoma	1
District of Columbia	1	Massachusetts	2	South Carolina	1
Indiana	2	Minnesota	1	Texas	3

Figure 1 – Location of the nineteen studies used in the review chromium supplementation on body composition.

Reviewed papers have been divided into three separate categories in order to logically present the findings. These sections are 6.1 Effect on body composition in trained/training individuals; 6.2 Effect on physical performance in trained/training individuals; and 6.3 Effect on body composition in non-active individuals. Studies which investigate two or more of the above categories are reported in the corresponding section in each case.

6.1 Effect on body composition in trained/training individuals

This section is concerned with review and analysis of studies or aspects of studies which have investigated the effects of chromium supplementation on body composition parameters (lean body mass, body fat mass, etc.) in subjects where physical activity is a factor (e.g. strength, endurance training). The rationale for concentrating individually on the effects of chromium supplementation on physically active and sedentary subjects is to determine, if any, the differences in effect on body composition. Physical activity is considered an aspect of the study if an exercise or training programme is employed, or if the subjects are described as athletes, ideally in this situation training should be recorded to control for differences in energy expenditure between subjects.

Table 3 illustrates the duration, dosages, forms of chromium, exercise training, body composition analytical technique and the main effects on body composition associated with chromium supplementation.

Table 3 – Effects of chromium supplementation during exercise training on body mass or composition

Author	**Date**	**Jadad 3-item Score**	**Subjects (*n*)** [a]	Dosage (μg Cr · d^{-1})	**Chromium Supplement**	**Duration (weeks)**	**Training Protocol (frequency)**	**Compliance Monitored** [b]	**Measurement Technique** [c]	**Chromium Effects** [d]
Evans (study one)	1989	1/5	10 Males	200	CrPic	5.7	Resistance (2 d · wk^{-1})	No	3-site Skinfold, 2-site Circumference	Increase in Lean Body Mass
Evans (study two)	1989	3/5	31 Males Football Players	200	CrPic	6	Resistance (4 d · wk^{-1})	No	3-site Skinfold 3-site Circumference	Increase in Lean Body Mass, Loss of Body Fat
Hasten et al.	1992	2/5	37 Males 22 Females	200	CrPic	12	Resistance (3 d · wk^{-1})	Yes	3-site Skinfold, 3-site Circumference	Females increased Body Weight
Clancy et al.	1994	4/5	21 Football Players	200	CrPic	9	Resistance & Running (4 d & 2 d · wk^{-1})	Yes	7-site Skinfold, 20-site Circumference	No Effects
Trent et al.	1995	3/5	79 Males 16 Females Obese	400	CrPic	16	Aerobic Exercise (3 hrs · wk^{-1}) Anaerobic (1.5 hrs · wk^{-1})	Yes	2-site(M); 3-site(F) Circumference	No Effects
Hallmark et al.	1996	3/5	16 Males	200	CrPic	12	Resistance (3 d · wk^{-1})	Yes	Hydrodensitometry, 6-site Skinfold, 5-site Circumference	No Effects
Lukaski et al.	1996	2/5	36 Males	171 & 182	CrChl & CrPic	8	Resistance (5 d · wk^{-1})	Yes	Dual X-ray Absorptiometry, 4-site Skinfold	No Effects
Grant et al.	1997	1/5	43 Females Obese	400	CrNic & CrPic	9	Resistance, Cycling & Aerobic (2 d · wk^{-1})	Yes	Hydrostatic Weighing	Increase in Body Weight in none exercising CrPic subjects, Decrease in Body Weight in exercising CrNic subjects
Walker et al.	1998	5/5	20 Males Wrestlers	200	CrPic	14	Resistance (3 d · wk^{-1})	Yes	Hydrostatic Weighing, 9-site Skinfold, 10-site Circumference	No Effect
Campbell et al.	1999	4/5	18 Males (56-69 yrs)	924	CrPic	12	Resistance (2 d · wk^{-1})	Yes	Hydrostatic Weighing, 8-site Skinfold, 2-site Circumference	No Effect
Livolsi et al.	2001	4/5	15 Females Softball Players	500	CrPic	6	Resistance (3 d · wk^{-1})	Yes	Hydrostatic Weighing	No Effect

Table 3 (continued) – Effects of chromium supplementation during exercise training on body mass or composition

Volpe et al.	2001	4/5	44 Females Obese	400	CrPic	12	Resistance & Walking ($2\ d \cdot wk^{-1}$)	Yes	Hydrostatic Weighing, 2-site Circumference	No Effect
Campbell et al.	2002	3/5	17 Females Obese (54-71 yrs)	924	CrPic	12	Resistance ($2\ d \cdot wk^{-1}$)	Yes	Hydrostatic Weighing, 8-site Skinfold	No Effect
Diaz et al.	2007	4/5	35 Females Overweight	447	CrPic	12	Aerobic ($5\ d \cdot wk^{-1}$)	Yes	Dual X-ray Absorptiometry	No Effect

[a] Subjects (numbers of males/females, and author specified classification)

[b] This refers to compliance to exercise protocol, which could be achieved through supervision of training or activity logs and compliance with regards to chromium supplementation, which could be achieved via capsule count, interviews or questionnaires.

[c] Refers to the measurement technique to assess body composition (skinfold thickness, circumference measures, hydrostatic weighing or dual x-ray absorptiometry).

[d] These are significant ($p < 0.05$) changes in body mass or composition compared to baseline and placebo trials.

Key
Cr = Chromium; **CrPic** = Chromium Picolinate; **CrNic** = Chromium Nicotinate; **CrChl** = Chromium Chloride

6.1.1 Initial Research

Evans (1989) was the first to investigate the theoretical principle of chromium supplementation effect on body composition. In a single paper, Evans (1989) presented a brief report of four studies designed to test the efficacy of chromium supplementation, as organic chromium picolinate, in altering blood lipid parameters, fasting blood glucose, blood pressure and body composition. The third and fourth studies are of particular importance with regard to this review, since Evans (1989) investigated chromium supplementation, as 200 $\mu g \cdot d^{-1}$ chromium picolinate, and weight training on changes in body composition parameters assessed by skinfold thickness and limb girth/circumference.

The first body composition study by Evans (1989) involved ten male volunteers (age 18-21 years) recruited from weight training classes. Subjects were randomly supplied with either placebo or 200 $\mu g \cdot d^{-1}$ chromium picolinate to be consumed for 40 days (5.7 weeks). The exercise programme consisted of upper and lower body resistance exercises, the duration and frequency reported as 40-minutes ($40 \text{ min} \cdot d^{-1}$), twice a week ($2 \text{ d} \cdot wk^{-1}$). At completion of the study, Evans (1989) found body weight significantly ($p < 0.05$) increased by 2.2 kg in the chromium group compared to baseline, whilst the placebo group increased by 1.25 kg ($p < 0.05$) from baseline. The chromium group demonstrated a slight (no values provided), non-significant increase in percentage body fat, whilst the placebo group significantly ($p < 0.05$) increased percentage body fat by 1.1 %, compared to baseline. The increase in body weight in the chromium group was largely due to a significant

($p < 0.05$) increase in lean body mass (1.6 kg) from baseline, which was also significantly ($p = 0.019$) different from the placebo group.

The second body composition study by Evans (1989) examined 200 $\mu g \cdot d^{-1}$ chromium picolinate supplementation, for a duration of six weeks in 31 male football players (no values of age or physique provided). Again a resistance training programme similar to the previous study was used, however, subjects were required to exercise 60 $min \cdot d^{-1}$, 4 $d \cdot wk^{-1}$ (supervised, but compliance not reported). Percentage body fat was determined from the sum of thigh, abdomen and chest skinfolds thickness. Lean body mass was derived from anthropometrically determined percentage body fat: weight – (weight x percentage body fat). In contrast to the findings of the previous study, subjects receiving chromium lost 1.2 kg body weight, which was attributed to a 3.4 kg reduction in body fat, significantly ($p = 0.001$) different to placebo group, and a 2.6 kg increase in lean body mass, significant ($p = 0.031$) compared to placebo group. Although, changes following 14 days chromium supplementation were described as “significant” ($p < 0.05$), the authors failed to state if the changes at completion were also significant from baseline. Figure 2 illustrates the changes in body composition in the two studies conducted by Evans (1989).

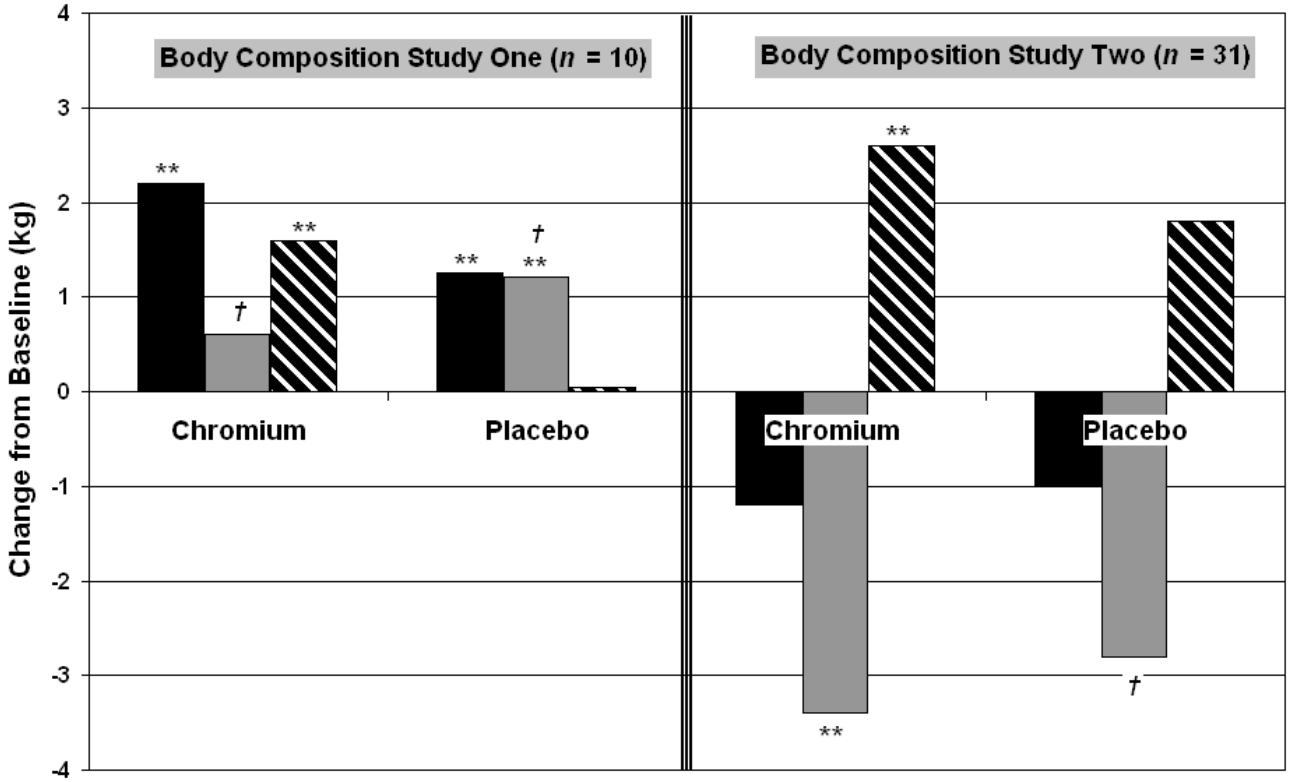


Figure 2 – Evans (1989). Change in body composition parameters from baseline following supplementation and resistance training in two separate studies. Black filled bars represent total body mass (kg). Grey filled bars represent fat mass (kg). Hatched bars represent lean body mass (kg). ** Indicate significantly ($p < 0.05$) changed from baseline. † Indicate change in fat mass values not provided and calculated approximately from difference in body weight and lean body mass.

Comparison of the findings from the two studies by Evans (1989) illustrated in Figure 2 demonstrates the contrasting findings. Where as in the first study, body weight in general increased, body weight decreased in the subsequent study, despite greater increases in lean body mass. Fat mass increased in both the chromium and significantly ($p < 0.05$) in the placebo groups during the first study, whilst in the second study fat mass was found to decrease in both groups, significantly ($p = 0.001$) in the chromium group compared to the placebo group. Fat mass, assessed by skinfold measurements, may be the reason for the discrepancy of the results as these are subjective measures which predict large fluctuations in body fat depending on the anthropometric

equation used (Reilly, Wilson & Durnin, 1995). Training volume may also be a factor, although both studies were conducted under similar protocols subjects participated in a total of 80 min · wk^{-1} resistance training in the first study, compared to 240 min · wk^{-1} in the second (three-times more exercise). Unfortunately, not all of the results were provided (indicated by *†*), and approximate calculations were made for completeness of findings.

Hasten, Rome and Hegsted (1992) conducted a similar study to investigate the effects of 12-week chromium picolinate supplementation (200 μg · d^{-1}) with resistance training (40 min · d^{-1}, 3 d · wk^{-1}) on body composition, assessed by skinfold thickness and limb circumference, in fifty-nine healthy subjects (37 male, 22 female) aged 18-36 years. Hasten et al. (1992) found that chromium supplementation was associated with a significant (p = 0.0048) increase of 2.5 kg body weight in the female chromium group, compared to all other groups (see Figure 3).

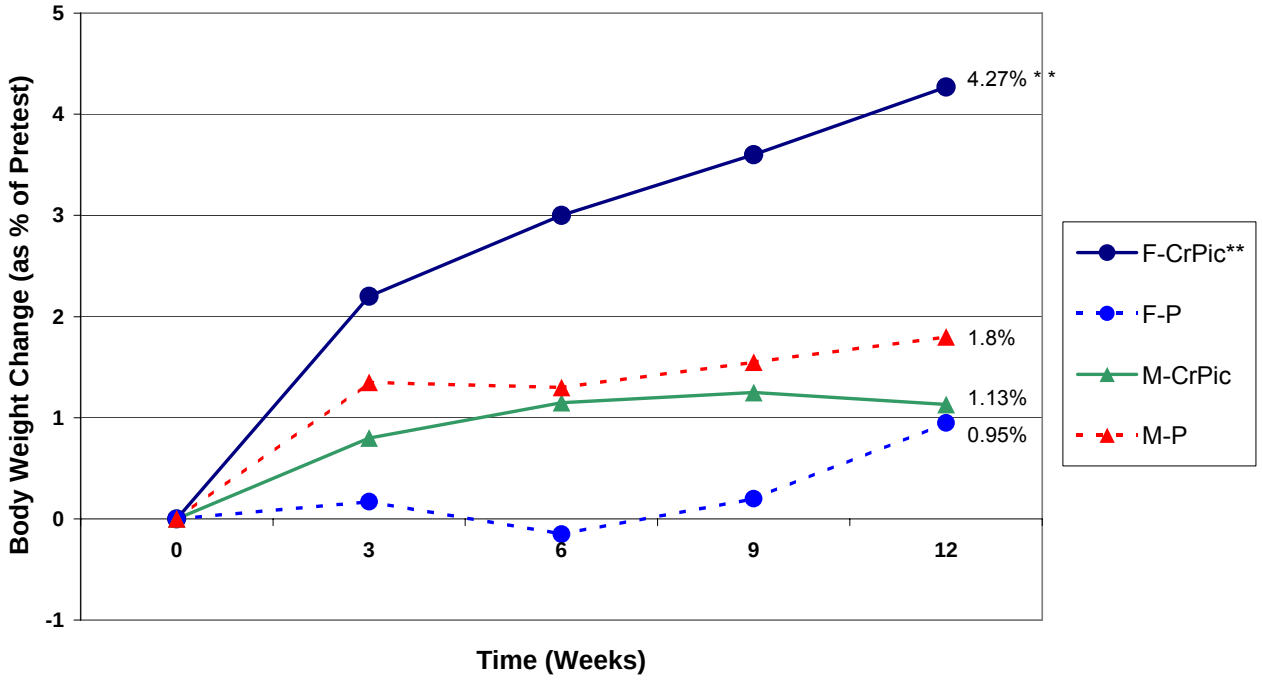


Figure 3 - Hasten et al. (1992). Relative body weight changes over twelve weeks. F-CrPic = Female Chromium Picolinate Group; F-P = Female Placebo Group; M-CrPic = Male Chromium Picolinate Group; and M-P = Male Placebo Group.

**** Significantly different from the other groups ($p < 0.001$).**

The increase in body weight reported in the female chromium group was attributed to an estimated 6.2% non-significant increase in lean body mass, double that of the placebo group. Hasten et al. (1992) commented "The trend toward increased lean body mass, if confirmed in future studies, could have long-term effects on body fat reductions since lean body mass is the primary determinant of the basal metabolic rate". Hasten et al. (1992) concluded that the results showed that chromium picolinate supplementation in combination with weight training was beneficial in increasing body weight in females, predominately through increasing lean body mass in female weight-lifting student but not in male counterparts.

Hasten et al (1992) commented on the lack of an observable effect in the male chromium supplemented group to be potentially due to a lower relative dose of chromium in the males, due to significantly ($p < 0.01$) greater body weight and lean body mass of male subjects compared to the females. Average body weight of the female chromium supplemented group was 58.5 kg; the dose per kg would be equal to 3.4 $\mu g \cdot kg^{-1}$ body weight. To achieve a similar dose in the male supplemented group (mean body weight 71 kg) a mean total dose of 243 $\mu g \cdot d^{-1}$ chromium picolinate would be required (compared to 200 $\mu g \cdot d^{-1}$). Hasten et al. (1992) indicates that future studies should examine chromium status within the subjects also. Later studies assess higher doses of chromium supplementation (> 200 $\mu g \cdot d^{-1}$).

6.1.2 Advancement in Analytical Technique of Body Composition

A subsequent study by Clancy et al. (1994) investigated the effects of chromium supplementation, as nine-weeks of 200 $\mu g \cdot d^{-1}$ chromium picolinate supplementation, on body composition, assessed by hydrostatic weighing, strength and urinary chromium loss in twenty-one football players (gender not provided) during off-season strength training (4 $d \cdot wk^{-1}$ weight-lifting, 2 $d \cdot wk^{-1}$ running exercise). Clancy and colleagues hypothesised that chromium supplementation would increase muscle mass and strength more than training alone, based on the findings of Evans (1989) and Hasten et al. (1992). The study represents the transition to the use of more accurate techniques for assessment of body composition. Hydrostatic weighing was utilised to indirectly obtain estimates of percentage body fat and lean body mass, in addition to limb circumference and skinfold measures.

Clancy et al. (1994) found no significant ($p > 0.05$) change in lean body mass or percentage body fat following supplementation and training in either the chromium or placebo groups. No report was provided on changes to total body mass, which also may have remained constant. The authors described the exercise as “spring training, which included a weight-lifting programme”, consisting of 4 d · wk^{-1} resistance training and 2 d · wk^{-1} running exercises. It is likely that the training programme was inadequate as following 9 weeks of training, no notable enhancement to body composition or strength in chromium or placebo groups could be observed. The lack of an observable effect on strength may be due to the testing procedures, which the authors acknowledge may have lacked specificity to that of the training protocol. The findings of Clancy et al. (1994) do not support the use of chromium picolinate as a muscle developing, fat burning agent. Chromium supplementation was associated with a significant ($p < 0.05$) increase in urinary chromium excretion (1.57 μg · $24hr^{-1}$) compared to baseline (0.28 μg · $24hr^{-1}$) and the placebo group (0.27 μg · $24hr^{-1}$), suggestive that urinary chromium excretion maybe an indicator of excessive chromium intake.

Trent and Thielding-Cancel (1995) investigated the efficacy of 400 μg · d^{-1} chromium picolinate supplementation for 16 weeks as a fat-reduction aid for obese U.S. Navy personnel (95 total; 79 male, 16 female) enrolled in a physical exercise programme (3 d · wk^{-1}, at least 30 minutes supervised aerobic exercise each session). At baseline, 75% of the men and 81% of the women sampled exceeded the U.S. Navy’s body fat standards (22% body fat for males and 30% for females) and were therefore subject to the Navy’s

remedial conditioning programme. No significant (p > 0.05) differences from baseline or between treatment groups were reported for body weight or percentage body fat or lean body mass, assessed by circumference measurements alone. As circumference measures were the sole analytical technique to assess body composition parameters by Trent et al. (1995) this study represents the least sophisticated study reviewed with regards to analytical technique of body composition.

Hallmark et al. (1996) investigated the effects of 200 $\mu g \cdot d^{-1}$ chromium picolinate and 3 $d \cdot wk^{-1}$ resistance training on sixteen previously sedentary male subjects (aged 18-35 years). Following pair matching on the basis of total one-repetition maximum strength at baseline, subjects were randomly assigned 200 $\mu g \cdot d^{-1}$ chromium picolinate or placebo. Body composition, assessed by hydrostatic weighing, revealed no significant (p < 0.05) changes in percentage body fat, or lean body mass in either the chromium or placebo group in response to the twelve weeks of progressive resistive training. Body weight, sum of skinfold thickness, circumference measures and waist-to-hip ratio were also found to have not significantly (p > 0.05) differed from baseline or between treatment groups. The effects of chromium supplementation and resistive exercise on body composition, skinfold and circumference measures found by Hallmark et al. (1996) can be seen in the Table 4.

Table 4 – Hallmark et al. (1996). Change in body composition, skinfold and circumference measures following chromium supplementation and resistance training.

		Pre	Post	Mean Difference
Chromium Group (*n* = 8)	Body Weight (kg)	81.6 ± 4.1	82.0 ± 4.2	+ 0.4 kg
	Body Fat (%)	19.8 ± 1.9	18.8 ± 2.0	- 1.0 %
	Body Fat (kg) [a]	16.2 ± 1.55	15.4 ± 1.6	- 0.8 kg
	LBM (kg) [b]	64.8 ± 2.4	65.8 ± 2.4	+ 1.0 kg
	Waist/Hip [c]	0.88 ± 0.01	0.88 ± 0.01	no change
	Skinfolds, ∑7 (mm) [d]	140 ± 13	118 ± 13	- 22 mm
	Circumference, ∑5 (cm) [e]	74.6 ± 10.8	73.4 ± 11.1	- 1.2 cm
Placebo Group (*n* = 8)	Body Weight (kg)	80.5 ± 5.2	80.9 ± 4.9	+ 0.4 kg
	Body Fat (%)	20.0 ± 3.7	20.1 ± 3.4	+ 0.1 %
	Body Fat (kg) [a]	16.1 ± 3.0	16.3 ± 2.7	+ 0.2 kg
	LBM (kg) [b]	63.0 ± 2.7	63.5 ± 2.7	+ 0.5 kg
	Waist/Hip [c]	0.89 ± 0.02	0.88 ± 0.02	- 0.01
	Skinfolds, ∑7 (mm) [d]	153 ± 26	119 ± 17	- 34 mm
	Circumference, ∑5 (cm) [e]	74.6 ± 11.1	74.5 ± 10.7	- 0.1 cm

Values are means ± Standard Deviation; [a] Body fat (kg) calculated using percentage body fat and total body weight; [b] LBM = Lean Body Mass; [c] Waist/Hip = waist to hip ratio; [d] Skinfolds, sum of seven skinfold sites (triceps, chest, subscapular, abdominal, iliac, mid-axiliary, thigh); [e] Circumference, sum of five sites (biceps, chest, waist, hip, calf)

Table 4 illustrates the non-significant trends which occurred in the chromium and placebo groups following resistance training and supplementation by Hallmark et al. (1996). Brief analysis indicates that the chromium group experienced the most desirable changes in body composition, as body fat mass decreased by 0.8 kg and lean body mass increased by 1 kg, compared to increases in body fat mass (0.2 kg) and lean body mass (0.5 kg) in the placebo group. As both groups were determined to have increased in body weight by 0.4 kg, based on the hydrostatic weighing, body weight changes would be predicted to be an increase of 0.2 kg and 0.7 kg in the chromium and placebo group, respectively. Hydrostatic weighing, although often considered

the gold standard approach to body composition assessment, is an indirect assessment dependent on an anthropometric equation (such as Siri). Hydrostatic weighing is susceptible to error when air is not fully exhaled from lungs, or account is not taken for residual lung volume. In the case of Hasten et al. (1996), hydrostatic weighing predicted that body weight would only change by half that of actual change (0.2 vs. 0.4 kg) in the chromium group, compared to almost twice that of actual change (0.7 vs. 0.4 kg) in the placebo group.

Lukaski, Bolonchuk, Siders and Milne (1996) conducted an original study of the effects of eight week supplementation with chromium picolinate (171 $\mu g \cdot d^{-1}$ Cr), chromium chloride (182 $\mu g \cdot d^{-1}$ Cr) or placebo (5 $\mu g \cdot d^{-1}$ Cr) in combination with intensive and carefully monitored weight training (5 $d \cdot wk^{-1}$, 60 $min \cdot d^{-1}$) in 36 males. Body composition was assessed by dual x-ray absorptiometry, which provides accurate analysis of whole-body and regional bone and soft tissue composition. In addition to urinary chromium excretion, serum chromium concentration was also assessed which provides further control on relative chromium intake and status in tested subjects. Body weight significantly ($p < 0.001$) increased in all groups (0.6-1.8kg), although there was no significance ($p > 0.05$) between the groups. Increase in body weight was a result of resistance training and was predominantly due to a significant ($p < 0.001$) increase in fat-free mass in the placebo (+1.4 kg), chromium chloride (+1.9 kg) and chromium picolinate (+1.9 kg) groups, without any statistically significant ($p > 0.05$) differences between the groups. Figure 4 is directly from

Lukaski et al. (1996), as no values were provided, and illustrates the changes in serum chromium concentration.

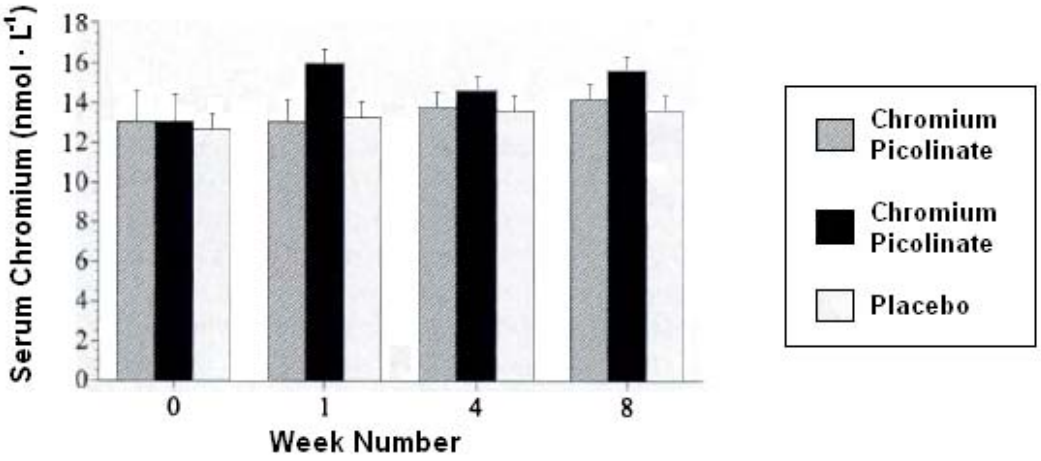


Figure 4 – Lukaski et al. (1996). Serum chromium concentration at baseline (0) and during weeks 1, 4 and 8 of resistance training and chromium supplementation. ANOVA results: chromium ($p < 0.01$) and resistance training ($p < 0.03$).
Source: Lukaski et al. (1996).

Serum chromium concentration significantly ($p < 0.003$) increased in response to the resistance training in all groups (Figure 4), however chromium supplementation as both chloride and picolinate was responsible for a further significant ($p < 0.01$) increase in serum chromium concentration. Figure 5 also acquired from Lukaski et al. (1996) illustrates the change in urinary chromium excretion.

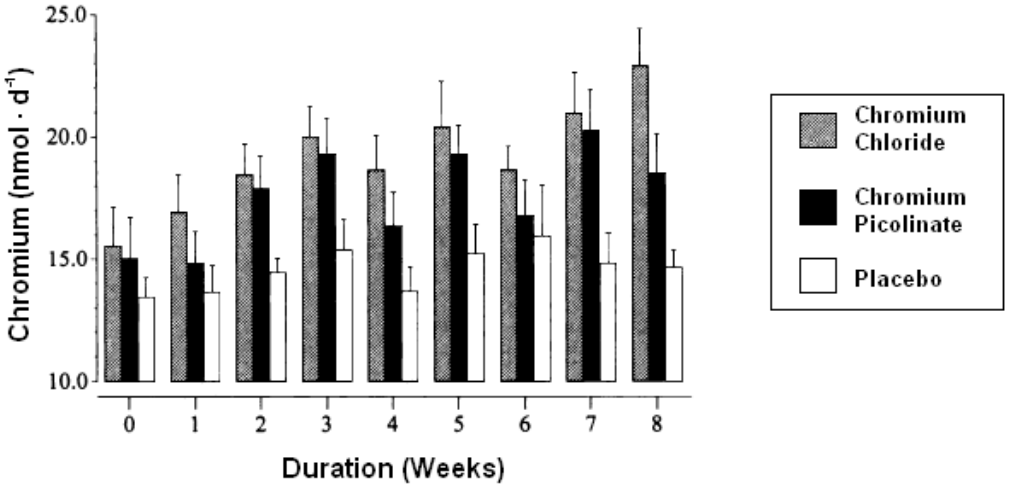


Figure 5 – Lukaski et al. (1996). Urinary chromium excretion in 3-d pooled samples before and during resistance training. ANOVA results: chromium ($p < 0.002$).
Source: Lukaski et al. (1996).

Similar to the changes in serum chromium concentration, Lukaski et al. (1996) found that compared to pre-training values, chromium excretion significantly ($p < 0.05$) increased during weeks 2, 3, 5, 7, and 8 in all groups (Figure 5) as a result of resistance training. Urinary chromium excretion was significantly ($p < 0.002$) increased in response to chromium supplementation compared to baseline and placebo, and although there was a trend for greater chromium loss in chromium chloride subjects compared to chromium picolinate, the differences were not statistically significant ($p > 0.05$). Lukaski et al. (1996) provide further support that urinary chromium excretion and serum chromium concentration are reliable indicators in subjects consuming high doses (≥ 200 $\mu g \cdot d^{-1}$) of chromium. As an indicator of chromium supplementation, these measures could be used to monitor compliance or chromium status.

Grant, Chandler, Arthur and Ivy (1997) also investigated the effects of alternative forms of chromium supplementation. The authors examined the

effect of either 400 μg · d^{-1} chromium picolinate or chromium nicotinate, with and without exercise training on changes in body weight and composition, glucose tolerance and plasma lipids in 43 sedentary overweight/obese (50.8 to 96.1 kg) females (aged 18-35 years). All exercise training was supervised and consisted of 1-hour, 2 d · wk^{-1} step aerobics; 30-minutes, 2 d · wk^{-1} cycling at 75-80% maximum heart rate and 2 d · wk^{-1} resistance training.

Following nine-weeks of training and supplementation no significant ($p > 0.05$) changes in any aspect of body composition (percentage body fat, fat mass or fat-free mass) were reported compared to baseline in any group (exercise/CrPic; no exercise/CrPic; exercise/CrNic; exercise placebo). Body weight significantly ($p < 0.05$) increased in the no exercise/CrPic group (1.9 kg) and significantly decreased in the exercise/CrNic group (-1.1 kg). No significant ($p > 0.05$) changes in body weight were found in the exercise/placebo and exercise/CrPic groups compared to baseline. The effect of chromium nicotinate supplementation in the non-exercising subjects cannot be determined by this study, as no such treatment group was reported.

Walker et al. (1998) and Campbell et al. (1999) provided high-quality studies into the efficacy of chromium supplementation, scoring 5/5 and 4/5, respectively, on the Jadad quality assessment scale. These two separate studies have been compiled as they investigate similar areas of chromium supplementation. Both investigations assessed changes in body composition via hydrostatic weighing on male subjects, Walker et al. (1998) supplemented twenty-young wrestlers (aged 18-23 years) with 200 μg · d^{-1} chromium

picolinate for 14-weeks, whilst Campbell et al. (1999) supplemented elderly males (aged 56-69 yr) with high dose 924 $\mu g \cdot d^{-1}$chromium picolinate for 12-weeks. Both studies used similar resistance training protocols, however, subjects in the Walker et al. (1998) study exercised 4 $d \cdot wk^{-1}$, compared to 2 $d \cdot wk^{-1}$ in the study by Campbell et al. (1999).

Walker et al. (1998) and Campbell et al. (1999) found that neither 200 or 924 $\mu g \cdot d^{-1}$ chromium picolinate supplementation were able to significantly ($p > 0.05$) enhance parameters of body composition (body weight, percentage body fat, fat mass or fat-free mass) beyond that of resistance training alone. Campbell et al. (2002) used an identical protocol to investigate the effects of high-dose (924 $\mu g \cdot d^{-1}$) chromium picolinate on seventeen overweight to moderately obese (28.8 ± 2.4 BMI), elderly females (age 54-71 years). Consistent with the findings in elderly males (Campbell et al., 1999), no significant ($p > 0.05$) influence of 12-weeks of chromium supplementation was found on variables of body composition or type I and type II muscle fibre size. Urinary chromium excretion of the chromium group was 60-fold higher than that of the placebo group, which was a significant difference ($p < 0.001$).

Crawford, Scheckenbach and Preuss (1999) investigated the effect of long-term supplementation (two months) with 600 $\mu g \cdot d^{-1}$ niacin-bound chromium on body composition in eighteen overweight African-American women (mean body weight 84 kg) whilst engaging in a modest-diet exercise regimen. Niacin-bound chromium is the fourth form of chromium to be reviewed and represents another weight-loss supplement on the health market, ChromeMate™

(InterHealth Neutraceutical Inc. Concord, CA, USA). Crawford et al. (1999) used a cross-over designed study where group one (*n* = 10) were provided with placebo followed by niacin-bound chromium for two months each, with one month "wash-out period" between treatments. Whilst, group two (*n* = 8) received niacin-bound chromium followed by placebo. The findings of supplementation and exercise training on body weight and composition are displayed in Figure 6, adapted from Crawford et al. (1999).

Figure 6 – Crawford et al. (1999). Changes in body weight, fat and non-fat mass in group one (received placebo [light green] followed by niacin-bound chromium [dark green]) and group two (received niacin-bound [light red] followed by placebo [dark red]).

*** Signifies significant ($p < 0.05$) differences between other treatment periods.**

As illustrated by Figure 6, Crawford et al. (1999) found that fat mass, determined by bioelectrical impedance technology, significantly ($p < 0.05$)

decreased whilst receiving chromium (-2.1 ± 0.4 lbs) compared to the placebo period (0.2 ± 0.5 lbs) whilst non-fat mass was found to have been significantly ($p < 0.05$) preserved during chromium supplementation (-4.0 ± 0.2 lbs) compared to placebo (-2.4 ± 0.9 lbs) in group one. In contrast, fat weight lost in group two (-1.8 ± 0.8 lbs) during the initial chromium period was similar to that of group one under chromium, however, during the following placebo period fat weight loss was significantly ($p < 0.05$) greater compared to the chromium period (-3.5 ± 0.45 lbs) in group two. Crawford et al. (1999) explained the greater fat loss during the placebo period was due to the accumulative effects of chromium supplementation. The one-month wash-out period between treatments was thought to not be enough to remove the effects of chromium supplementation. Crawford et al. (1999) concluded that 600 $\mu g \cdot d^{-1}$ niacin-bound chromium supplementation in addition to a modest dietary and exercise regimen was able to significantly enhance fat loss and preserve lean body mass in overweight, African-American women.

Livolsi, Adams and Laguna (2001) investigated the effect of 500 $\mu g \cdot d^{-1}$ chromium supplementation on the body composition (assessed by hydrostatic weighing) of fifteen female softball players (aged 17-21 years, body weight 47.8-82.5 kg) undergoing 3 $d \cdot wk^{-1}$ supervised resistance training. Urinary chromium excretion significantly ($p = 0.0117$) increased in the chromium group, compared to placebo and baseline. No significant ($p > 0.05$) effects of chromium supplementation were found, despite body weight, percentage body fat and lean body mass changed by –0.394 kg, -2.879% and +1.785 kg in the chromium group, respectively, compared to +0.361 kg, -0.571% and +0.343 kg

in the placebo group, respectively. The authors concluded that chromium supplementation was ineffective at influencing change in body composition, although as placebo and chromium groups experienced opposing trends Livolsi et al. (2001) speculate that the study period, 6-weeks, may have been too short to elicit any significant findings.

Volpe, Huang, Larpadisorn and Lesser (2001) investigated the effect of 400 μg $\cdot$ d^{-1} chromium picolinate supplementation, combined with 12-weeks exercise programme (3 d $\cdot$ wk^{-1}), consisting of 30-minutes resistance training, 30-minutes vigorous walking at 60-80% predicted maximum heart rate, on changes in body composition, as assessed by hydrostatic weighing. Subjects for this study were described as moderately obese (range 27-41 BMI) females, aged 27-51 years. Similar to the findings of Livolsi et al. (2001), Volpe et al. (2001) was unable to find any significant ($p > 0.05$) changes to body mass, percentage body fat, fat mass or lean body mass as a result of chromium supplementation. Only when the data from chromium and placebo groups were combined were significant ($p < 0.05$) decreases in percentage body fat and fat mass and increases in lean body mass found, post-test compared to pre-test, due to exercise training. No significant ($p > 0.05$) changes occurred in blood glucose, insulin, glucagon concentration in either chromium or placebo groups, which are hormones central to glucose metabolism and highly influential to changes in body composition. Urinary chromium excretion at mid-test (6-weeks) in the chromium group (3.0 ppb), was significantly ($p < 0.05$) higher compared to base-line (1.5 ppb) and placebo group (1.85 ppb). However, urinary chromium excretion returned to base-line levels in the

chromium group when assessed post-test (12-weeks) suggesting an adaptation to preserve excess chromium with time. Post chromium supplementation (12-weeks) fasting serum chromium concentration was significantly (p = 0.02) elevated in the chromium group (2.62 ± 2.7 ng · mL^{-1}), compared to both pre-chromium supplementation (0.26 ± 0.33 ng · mL^{-1}) and placebo (0.4 ± 0.41 ng · mL^{-1}) levels.

Diaz, Watkins, Li, Anderson and Campbell (2007) conducted the most recent investigation of chromium supplementation. The authors examined a novel research area, combining chromium picolinate supplementation (447 μg · d^{-1}) with another substance suggested to positively affect body composition, conjugated linoleic acid (dose 1.92 g · d^{-1}). Thirty-five overweight (BMI 28 ± 0.5 kg/m^2) females (age 36 ± 1 years) were recruited for the study. Subjects were trained and instructed to perform 30-minutes of moderate-intensity (rating of perceived exertion = 12, on a scale of 6-20) walking or jogging exercise, 5 day · $week^{-1}$ and record all activities in a daily log, although training was not supervised. In addition, the participants were advised on how to restrict energy and nutrient intake to create a 500 kcal · day^{-1} energy deficit, and were required to keep detailed food records on three non-consecutive days during baseline and intervention weeks 1-2 and 11-12.

Diaz et al. (2007) hypothesised that women receiving the chromium picolinate/conjugated linoleic acid (CP/CLA) supplement would achieve greater fat mass loss and preservation of lean body mass, as individually and combined CP/CLA are promoted as effective weight loss agents. Diaz et al.

(2007) found that 12-week supplementation with CP/CLA did not result in significant ($p > 0.05$) changes in body composition (fat mass, fat-free mass), as assessed by dual x-ray absorptiometry, compared to base-line levels or the placebo group. Factors which are central to body composition and cardiovascular health, glucose metabolism (haemoglobin A_1c, fasting plasma glucose and insulin), lipid lipoprotein profile (TC, HDL-c, LDL-c, TG) and blood pressure also were not significantly ($p > 0.05$) changed in the CP/CLA group compared to base-line or the placebo group. In agreement with previous studies urinary chromium excretion significantly ($p < 0.0001$) increased in the CP/CLA group from baseline and compared to the placebo group.

6.2 Effect on physical performance parameters in trained/training individuals

This section concentrates on studies into the effects of chromium supplementation on selected parameters of physical performance, which may manifest as strength (one-repetition maximum of a weight), aerobic or anaerobic performance (e.g. running and sprinting). In many instances, studies presented in this section may have previously been reported in the body composition section (6.1).

Table 5 illustrates the duration, dosages, forms of chromium and changes in physical performance parameters associated with chromium supplementation.

Table 5 - Effects of chromium supplementation on physical performance parameters with exercise training.

Author	Date	Jadad 3-item Score	Subjects (*n*) [a]	Dosage (μg Cr · d^{-1})	Cr. Supplement	Duration (weeks)	Training Protocol (frequency)	Measurement Technique [b]	Chromium Effects [c]
Hasten et al.	1992	2/5	37 Males 22 Females	200	CrPic	12	Resistance (3 d · wk^{-1})	1RM	No Effect
Clancy et al.	1994	4/5	21Males	200	CrPic	9	Resistance & Running (4 d & 2 d · wk^{-1})	Biodex - 1RM	No Effect
Hallmark et al.	1996	3/5	16 Males	200	CrPic	12	Resistance (3 d · wk^{-1})	Keiser - 1RM	No Effect
Walker et al.	1998	5/5	20 Males	200	CrPic	14	Resistance (3 d · wk^{-1})	Cybex - 1RM, Bruce Protocol - $VO_{2max,}$ Windgate - AnP	No Effects
Campbell et al.	1999	4/5	18 Males	924	CrPic	12	Resistance (2 d · wk^{-1})	Keiser - 1RM	Placebo group gained more left & right knee-extension strength
Davis et al.	2000	2/5	8 Males (repeated measures)	400 (1hr prior to exercise)	CrPic	n/a[d]	n/a[d]	Shuttle Running	No Effects
Livolsi et al.	2001	4/5	15 Females Softball Players	500	CrPic	6	Resistance (3 d · wk^{-1})	Cybex - 1RM	No Effects
Campbell et al.	2002	3/5	17 Females	924	CrPic	12	Resistance (2 d · wk^{-1})	Keiser - 1RM	No Effects

Table 5 (continued) - Effects of chromium supplementation on physical performance parameters with exercise training.

[a] Subjects (number of males/females, and author specified classification)

[b] Measurement technique (Brand of exercise equipment used or exercise protocol used, e.g. Bruce protocol, Windgate test and Shuttle running.

[c] These are significant ($p < 0.05$) changes in physical performance reported in the study determined to be directly associated with chromium supplementation.

[d] Duration shown in weeks, with the exception of Davis et al. (2000) where an alternative study design was used, assessing short-term effects of acute chromium consumption 60 minutes prior to exercise.

Key

Cr = Chromium; **CrPic** = Chromium Picolinate

1RM - The maximum amount of weight which can be lifted in one-repetition.

VO_{2max} – maximal aerobic capacity. AnP – peak anaerobic capacity

Hasten et al. (1992) investigated the effects of chromium supplementation (200 μg · d^{-1}) and weight training (3 d · wk^{-1}) on strength, assessed as one-repetition maximum for squat and bench press in male and female college students. Male subjects significantly increased strength, regardless of treatment, in both squat (41.3 kg, p = 0.0001) and bench press (11.9 kg, p = 0.0093) compared to females (26 and 10.3 kg, respectively). However, despite a trend for greater increase in strength in the female-chromium group for squat (28.5 kg) and bench press (11.5 kg) compared to female-placebo (22.9 and 8.7 kg, respectively) no significant (p > 0.05) effect of chromium supplementation compared to placebo was demonstrated in either the male or female groups. Figure 7 below illustrates the changes in strength in the chromium and placebo groups following 12-weeks of resistance training.

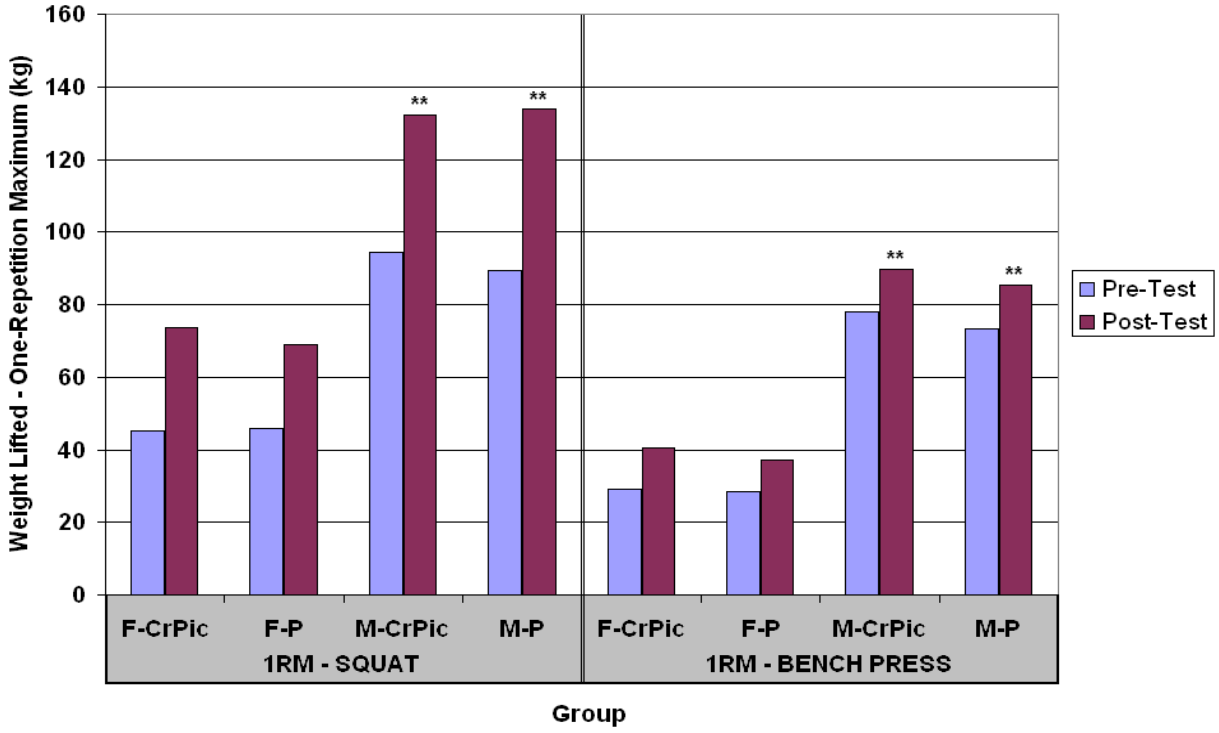


Figure 7 – Hasten et al. (1992). Pre- and Post-Test One-Repetition Maximum (1RM) for Squat and Bench Press in Male (M) and Female (F), Chromium Picolinate (CrPic) and Placebo (P) groups. ** Significantly different from other groups (p = 0.0001 for Squat and p = 0.0093 for Bench Press).

Clancy et al. (1994) attempted to determine the effects of chromium supplementation (200 μg · d^{-1}) in addition to weight training (4 d · wk^{-1}) on strength, determined by maximal isometric and concentric contractions of the flexors and extensors of the elbow and knee. The results showed no significant (p > 0.05) effect of chromium on increasing strength parameters compared to placebo. In many instances, results increase or decrease from pre to mid, and mid to post making analysis difficult and suggestive that the test may not be highly reliable, indicating insufficient or inappropriate training and testing. Clancy et al. (1994) commented on the appropriateness of the strength tests stating, "[Strength] Testing the athletes on the bench press and squat exercises might be more appropriate because these lifts are used in the training programme by the players".

Hallmark et al. (1996) investigated the effects of chromium supplementation (200 μg · d^{-1}) and resistance training (3 d · wk^{-1}) on muscle strength in previously sedentary males. Hallmark et al. (1996) assessed strength as one-repetition maximum on upper body (chest press, lateral pulldown, seated rows and overhead press) and lower body (leg press and leg extension) exercises. Hallmark et al. (1996) found that both chromium and placebo groups significantly (p < 0.05) increased upper, lower and total body strength compared to pre-training, indicating effective training and testing protocols. Subjects were pair-matched on the basis of baseline one-repetition maximum strength prior to supplementation and training. However, by completion of the study, the placebo group had increased total strength by 33% from pre (1500 kg) to post (1994 kg), compared to only a 24% increase in the chromium group

from pre (1574 kg) to post (1950 kg). The magnitude of strength gains was not significantly ($p > 0.05$) different between the chromium and placebo groups (376 vs. 494 kg, respectively). Although a non-significant trend, the placebo group improved total-body, one-repetition maximum by 118 kg (equivalent to almost 24% difference) above that of the chromium group, suggesting a possible inhibitory effect rather than a positive effect of chromium picolinate supplementation on strength accretion.

Lukaski et al. (1996) investigated the effect of chromium chloride (182 $\mu g \cdot d^{-1}$) and chromium picolinate (171 $\mu g \cdot d^{-1}$) supplementation with resistance training (5 $d \cdot wk^{-1}$) on strength, assessed as one-repetition maximum of upper body (bench press, lateral pulldown) and lower body (leg press, leg curl), in 36 males. Eight weeks of resistance training significantly ($p < 0.05$) increased strength in all treatment groups (placebo, chromium chloride and chromium picolinate) from baseline, however, there were no significant ($p > 0.05$) differences in the degree of strength between treatment groups.

Walker et al. (1998) studied the effect of 200 $\mu g \cdot d^{-1}$ chromium supplementation on muscular performance, assessed as upper- and lower-body endurance (maximal repetitions of seated low-pulls and leg press), global muscular power (Olympic power clean) and maximal upper-body strength (one-repetition maximum bench press). Upper-body endurance (maximum seated low-pulls to failure) significantly increased in the placebo and control groups by 5-6 additional repetitions compared to baseline ($p < 0.05$ and $p = 0.038$, respectively) and compared to the chromium group ($p = 0.037$) which

decreased by two repetitions from baseline. Bench press power ($W \cdot kg^{-1}$) significantly ($p = 0.05$) increased in the placebo group (1.97 $W \cdot kg^{-1}$) from baseline, however, no further significant changes from baseline were demonstrated for other muscular performance parameters. Whereas in general the placebo and control groups experienced increases in one-repetition maximum strength, muscular endurance and muscular power compared to pre-training values, with the exception of muscular power, the chromium group experienced non-significant ($p > 0.05$) decreases in strength from baseline. Supervision of training was not indicated, neither were compliance or training logs reported. Therefore, the various trends and significant interactions between treatment groups suggested by Walker et al. (1998) are limited, since the observed changes in muscular performance may be due to compliance to the training regimen.

Campbell et al. (1999) investigated the effect of high dosage chromium picolinate (924 $\mu g \cdot d^{-1}$) and resistance training (2 $d \cdot wk^{-1}$) in 18 males (aged 56-69 years). All subjects increased ($p < 0.0001$) maximal muscle strength, assessed as one-repetition maximum of right and left knee extension and flexion exercises, double leg press, chest press and arm pull, following 12-weeks of training. Campbell et al. (1999) found that males in the placebo group gained more strength in both the left and right knee-extension exercises, which was significantly different compared to the chromium group ($p = 0.035$ and $p = 0.009$, respectively). No significant ($p > 0.05$) differences in maximal muscle strength between treatment groups were reported for the remaining five-exercises, however, the trend was for greater change from

baseline in the placebo group (mean for seven-exercises, 28%) compared to the chromium group (mean for seven-exercises, 20%). This is in agreement with the findings of Hallmark et al. (1996), where a non-significant ($p > 0.05$) trend for greater strength gains in the placebo group compared to the chromium group was found in young males (aged 23 ± 4 years). The significant findings of Campbell et al. (1999) although only limited to knee-extension exercises, may be suggestive of an inhibitory effect of chromium supplementation in development of strength during a resistance training programme.

Davis et al. (2000) conducted a unique experiment into the short-term effects of acute chromium picolinate supplementation (400 μg) combined with a carbohydrate (CHO) drink (5 ml · kg body weight^{-1}, 6% CHO) consumed by eight physically active male subjects prior to performing intermittent, high-intensity shuttle running to fatigue. Davis et al. (2000) proposed that chromium supplementation may enhance the ergogenic effect of carbohydrate feedings by enhancing insulin actions and slowing the rate of glycogen depletion. Average run time to fatigue was found to be significantly ($p < 0.05$) longer in trials where supplementation with carbohydrate (11.2 ± 2.1 min) and carbohydrate combined with chromium (11.1 ± 2.3 min) compared to placebo (8.5 ± 1.6 min). However, there was no significant ($p > 0.05$) difference in shuttle-running time to fatigue when subjects received carbohydrate or carbohydrate/chromium beverage. Figure 8 illustrates the main findings of the report by Davis et al. (2000).

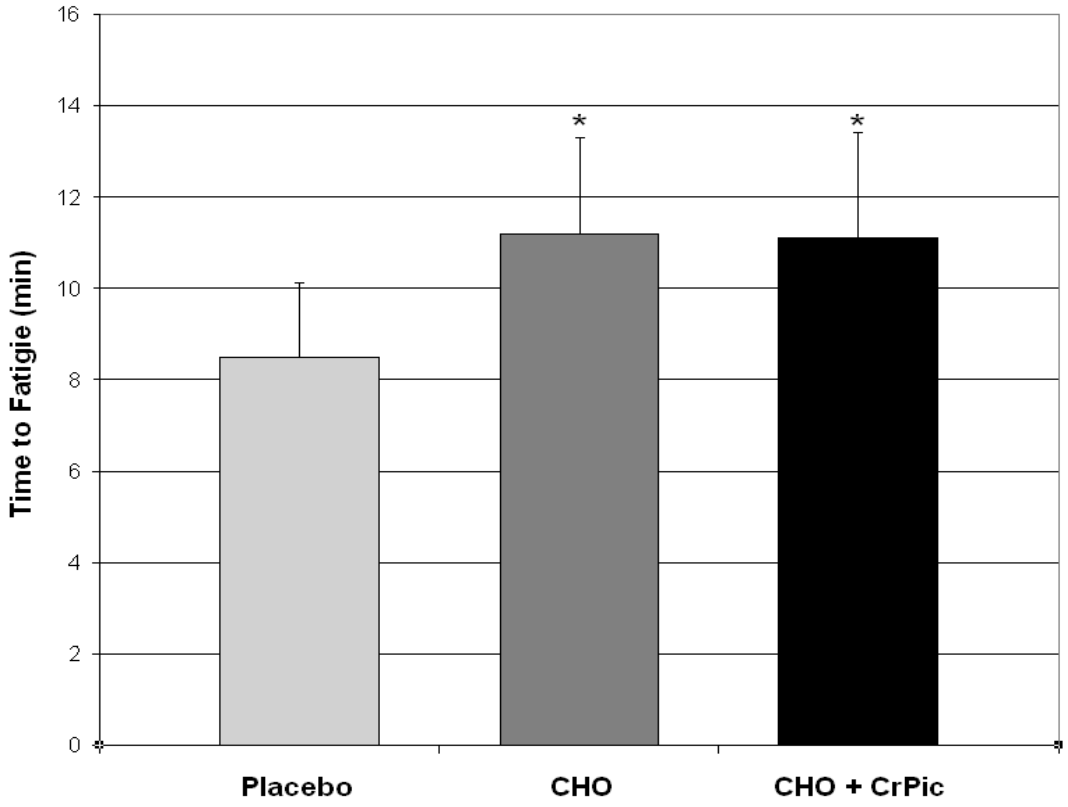


Figure 8 – Davis et al. (2000). Shuttle running time to fatigue during the performance bout, following 75 minutes of shuttle running protocol. * Signifies significantly ($p < 0.05$) different compared to placebo trial.

The findings of Davis et al. (2000) identify that supplementation with carbohydrate resulted in a significant ($p < 0.05$) 32% increase in run time to fatigue during the performance bout. Heart rate was significantly ($p < 0.01$) lower at all time points in the carbohydrate and carbohydrate combined with chromium (range 160-165 beats · min^{-1}) compared to placebo trial (166-170 beats · min^{-1}). At fatigue, only the carbohydrate trial resulted in a lower heart rate compared to placebo ($p < 0.01$). Plasma glucose concentration was significantly ($p < 0.01$) higher in the carbohydrate group compared to the placebo group during the first 45-minutes of exercise. However, 15-minutes post oral carbohydrate intake and exercise, carbohydrate trials resulted in a significantly ($p < 0.01$) higher plasma glucose concentration compared to both carbohydrate with chromium and placebo trials. Davis et al. (2000) claimed

that this might be weak support for the hypothesis that chromium supplementation enhanced insulin action and facilitated glucose transport into muscle cells.

Livolsi et al. (2001) investigated the effect of 500 $\mu g \cdot d^{-1}$ chromium picolinate supplementation in combination with 3 $d \cdot wk^{-1}$ supervised resistance training on muscular strength, assessed as total cumulative weight lift in one-repetition maximum of eight resistance exercises. Chromium and placebo groups showed significant ($p < 0.05$) increases in strength (106.625 and 76.429 kg, respectively) compared to pre-testing. The trend was for female softball players receiving chromium supplementation to gain more strength compared to the placebo group, however, this difference was not significant ($p > 0.05$).

6.3 Effect on body composition in uncontrolled, free-living individuals

This section reviews the effect of chromium supplementation on body composition in sedentary subjects, where exercise is not a factor. In many respects studies which attempt to determine the effects of chromium supplementation in free-living, uncontrolled subjects represent the potential benefits of enhancing body composition in individuals within the general population. Individuals often consume chromium in an effort to enhance the effects of a diet regimen (Nutrition 21, Inc. 2004). Individuals will use a variety of calorie restrictions and exercise protocols to achieve fat mass reduction, in much the same way as free-living subjects involved in studies of chromium supplementation efficacy. Ideally, energy expenditure and energy intake should be controlled to avoid bias.

Table 6 illustrates the duration, dosages, forms of chromium, body composition analytical technique and the main effects on body composition associated with chromium supplementation.

Table 6 - Effects of chromium supplementation on body mass or composition in "free-living" subjects

Author	Date	Jadad 3-item Score	Subjects (*n*) [a]	Dosage (μg Cr · d^{-1})	Chromium Supplement	Duration (weeks)	Training Protocol (frequency)	Compliance Monitored [b]	Measurement Technique [c]	Chromium Effects [d]
Kaats et al.	1996	3/5	154	200 & 400	CrPic	10.3	None	Yes	Water Displacement	Decrease in Body Weight, Percentage Body Fat and Fat Weight
Grant et al.	1997	1/5	43 Females Obese	400	CrNic & CrPic	9	Resistance, Cycling & Aerobic (2 d · wk^{-1})	Yes	Hydrostatic Weighing	Increase in Body Weight in none exercising CrPic subjects, Decrease in Body Weight in exercising CrNic subjects
Kaats et al.	1998	5/5	17 Males 105 Females	400	CrPic	12.9	No (pedometer to assess EE)	Yes	Dual X-ray Absorptiometry	Decrease in Fat Mass, Decrease in Body Weight, Percentage Body Fat and Fat Mass when adjusted for differences in EI & EE
Amato et al.	2000	5/5	9 Males 10 Females	1000	CrPic	8	Exercise (activity recorded)	Yes	Dual X-ray Absorptiometry	No Effect
Lukaski et al.	2007	4/5	83 Females	200	CrPic	12	None	Yes	Dual X-ray Absorptiometry, 4-site Skinfold	No Effect

[a] Subjects (numbers of males/females, and author specified classification)

[b] This refers to compliance to exercise protocol, which could be achieved through supervision of training or activity logs and compliance with regards to chromium supplementation, which could be achieved via capsule count, interviews or questionnaires.

[b] Refers to the measurement technique to assess body composition (skinfold thickness, circumference measures, hydrostatic weighing or dual x-ray absorptiometry).

[c] These are significant ($p < 0.05$) changes in body mass or composition compared to baseline and placebo trials.

Key
Cr = Chromium; **CrPic** = Chromium Picolinate; **CrNic** = Chromium Nicotinate; **CrChl** = Chromium Chloride

Kaats, Blum, Fisher and Adelman (1996) investigated the effects of receiving placebo, 200 or 400 $\mu g \cdot d^{-1}$ chromium picolinate on body composition in 154 subjects (males and females). Subjects were randomly assigned to receive a protein/carbohydrate nutritional drink which contained 0, 100 or 200 μg chromium picolinate and were instructed to consume two servings per day, resulting in a study duration of 72-days (10.3 weeks). No dietary or exercise programme was provided, subjects were asked to pursue whatever programme they desired during the testing-period, however, no attempt was made by the authors to control variation in energy intake/expenditure of subjects. Following completion of the study, subjects receiving 200 $\mu g \cdot d^{-1}$ chromium supplementation significantly reduced percentage body fat (-1.4%, $p = 0.023$) and fat weight (-1.62 kg, $p = 0.019$) compared to placebo, whilst 400 $\mu g \cdot d^{-1}$ chromium supplementation was associated with significant reductions of body weight (-1.4 kg, $p = 0.016$), percentage body fat (-1.9%, $p = 0.0003$) and fat weight (-2.07 kg, $p = 0.0002$) compared to the placebo group. There were no significant ($p > 0.05$) differences in lean body mass accretion in either the 200 or 400 $\mu g \cdot d^{-1}$ chromium groups individually or combined compared to the placebo group. Despite a tendency for further fat loss and more lean body mass accretion in the 400 compared to the 200 $\mu g \cdot d^{-1}$ chromium groups, these differences were not significant ($p > 0.05$).

Kaats et al. (1996) assessed body composition using a water-displacement method, which the authors insist correlates highly with hydrostatic weighing and has a test-retest reliability between 0.96 and 0.99. Subjects were also not adequately controlled on energy intake/expenditure or the dose of chromium

picolinate received, factors which could heavily influence changes in body composition. Subjects were instructed to consume two servings per day of the protein/carbohydrate drink, therefore the responsibility of consuming the correct dose of chromium was placed upon the subject. Furthermore, the drop-out rates were high, with 34% (79 from 233) of the original subjects enrolled withdrawing from the study. The drawbacks of the study by Kaats et al. (1996) cast doubt over the significance of the findings.

In an attempt to rectify some of these drawbacks of the previous study, Kaats, Blum, Pullin, Keith and Wood (1998) published a similar report into the effects of 90 day (12.9 weeks) supplementation with 400 $\mu g \cdot d^{-1}$ chromium picolinate on body composition in a sample of 122 subjects (gender composition not stated). Kaats et al. (1998) assessed body composition by dual energy x-ray absorptiometry (DXA), a sophisticated technique for analysis of bone and soft tissue density. To reduce the reliance on subject compliance, chromium picolinate was administered in a single 400 μg capsule. Efforts were made to control energy intake and expenditure by instructing subjects to record daily calorie balances and wear a pedometer during all waking hours. Finally, to minimise subject drop-out rates, subjects were asked to provide a $100 deposit, to be returned following completion of the study.

Following completion of the study, body weight, percentage body fat and fat mass were significantly ($p < 0.001$) reduced in both chromium and placebo groups compared to baseline, although neither group experienced a significant ($p > 0.05$) change in lean body mass. When change in body composition

parameters were compared between chromium and placebo groups, no significant differences were found for body weight (p = 0.24), percentage body fat (p = 0.12) or lean body mass (p = 0.568). However, fat mass was found to have been significantly (p = 0.023) reduced in the chromium group compared to the placebo group. Table 7 illustrates the findings of both Kaats et al. (1996) and Kaats et al. (1998) changes in body composition with and without chromium supplementation.

Table 7 - Comparison of the findings by Kaats et al. (1996) and Kaats et al. (1998).

		Body Weight Change (kg)	Percentage Body Fat Change (%)	Fat Mass Change (kg)	Fat-Free Mass Change (kg)
Kaats et al. (1996)	Placebo (***n* = 55**)	– 0.14 ± 2.66	– 0.3 ± 2.1	– 0.18 ± 2.61	+ 0.09 ± 1.35
	Chromium 200 μg (***n* = 33**)	– 1.08 ± 3.42	– 1.4 ± 2.2 *	– 1.62 ± 2.93 *	+ 0.54 ± 1.53
	Chromium 400 μg (***n* = 66**)	– 1.4 ± 2.93 *	– 1.9 ± 2.6 *	– 2.07 ± 2.7 *	+ 0.68 ± 2.2
	Chromium Groups Combined (***n* = 99**)	– 1.26 ± 3.01 *	– 1.7 ± 2.5 *	– 1.89 ± 2.75 *	+ 0.63 ± 1.98
Kaats et al. (1998)	Placebo (***n* = 60**)	– 1.81 ± 2.99	– 1.2 ± 2.9	– 1.53 ± 2.8	– 0.29 ± 2.0
	Chromium 400 μg (***n* = 62**)	– 2.88 ± 3.5	– 2.07 ± 3.2	– 2.81 ± 3.2 *	– 0.07 ± 2.2

*** Significantly changed compared to the placebo group, $p < 0.05$.**

Free-living, uncontrolled subjects receiving the chromium supplement demonstrated a non-significant ($p > 0.05$) trend for greater reduction in body weight, percentage body fat and preservation of lean body mass, which do not corroborate the highly significant findings by Kaats et al. (1996). The reason for this may be due to enhancement of factors which could lead to bias (e.g. measurement technique, drop-out rate). Kaats et al. (1998) reveal that the lack of a significant effect of chromium supplementation can be corrected when differences in energy intake/expenditure between groups are taken into account. Kaats et al. (1998) used the placebo group as the control and body composition parameters were adjusted according to differences in energy intake/expenditure compared to the chromium group, using the formula ± 3500 kcal is equal to a change of one pound (lb) body fat. Following this adjustment to body composition further reductions in body weight (–7.79 kg), percentage body fat (–6.3%) and fat mass (–7.71 kg) were reported in the chromium group, which were all significantly ($p < 0.001$) different compared to placebo. On the principle of this formula and the further 4.9 kg of body fat which would have been expected to have been lost if energy balances were identical between treatment groups, the total energy surplus must have been approximately 37,730 kcal over the 12.9 week period compared to the placebo group (see Table 8).

Table 8 - Calculation of energy difference between Chromium and Placebo Groups (Kaats et al. 1998).

Adjusted change in fat mass (kg) – Actual change in fat mass (kg) =

7.71 – 2.81 = **4.9 kg** fat mass difference

Conversion kilograms (kg) to pounds (lb) (1 kg = 2.2 lb) =

4.9 × 2.2 = **10.78 lb** fat mass difference

Converting fat mass (lb) into calories =

10.78 lb × 3500 kcal = **37,730 kcal**

Grant et al. (1997) investigated the effect of 400 $\mu g \cdot d^{-1}$ chromium picolinate following nine-weeks of supplementation in obese females (aged 18-35 years) with and without exercise. Of the four experimental groups which the authors identified, three were associated with exercise and one without. The sole sedentary group received 400 $\mu g \cdot d^{-1}$ chromium picolinate. Grant et al. (1997) found that chromium supplementation resulted in a significant ($p < 0.05$) increase (+1.9 kg) in body weight compared to baseline values. However, without an adequate control group (i.e. placebo receiving subjects) the extent to which the change in body weight is due to chromium supplementation is unknown. Non-exercising, chromium picolinate subjects may have participated in some form of exercise training to which the authors were unaware, since these subjects experienced a non-significant ($p > 0.05$) increase in lean body mass by 1 kg, which is over double the increase experienced by subjects participating in exercise training and receiving chromium supplementation (0.4 kg lean body mass).

Amato, Morales and Yen (2000) conducted an investigation to examine the effect of high dose (1000 $\mu g \cdot d^{-1}$) chromium picolinate on healthy (BMI 22-28 kg/m^2), non-obese elderly (aged 63-77 years) men ($n = 9$) and women ($n = 10$)

over a period of eight weeks. Amato et al. (2000) indicated that subjects were instructed to continue their normal dieting strategy and exercise, however the study protocol utilised no structured, supervised exercise programme. Amato et al. (2000) found that eight weeks of chromium supplementation was associated with a significant ($p < 0.0001$) elevation of serum chromium concentrations compared to baseline and the placebo group, however, this did not result in any significant ($p > 0.05$) changes in body composition (percentage body fat as measured by dual energy x-ray absorptiometry), body mass index (BMI), serum lipids (total cholesterol, triglycerides, HDL-c, LDL-c, Apolipoprotein-A_1 or B), insulin sensitivity or glycaemic levels.

Lukaski, Siders and Penland (2007) conducted the most recent study into the effects of 200 $\mu g \cdot d^{-1}$ (chromium concentration found to be 187 μg following chemical analysis) chromium picolinate supplementation on non-exercising subjects. Eighty-three females were recruited, age range 19-50 years, BMI 18-30 kg/m^2. Lukaski et al. (2007) created a placebo group, which received a starch compound and a control group, which received picolinic acid (1720 μg). To control energy and chromium intake, Lukaski et al. (2007) designed an experimental diet to be provided to each subject participating in the study which provided 29 ± 2 μg chromium $\cdot d^{-1}$ at an energy intake of 2000 kcal.

Following 12-weeks of supplementation, body mass and fat mass (assessed by dual x-ray absorptiometry – DXA) decreased significantly ($p = 0.0001$) when all groups were combined. Skinfold thickness also significantly ($p = 0.0001$) decreased when groups were analysed collectively, consistent with

the observed reduction in fat mass. Chromium supplementation was not associated with any significant ($p > 0.05$) difference in body weight or fat mass compared to baseline or placebo and picolinic acid groups. Change in fat-free, mineral-free mass approached significance ($p = 0.057$) in the chromium group compared to the control and placebo groups. Chromium supplementation was not associated with any significant ($p > 0.05$) effect on serum iron concentrations, which was found to significantly ($p = 0.013$) increase when all treatment groups were combined. Serum chromium concentrations and urinary chromium excretion increased significantly ($p < 0.0001$) in the chromium supplemented group compared to the placebo and control groups.

The lack of effect of chromium supplementation may be a result of the success of the experimental diet protocol. Since the diet was designed to provide 29 ± 2 μg chromium · d^{-1} at an energy intake of 2000 kcal, the authors indicate that this was within the normal range 25-30 $\mu g \cdot d^{-1}$ (Trumbo et al. 2001). This undermines the principle of chromium supplementation, which is to provide adequate chromium when dietary chromium is deficient. Many studies into the efficacy of chromium supplementation quote national figures on dietary chromium deficiency, such as Kaats et al. (1996) "[…] the most reliable studies report that [chromium] intake among Americans is suboptimal – only 40% of the minimum for women and 60% for men. These figures are similar to findings in England, Finland and Canada." The findings by Lukaski et al. (2007) confirm that chromium supplementation of 200 $\mu g \cdot d^{-1}$ chromium picolinate does not enhance changes in body composition when dietary

chromium intake is adequate (Trumbo et al. (2001) recommend 25-35 $\mu g \cdot d^{-1}$ chromium for females and males, respectively).