doi: 10.1111/j.1467-789X.2011.00908.x

Supplement: Fat Metabolism

Key Papers from a meeting organized by the Product Research Group of Lucozade Sport

Fat burners: nutrition supplements that increase fat metabolism

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Received 3 March 2011; revised 12 June 2011; accepted 12 June 2011

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Summary

The term 'fat burner' is used to describe nutrition supplements that are claimed to acutely increase fat metabolism or energy expenditure, impair fat absorption, increase weight loss, increase fat oxidation during exercise, or somehow cause long-term adaptations that promote fat metabolism. Often, these supplements contain a number of ingredients, each with its own proposed mechanism of action and it is often claimed that the combination of these substances will have additive effects. The list of supplements that are claimed to increase or improve fat metabolism is long; the most popular supplements include caffeine, carnitine, green tea, conjugated linoleic acid, forskolin, chromium, kelp and fucoxanthin. In this review the evidence for some of these supplements is briefly summarized. Based on the available literature, caffeine and green tea have data to back up its fat metabolism-enhancing properties. For many other supplements, although some show some promise, evidence is lacking. The list of supplements is industry-driven and is likely to grow at a rate that is not matched by a similar increase in scientific underpinning.

Keywords: Caffeine, carnitine, conjugated linoleic acid, forskolin, green tea, taurine.

obesity reviews (2011) **12**, 841–851

Introduction

One of the most popular categories of nutrition supplements is often referred to as 'fat burners'. The reasons for the popularity of these supplements generally include the proposed improvements in health, improvements in performance, weight loss or a combination of these factors. The term 'fat burner' is used to describe nutrition supplements that are claimed to acutely increase fat metabolism or energy expenditure, impair fat absorption, increase weight loss, increase fat oxidation during exercise, or somehow cause long-term adaptations that promote fat metabolism (Fig. 1). Often, these supplements contain a number of ingredients, each with its own proposed mechanism of action. It is often claimed that the combination of a number of these substances will have additive effects. The advertisements for many of these supplements are often accompanied by too-good-to-be-true before and after photographs of individuals. The purpose of this review is to examine the evidence for a number of the most popular ingredients that are proposed to enhance fat metabolism in some way and/or the supplements that have some research to support or not support their use. It is beyond the scope of this short review to discuss all available supplements (Table 1) that appear in this rather dynamic market. There will be a focus on studies performed in humans when these studies are available.

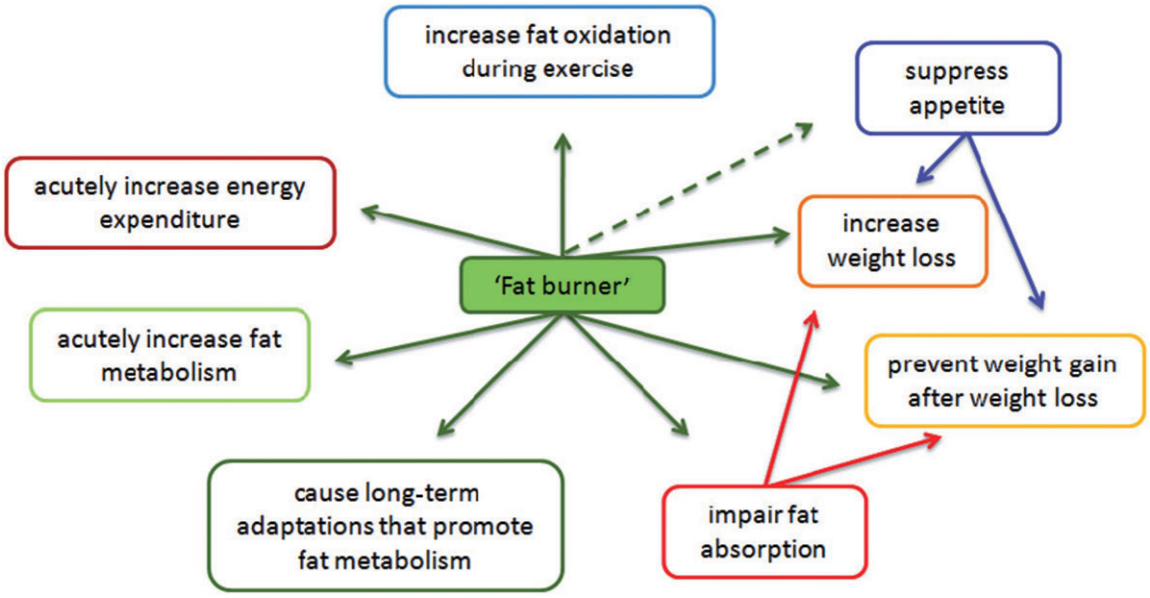

Figure 1 The interaction of 'fat burners' on increasing fat metabolism and promoting weight loss.

Table 1 Fat burners

Caffeine	Dihydroxyacetone	**Conjugated linoleic acid (CLA)**
Carnitine	Ephedra	Psyllium
Calcium	**Green tea extracts**	Pyruvate
Choline	Hydroxycitrate (HCA)	Leucine
Chromium	Lipase	**Forskolin**
Lecithin	Ma huang	Beta-sitosterol
Fucoxanthin	**Kelp**	Cayenne pepper (Capsaicin)
Garcinia cambogia	Inositol	**Epigallocatechin-3-gallate (EGCG)**
Capsaicin	**Taurine**	**Tea**

A list of available supplements that have been proposed to increase fat metabolism. Supplements in bold will be discussed in this review.

Caffeine

Caffeine (1,3,7-trimethylxanthine) is an alkaloid derivative found naturally in, and added to, a variety of foods and beverages. Most of the caffeinated beverages consumed worldwide are extracted from coffee beans or tea leaves or eaten as chocolate derived from the cacao bean. There are a variety of other metabolites in coffee and tea including other alkaloids (theobromine, paraxanthine, theophylline) and polyphenols (tannins and flavonoids). Consumption of caffeine containing tablets and supplemented foods should not be directly equated to the consumption of tea and coffee, especially from a health perspective. Caffeine is absorbed from foods and beverages with a time to peak plasma concentration of 30–90 min and half-life of approximately 4–6 h. Caffeine is extensively metabolized by the cytochrome P-450 oxidase system with ~1–3% being excreted in the urine as free caffeine.

A lot of the interest in the effects of caffeine on metabolism stems from exercise physiology studies in the 1970s. Early studies by Costill and co-workers (1) showed that caffeine ingested (coffee and pure caffeine), prior to an exercise bout, significantly elevated fat oxidation rates as well as performance. Essig *et al.* (2) also reported a shift in substrate metabolism during exercise from carbohydrate to fat, following caffeine ingestion which was accompanied by a modest increase in serum plasma fatty acid concentrations. The theory was developed that caffeine mobilized fat and spared muscle glycogen resulting in performance enhancement. Later, these two effects have been dissociated from each other, and the ergogenic effect of caffeine is more likely due to central mechanisms.

Nevertheless, caffeine has been shown to increase sympathetic nervous system (SNS) activity, liberating fatty acids from the adipose and/or intramuscular stores. This mechanism, occurring indirectly through increased circulating adrenaline levels, has the potential to enhance the availability of fatty acids for oxidation. Caffeine has also been associated with a more direct effect on lipolysis. It has been suggested from *in vitro* studies that caffeine inhibits phosphodiesterase (3), the enzyme responsible for degrading cyclic AMP (cAMP). An increase in the cAMP half-life enhances lipolysis, subsequently increasing fatty acid availability for fuel use. Whether such an effect also plays a role *in vivo* is unclear.

Caffeine has shown to elicit short-term thermogenic effects (4–6). Acheson *et al.* (4) found that administering

a high dose of caffeine (8 mg kg^{-1}) significantly increased resting metabolic rate (RMR) (20 kJ m^{-2} h^{-1}) in the 3 h after ingestion. Interestingly, in the final hour of measurements, fat oxidation was significantly higher after caffeine ingestion compared to placebo, reaching 75 ± 4 mg min^{-1}. In agreement with these findings, Dulloo *et al.* (5) reported that even a low dose of caffeine (100 mg) has the potential to induce a thermogenic effect at rest. Over a 150-min period, RMR was increased by 3–4% in both lean and post-obese individuals. In the same study, RMR was further augmented when repeated doses (2-h intervals over 12 h) of caffeine were ingested (8–11% increase) (5). It is unknown whether this increase was due to increased fat oxidation, increased carbohydrate oxidation or both. Astrup *et al.* (7) observed a linear dose-dependent response of caffeine ingestion on energy expenditure. However, this was attributed to equal increases in both fat and carbohydrate oxidation, as respiratory quotient (RQ) did not differ from placebo. In a follow-up study, Astrup *et al.* (8) supplemented obese patients with caffeine, over a 24-week period, while on an energy-restricted diet. Over time, there was a pronounced weight loss in individuals that consumed both the caffeine and placebo supplement. However, total weight loss did not differ between these two groups. In the same study, when ephedrine (a known stimulant of the SNS) was ingested alongside caffeine, weight loss was significantly greater than the placebo group (16.6 ± 6.8 kg vs. 13.2 ± 6.6 kg respectively), proposing a supra-additive effect on thermogenesis and body weight with a combination of two SNS stimulants. This was also shown more recently in a study in which 6-month ingestion of an ephedra/caffeine supplement promoted body weight (–5.3 ± 5.0 kg) and body fat (–4.3 ± 3.3 kg) reduction compared to placebo (9). The observation that ingestion of green tea–caffeine supplement did not show greater weight maintenance in a group of habitually high-caffeine consumers suggests that sensitivity to caffeine could be lost over a period of time (10). Thus, acute caffeine ingestion has the potential to enhance metabolism, but it may not be potent enough alone to act as a weight loss product if ingested over a longer period of time or in habitually high-caffeine consumers.

In summary, in some circumstances caffeine can increase energy expenditure (at rest) or fat oxidation (at rest and during low-intensity exercise), but these effects are less obvious during moderate- to high-intensity exercise. Caffeine on its own has not been shown to be effective in reducing body weight and if caffeine increases fat metabolism, the effects are generally small (<20%). Of course, it cannot be excluded that such changes still have significant practical value. For a complete review of the effects of caffeine on substrate metabolism, see Graham *et al.* (11).

L-carnitine

Carnitine in the body

L-carnitine (carnitine), a substance present in relatively large quantities in meat (the Latin word caro-carnis means meat or muscle), has received a lot of attention over the past 20 years. Carnitine is claimed to improve fat metabolism, reduce fat mass and increase muscle mass. Therefore, carnitine is often used to lose weight, reduce body fat and improve 'sharpness'. Endurance athletes use carnitine to increase the oxidation of fat and spare muscle glycogen.

L-carnitine is derived from red meats and dairy products in the diet and from endogenous production in the body. Even when dietary carnitine is insufficient, healthy humans produce enough from methionine and lysine to maintain functional body stores (for this reason, carnitine is not regarded as a vitamin, but as a vitamin-like substance). Carnitine is synthesized in the liver and kidney, which together contain only 1.6% of the ~27 g whole-body carnitine store. About 98% of the carnitine of the human body is present in skeletal and heart muscle. Skeletal muscle and the heart are dependent upon transport of carnitine through the circulation, which contains about 0.5% of whole-body carnitine.

Muscle takes carnitine up against a very large (~1,000-fold) concentration gradient (plasma carnitine is 40–60 μmol L^{-1}, and muscle carnitine is 4 mmol L^{-1} to 5 mmol L^{-1}) by a saturable active transport process. Carnitine is an end product of human metabolism and is only lost from the body via excretion in urine and stool. Daily losses are minimal (<60 mg d^{-1}) and are reduced to less than 20 mg d^{-1} on meat-free and carnitine-free diets (12). These minimal losses imply that the rate of endogenous biosynthesis, which is needed to maintain functional body stores, is also only about 20 mg d^{-1}. The amounts lost in stool can usually be ignored except after ingestion of oral supplements.

The role of carnitine in fat metabolism

L-carnitine plays an important role in fat metabolism. In the overnight fasted state and during exercise of low to moderate intensity, long-chain fatty acids are the main energy sources used by most tissues, including skeletal muscle. The primary function of L-carnitine is to transport long-chain fatty acids across the mitochondrial inner membrane, as the inner membrane is impermeable to both long-chain fatty acids and fatty acyl-CoA esters (12). Once inside the mitochondria, fatty acids can be degraded to acetyl-CoA through β-oxidation and proceed to the tricarboxylic acid cycle. Carnitine also plays an important role in maintaining the mitochondrial acetyl-CoA/CoASH ratio, which is a regulator of the flux through the pyruvate dehydrogenase (PDH) complex and thus carbohydrate metabolism (13,14).

Carnitine and fat metabolism

The belief that carnitine supplementation helps weight loss is based on the assumption that regular oral ingestion of carnitine increases the muscle carnitine concentration. Another assumption is that if carnitine concentration in the muscle increases, fat oxidation also increases, thus leading to a gradual loss of the body fat stores. Carefully conducted studies (15,16) have demonstrated clearly that oral carnitine ingestion (up to 6 g d^{-1} for 14 days) does not change the muscle carnitine concentration. Also, calculations based on enzyme kinetics indicate that human muscle in resting conditions has more than enough free carnitine to allow the enzyme carnitine palmitoyl transferase I (CPT I) to function at maximal activity. Claims that carnitine promotes weight loss therefore are not only unfounded but also theoretically impossible (17).

Recently, however, there has been some renewed interest in carnitine. Stephens *et al*. (18,19) showed that if muscle carnitine can be increased, this can reduce muscle glycogen breakdown and possibly enhance fat metabolism. They increased muscle carnitine by simultaneously increasing the insulin concentration (by insulin infusion or feeding large amounts of carbohydrate) and providing carnitine at the same time (by infusion or ingestion) (18,19). Wall *et al*. (20) recently supplemented athletes with 80 g of carbohydrate per day or 80 g of carbohydrate plus 2 g of L-carnitine L-tartrate for 24 weeks. They observed a reduction in glycogen breakdown during exercise at 50% VO_2max, and reported a reduced activation of the PDH complex at that intensity. However, at 80% VO_2max, which would be closer to most competitive events, these effects were not present.

While it is possible that carnitine may be elevated and may have some effects on fat metabolism after several months of ingesting carnitine in combination with a relatively large amount of carbohydrate, it is too early to draw any conclusions. If used for weight loss reasons, it seems counterproductive to consume large amounts of carbohydrate to increase insulin to make sure carnitine concentrations in the muscle are slightly elevated and might result in small improvements in fat oxidation in the long term. Potentially for athletes who have very high energy expenditures anyway and consume carnitine with their meals or energy drinks, it may be possible to raise muscle carnitine concentrations. Overall, however, the practical implications of this are currently unclear and there is not enough evidence to recommend carnitine for weight loss or to increase fat oxidation.

Forskolin

Forskolin is a diterpene of the labdane family that is produced by the Indian Coleus plant (*Coleus forskohlii*). Forskolin is often used to raise levels of cAMP in the study and research of cell physiology. The effects of forskolin on cAMP have been described in detail as early as the 1980s and can be observed in isolated cell preparations as well as in intact tissue. If this mechanism is also active *in vivo* in humans after forskolin ingestion, it could result in an activation of hormone-sensitive lipase, and increase lipolysis enabling greater fat oxidation.

It has been demonstrated that forskolin can stimulate lipolysis in adipose tissue in rats (21,22). There is only one study that investigated the effects of forskolin on body composition and metabolic rate in humans (23). In this study, 30 obese men were supplemented with forskolin (250 mg of a 10% forskolin extract twice a day) for 12 weeks. The authors concluded that forskolin ingestion resulted in favourable changes in body composition determined by dual-emission x-ray absorptiometry. Following forskolin supplementation body fat mass was significantly decreased by −11.23%, compared to −1.73% in the placebo group. This reduction in body fat mass, with forskolin ingestion, was accompanied with a significant reduction in body fat percentage from baseline (35.17 ± 8.03% to 31.03 ± 7.96%). Unfortunately, no measurements of fat metabolism were reported, although the authors did report that energy expenditure was not different between the forskolin-supplemented group and the placebo group. So although there is a theory that is promising, there is only one study at the present time and more work is required before forskolin can be recommended as a fat metabolism-enhancing substance.

Fucoxanthin

Fucoxanthin is a carotenoid found in edible brown seaweeds (*Undaria pinnatifida*). In animal studies it has been demonstrated that long-term fucoxanthin supplementation can result in weight loss. For example, a study by Maeda *et al*. (24) demonstrated that fucoxanthin (0.4% of body mass) or extract that contained fucoxanthin resulted in a significant reduction in white adipose tissue after 4 weeks. The mechanisms may be related to an up-regulation of mitochondrial uncoupling protein 1 (UCP1) (24), which would result in an increase in resting energy expenditure. Other potential mechanisms include a suppression of adipocyte differentiation and lipid accumulation by inhibiting glycerol-3-phosphate dehydrogenase activity (25) or down-regulation of peroxisome proliferator-activated receptor-γ (PPAR-γ) responsible for adipogenic gene expression (25). However, a quick calculation would reveal that 0.4% body mass in human would equate to 280 g of fucoxanthin per day for an average 70-kg person and would be considered a totally unrealistic dose. However, recently a Russian study was published that used fucoxanthin for the first time in humans (26). In this study, the effects of a product were investigated that contained brown marine algae fucoxan-

thin as well as pomegranate seed oil. Daily administration of 600 mg of an extract that contained 2.4 mg fucoxanthin per day resulted in a significant weight loss compared with placebo after 16 weeks. The authors also reported increases in resting energy expenditure, decreases in body and liver fat content and improvements in the plasma lipid profile. Weight reductions were about 5 kg more in the supplemented group compared with the placebo group (the placebo group also lost a small amount of weight). However, caution must be exercised when interpreting these findings. At least one of the authors is working for the company that holds the patents for fucoxanthin. At this point in time this is the only human study and therefore more studies need to be conducted to confirm any effects of fucoxanthin in humans.

Kelp

Kelp is brown seaweed, and the active ingredient with respect to fat metabolism is believed to be fucoxanthin, which has already been discussed above. Other than the fucoxanthin studies discussed, there appear to be no studies that have investigated the effect of a kelp supplement on fat metabolism.

Tea

Tea originates from the leaves of *Camellia Sinensis L*, a species of the Theaceae family. The leaves are processed as green, oolong and black tea, differing in composition because of differences in the fermentation process. Green tea is processed from non-oxidized/non-fermented leaves, therefore contains high quantities of catechin polyphenols, which are absent in black tea. The most abundant of the catechin polyphenols are epicatechin, epigallocatechin, epicatechin-3-gallate and epigallocatechin-3-gallate (EGCG), the latter being the most abundant and pharmacologically active. Oolong tea leaves vary in the degree of fermentation (10–70%) and are often referred to as partially oxidized but contain the same polyphenol catechins as green tea. Black tea leaves contain many compounds including polyphenols such as theaflavins and thearubigins, which are both products of full oxidation of flavan-3-ols during fermentation. Caffeine is present in all teas regardless of the fermentation process. In recent years tea has received a growing interest in the literature partly because of its potential ability to stimulate fat oxidation.

Catechins, more specifically EGCG, are thought to stimulate fat oxidation through direct inhibition of catechol-O-methyltransferase, an enzyme that degrades norepinephrine (27). This acute increase in SNS stimulation results in elevated concentrations of catecholamines, thus potentially increasing fatty acid mobilization and oxidation. Although this is the mechanism that is very often referred to, there is no convincing evidence.

Acute effects of green tea

In a short-term human study, encapsulated green tea extract (GTE) plus caffeine (120 mg GTE/50 mg caffeine), caffeine (50 mg) or placebo were consumed three times a day on three separate occasions (28). Relative to placebo, consumption of GTE/caffeine significantly increased 24-h fat oxidation (76.2 ± 10.6 and 103 ± 13 g respectively). Interestingly, 24-h fat oxidation, seen following ingestion of GTE, exceeded that which was observed when subjects received caffeine alone (20% higher). These findings, determined using a respiratory chamber, suggest that green tea has fat metabolism-enhancing properties independent of its caffeine content (28). Similar observations were found when oolong tea (EGCG + caffeine, 244 and 270 mg d^{-1} respectively) was consumed three days prior to 24-h calorimetry measurements (29). These two studies seem to suggest that the consumption of a tea extract containing moderate quantities of EGCG (244–270 mg d^{-1}) can augment fat oxidation at rest. It is generally thought that the stimulating effect on fat metabolism is a function of the EGCG content. However, when subjects ingested GTE supplements with differing EGCG content (270–1,200 mg) with a relatively high dose of caffeine (600 mg) (30), no effect on fat metabolism was found.

Gregersen *et al.* (31) found no effect of GTE ingestion, with varying levels of active ingredients, on fat metabolism. In this study, authors administered capsules containing caffeine enriched with either EGCG or a mixture of all catechins, in addition to a caffeine and placebo control. Fat oxidation rates during a 13-h period in a respiratory chamber did not differ following supplementation of a GTE or caffeine compared to placebo (31). However, this finding might be explained by the supplementation protocol employed. Subjects received low doses (40–101 mg/capsule EGCG) intermittently throughout the day. A dosage below 100 mg EGCG per administration could be beneath the threshold to elicit the substrate enhancing effect seen in other studies.

Hursel *et al.* (32) recently conducted a meta-analysis on four articles which investigated acute catechin–caffeine supplementation on resting fat oxidation. Of the four studies, three found an increase in fat oxidation rates over a 24-h period, which resulted in the authors reporting that a catechin–caffeine mixture can increase rates by 16%. Thus, it seems that GTE consumption does have the potential to increase fat oxidation at rest. However, the literature is still inconclusive with respect to the most effective supplementation protocol, the optimal catechin dosage and the inclusion/exclusion of caffeine.

Chronic effects of green tea

The above studies provided a green tea supplement and performed measurements in the following 24 h. However, it is possible that the supplements are more effective when supplemented over a longer period of time. Harada *et al.* (33) supplemented the diet of 12 men with a high (593 mg d^{-1}) or low (78 mg d^{-1}) catechin beverage over a 12-week period. Excretion of labelled CO_2 ($^{13}CO_2$) of a ^{13}C-labelled fatty meal was significantly increased in the high-catechin group at week 12 compared to baseline measurements. In another study, the RQ of subjects ingesting a GTE (~130 mg d^{-1}) was significantly lower after 8 weeks than placebo (0.81 and 0.83 respectively). However, this effect had diminished by week 12 (34).

Long-term GTE supplementation has also been reported to have positive effects on reducing and maintaining body weight (35–39). Westerterp-Plantenga *et al.* (10) administered a GTE to subjects during a weight maintenance period of 3 months (270 mg d^{-1} EGCG). Compared to placebo, body weight regain was significantly smaller in the group that received the GTE but only in those who were low habitual caffeine consumers. In this same cohort of subjects, RQ was significantly lower in this weight maintenance period. In contrast, Diepvens *et al.* (40) found that GTE (1,125 mg d^{-1} catechins) ingested alongside a low-energy diet had no effect on any body composition parameters or post-absorptive RQ in moderate caffeine users. Substantial weight loss of 14 kg was found when subjects on a hypocaloric diet consumed 300 mg d^{-1} of catechins, compared to 5 kg lost in the diet-only group (41). Compared to other studies, catechin intake was low and the authors did not report the levels of circulating plasma catechins, therefore the results of this study should be interpreted with caution. However, a recent meta-analysis found a favourable effect of catechin ingestion on weight loss and weight maintenance. It was estimated from results of 11 studies that subjects in a green tea intervention group lost on average 1.31 kg more weight, over a 12- to 13-week supplementation period, than the control group. Furthermore, the effect size was larger in populations with a low habitual caffeine intake compared to moderate-to-high. Interestingly, the review also highlighted the interaction of ethnicity as a moderator. Studies that used Asian subjects had a larger effect size than Caucasian (42). The equivocal findings in the area of GTE supplementation and weight loss may be due to confounding variables such as habitual caffeine intake and ethnicity. These factors should be taken into account when conducting future studies.

In animal models green tea seems to have a consistent effect on body weight. For example, Lee *et al.* (43) demonstrated that in high-fat diet-induced obese mice, diets supplemented with EGCG resulted in reductions of body weight and mass of adipose tissues at various sites in a dose-dependent manner. In the epididymal white adipose tissue of EGCG diet-fed mice, the mRNA levels of adipogenic genes such as PPAR-γ, CCAAT enhancer-binding protein-α (C/EBP-α), regulatory element-binding protein-1c (SREBP-1c), adipocyte fatty acid-binding protein (aP2), lipoprotein lipase and fatty acid synthase were significantly decreased. However, the mRNA levels of CPT-1, uncoupling protein 2 (UCP2), as well as lipolytic genes such as hormone-sensitive lipase and adipose triglyceride lipase, were significantly increased. In another study GTE ingestion increased the expression of PPAR-γ and CPT-1 (44). Although this increased expression of proteins involved in fat metabolism has not consistently been found (45), the data seem to suggest that chronic GTE supplementation can cause some adaptations in fat metabolism. An increase in the aforementioned genes, in humans, would result in a more efficient and augmented fat oxidation, which ultimately could result in weight loss.

Green tea and fat oxidation during exercise

Exercise increases metabolic rate several fold and moderate-intensity exercise has been found to elicit maximal fat oxidation rates (45–65% VO_2max) (46,47). A few studies have systematically investigated the interactions between GTE and substrate metabolism during exercise. Animal studies have consistently shown that when GTE is supplemented into the diet, fat oxidation rates are significantly increased during exercise (48–50).

Venables *et al.* (51) investigated the effects of acute GTE ingestion (day before and just before exercise ~366 mg d^{-1} EGCG) on substrate metabolism during moderate-intensity exercise in humans. Fat oxidation rates, during a 30-min cycling at 60% VO_2max, were significantly higher (17%) following GTE ingestion compared to placebo. Similar effects were seen with chronic feeding. When 218 mg d^{-1} of EGCG was ingested, during a 3-month exercise training period, 24% higher fat oxidation rates were found during exercise compared to placebo (52). However, this effect was not seen when a much lower dose of GTE (70 mg d^{-1} EGCG) was administered over 3 weeks (53). These findings suggest that higher doses of GTE (EGCG) may have the potential to increase fat oxidation during exercise.

Few studies have investigated the effects of chronic green tea ingestion in combination with an exercise intervention. Murase *et al.* (49) subjected mice to a 10-week intervention of dietary GTE ingestion (0.2% and 0.5% GTE) in combination with exercise training. Following the intervention, β-oxidation activity significantly increased in the GTE + exercise group above that of exercise alone (74% and 36% respectively). In a follow-up study, mRNA expression of enzymes involved in fat metabolism was

measured. A marked increase was observed in fatty acid translocase in the mice that ingested 0.5% and 0.2% EGCG. A recent study investigated the long-term (10-week) effects of GTE consumption in combination with a training regimen in humans (54). Chronic ingestion of a GTE supplement lowered the respiratory exchange ratio (RER) during a 90-min cycle exercise bout from 0.84 to 0.82. Although highly speculative, these results taken together suggest that chronic GTE supplementation in combination with exercise may augment fat metabolism by increased expression of certain fat metabolism enzymes.

Conclusion

Green tea has the potential to increase fat metabolism at rest, also during exercise, and may help to lose body fat and body weight. As with caffeine, the effects appear to be relatively small. The underlying mechanisms for the metabolic effects of GTE are incompletely understood and so are the practical implications.

Chromium

An enormous marketing hype has surrounded this popular supplement over the past years, as it is said to be a 'muscle builder' and 'fat burner'. Chromium is a trace element that is present in foods such as brewer's yeast, American cheese, mushrooms and wheat germ, and it is considered an essential nutrient. Because of insufficient methods to assess chromium status, the US Food and Nutrition Board could not establish an recommended daily allowance for chromium. Instead, an adequate intake was agreed: 20–30 μg (55). Anderson and Kozlovsky (56) suggested that many people in the USA are not ingesting even 50 pg d^{-1} of chromium. Chromium is marketed predominantly in the form of chromium picolinate, although chromium nicotinate and chromium chloride supplements also exist. Picolinic acid is an organic compound that binds chromium and is thought to enhance the absorption and transport (57).

Evans (57) was the first to report that ingesting chromium increased lean tissue in exercising humans. In those studies, untrained college students and trained football players were given 200 μg of chromium picolinate or a placebo each day for 40 to 42 d, while they were on a resistance training programme. Those subjects who took chromium supplements gained significantly more lean body mass compared with the placebo group. However, lean body mass was only estimated from circumference measures, and the changes observed were small, so measurement error could have influenced the results.

Subsequent studies (58–62) have not confirmed the results of Evans (57). In these carefully controlled studies, which used more sophisticated techniques to measure body composition, no effects were found in lean body mass (58,59). In one of the studies Lukaski *et al.* (62) concluded that under conditions of controlled energy intake, chromium supplementation of women did not independently influence body weight or composition. Thus, claims that supplementation of 200 μg of chromium promotes weight loss and body composition changes are not supported.

Thus, the majority of the studies show that chromium supplements are not effective in increasing lean body mass. Based upon laboratory studies of cultured cells, chromium picolinate was suggested to accumulate in cells and cause chromosome damage (63). Although this finding has not been confirmed in human studies (64), caution must be exercised in the use of chromium supplements.

Conjugated linoleic acid

Conjugated linoleic acids (CLA) are a group of positional and geometric isomers of the omega-6 essential fatty acid linoleic acid. *Cis-9,trans-11* (*c9,t11*) is the major isomer found in foods such as ruminant meats (beef and lamb) and dairy products (milk and cheese), whereas the commercial preparations contain equal quantities of *c9,t11* and *trans-10,cis-12* (*t10,c12*). It has been suggested that CLA can act as an anti-obesity agent through its ability to decrease energy and food intake, decrease lipogenesis and increase energy expenditure, lipolysis and fat oxidation.

Alterations in body mass, composition and fat oxidation

Rodent studies have observed alterations in body weight and composition when the *ad libitum* diet is supplemented with CLA. Mice supplemented with 0.5% CLA exhibited 60% reductions in body fat and 14% increases in lean body mass compared to controls (65). Similarly, when young rats were supplemented with 1% CLA for 4 weeks, body weight gain was significantly reduced with reductions of 44% in fat pad size (66). Zucker diabetic fatty rats supplemented with 1.5% CLA also had significantly reduced body weight (67).

On the basis of the results from animal studies, there is potential for CLA to have weight loss effects in humans. Malpuech-Brugère *et al.* (68) conducted a study investigating the effects of two CLA isomers (*c9,t11* and *t10,c12*) on body fat mass. After a 6-week run-in period, consuming high oleic sunflower oil (3 g) daily, overweight healthy men were allocated into one of five groups. These five groups included daily consumption of high (3 g) and low (1.5 g) doses of *c9,t11* and *t10,c12* daily for 18 weeks, plus a placebo control group. Following the intervention period there were no significant changes, among all five of the treatments groups, in body fat mass and other body composition parameters (body mass index, weight, per cent

body fat). More recent studies where chronic CLA supplementation has been administered, as a mixture containing both *c9,t11* and *t10,c12*, have found favourable effects on body composition. Gaullier and colleagues found a significant reduction in body fat mass after 6 (–3.4%) (69) and 12 months (–8.7% CLA-TG, –6.9% CLA-FFA) (70) of CLA supplementation compared to placebo. The interest in CLA, as a body fat regulator, has resulted in many studies differing in CLA isomers, dose and study duration. Whigham *et al.* (71) performed a meta-analysis of 18 studies which had all investigated the influence of CLA on improving body composition. Based on three studies, a conclusion cannot be made on supplementation of single CLA isomers (*c9,t11* and *t10,c12*) and their potential to reduce body fat. However, this meta-analysis concluded that 3.2 g CLA per day is effective in producing modest fat loss (0.05 ± 0.05 kg per week; $P < 0.001$).

Mechanisms

Although it has been shown that CLA supplementation can lead to reductions in food intake (72), this is usually not sufficient to account for the changes in body mass and even without reductions in food intake, reductions in body fat mass are apparent (65). CLA supplementation can increase energy expenditure (73) to a level sufficient to induce body fat loss and although it has been observed that CLA supplementation can increase UCP2 expression, this is not thought to be a valid mechanism. Rodent studies have provided evidence that the alterations in body composition and fat oxidation were associated with increases in CPT activity in brown adipose tissue, skeletal muscle and liver by up to 2.5 times that of the control, with increased rates of lipolysis being evident (65,66).

In addition to the actions of CLA on fat oxidation and weight loss, there are claims that CLA can benefit those with impaired glucose tolerance. Initial studies using Zucker diabetic fatty rats with a feeding schedule of 1.5% CLA for 14 d have shown normalized glucose tolerance and attenuated fasting hyperinsulinemia and plasma fatty acid concentrations (67). This effect appears to occur at the level of the adipocyte via the activation of PPAR-γ. The observed response is also isomer-specific with the *t10,c12* isomer being more effective than the *c9,t11* isomer (74).

While the effects of CLA supplementation in rodents appear positive, the effects in humans are inconsistent. In patients with non-insulin-dependent diabetes mellitus, 6 g d^{-1} of CLA for 2 weeks was associated with a correlation between body weight and plasma concentrations of the isomer *t10,c12* (75). However, in healthy obese and non-obese men and women, no change in body weight was observed (76,77). Furthermore, 3-month daily ingestion of *c9,t11* (3 g d^{-1}) (78) and *t10,c12* (3.4 g d^{-1}) (79) has been found to significantly lower insulin sensitivity (–15% in both treatment groups) in overweight Caucasian men. As insulin resistance and obesity are associated with the metabolic syndrome, increasing the risk of life-threatening diseases, CLA may not be suitable as a weight-regulating supplement. The biological effects of CLA are isomer-dependent and *cis*-9,*trans*-11 and *trans*-10,*cis*-12 may have distinctly different effects. It is also likely that some effects are induced and/or enhanced by these isomers acting synergistically. It has been suggested that the *trans*-10,*cis*-12 isomer is responsible for reduction in body fat and is also referred to as the most effective isomer affecting blood lipids.

Conclusion

In conclusion, it would appear that the majority of information with regards to the effects of CLA on altering body weight and composition has been gained from experiments on animals. In human studies, modest fat loss may be achieved through long-term supplementation of ~3 g d^{-1} CLA. Future studies should also address the safety issues.

Taurine

Taurine was recently linked to increased fat metabolism. In a study by Rutherford *et al.* (80), it was investigated whether acute taurine ingestion before prolonged cycling would improve time-trial performance compared with a control trial and a placebo trial in which participants were told they received taurine but did not. Participants cycled at 67% VO_2max for 90 min followed by a time trial. One hour before the start of exercise, they ingested 1.66 g of taurine (or control or placebo). The authors observed no effects on performance, but interestingly they reported a 16% higher total fat oxidation over the 90-min exercise period with taurine ingestion compared with control and placebo. A closer look at the results reveals that although the authors reported an increase in fat oxidation with taurine, RER was not significantly different from control or placebo. It also appears that there is already a difference in fat oxidation at the start of exercise, and the difference seems to get smaller as exercise progresses. This could indicate that a difference already existed that was independent of taurine or that taurine ingested in the hour before exercise is particularly effective in increasing fat oxidation in the first minutes of exercise. The findings need to be confirmed but cannot be dismissed at this point.

The findings are seemingly in contrast to two earlier studies which reported no effects of taurine on fat oxidation (81,82). However, it could be argued that these studies also gave carbohydrate either immediately before exercise or during exercise, and this may have masked any effect that taurine might have had. Rutherford *et al.* (80) suggested that, in their study, the taurine might have had an

effect through adenylyl cyclase activation, increasing cAMP, thereby increasing lipolysis and fat oxidation.

Taken together, there is insufficient evidence that taurine has a stimulating effect on fat metabolism, but one well-conducted study suggests that it is warranted to further investigate a role for taurine.

Concluding remarks

For most supplements discussed here, there is a lack of scientific data. Based on the available data, caffeine and green tea have evidence that they indeed have some properties that enhance fat metabolism. However, effects in humans have generally been small and more consistent in low habitual caffeine consumers. For most other supplements, although some show potential to enhance fat metabolism, like CLA, conclusive evidence is lacking. The ever increasing list of fat-burning supplements is industry-driven and is likely to grow at a rate that is not and cannot be matched by a similar increase in scientific underpinning.

Conflict of Interest Statement

No conflict of interest was declared.

References

1. Costill DL, Dalsky GP, Fink WJ. Effects of caffeine ingestion on metabolism and exercise performance. *Med Sci Sports Exerc* 1978; **10**: 155–158.
2. Essig D, Costill DL, Van Handel PJ. Effects of caffeine ingestion on utilization of muscle glycogen and lipid during leg ergometer cycling. *Int J Sports Med* 1980; **1**: 86–90.
3. Leijten PA, van Breemen C. The effects of caffeine on the noradrenaline-sensitive calcium store in rabbit aorta. *J Physiol* 1984; **357**: 327–339.
4. Acheson KJ, Zahorska-Markiewicz B, Pittet P, Anantharaman K, Jequier E. Caffeine and coffee: their influence on metabolic rate and substrate utilization in normal weight and obese individuals. *Am J Clin Nutr* 1980; **33**: 989–997.
5. Dulloo AG, Geissler CA, Horton T, Collins A, Miller DS. Normal caffeine consumption: influence on thermogenesis and daily energy expenditure in lean and postobese human volunteers. *Am J Clin Nutr* 1989; **49**: 44–50.
6. Hollands MA, Arch JR, Cawthorne MA. A simple apparatus for comparative measurements of energy expenditure in human subjects: the thermic effect of caffeine. *Am J Clin Nutr* 1981; **34**: 2291–2294.
7. Astrup A, Toubro S, Cannon S, Hein P, Breum L, Madsen J. Caffeine: a double-blind, placebo-controlled study of its thermogenic, metabolic, and cardiovascular effects in healthy volunteers. *Am J Clin Nutr* 1990; **51**: 759–767.
8. Astrup A, Buemann B, Christensen NJ, Toubro S, Thorbek G, Victor OJ *et al*. The effect of ephedrine/caffeine mixture on energy expenditure and body composition in obese women. *Metabolism* 1992; **41**: 686–688.
9. Boozer CN, Daly PA, Homel P, Solomon JL, Blanchard D, Nasser JA *et al*. Herbal ephedra/caffeine for weight loss: a 6-month randomized safety and efficacy trial. *Int J Obes Relat Metab Disord* 2002; **26**: 593–604.
10. Westerterp-Plantenga MS, Lejeune MP, Kovacs EM. Body weight loss and weight maintenance in relation to habitual caffeine intake and green tea supplementation. *Obes Res* 2005; **13**: 1195–1204.
11. Graham TE, Battram DS, Dela F, El-Sohemy A, Thong FS. Does caffeine alter muscle carbohydrate and fat metabolism during exercise? *Appl Physiol Nutr Metab* 2008; **33**: 1311–1318.
12. Bremer J. Carnitine – metabolism and functions. *Physiol Rev* 1983; **63**: 1420–1479.
13. Constantin-Teodosiu D, Carlin JI, Cederblad G, Harris RC, Hultman E. Acetyl group accumulation and pyruvate dehydrogenase activity in human muscle during incremental exercise. *Acta Physiol Scand* 1991; **143**: 367–372.
14. Timmons JA, Poucher SM, Constantin-Teodosiu D, Worrall V, Macdonald IA, Greenhaff PL. Increased acetyl group availability enhances contractile function of canine skeletal muscle during ischemia. *J Clin Invest* 1996; **97**: 879–883.
15. Barnett C, Costill DL, Vukovich MD, Cole KJ, Goodpaster BH, Trappe SW *et al*. Effect of L-carnitine supplementation on muscle and blood carnitine content and lactate accumulation during high-intensity sprint cycling. *Int J Sport Nutr* 1994; **4**: 280–288.
16. Vukovich MD, Costill DL, Fink WJ. Carnitine supplementation: effect on muscle carnitine and glycogen content during exercise. *J Appl Physiol* 1994; **26**: 1122–1129.
17. Wagenmakers AJM. *Nutritional Supplements: Effects on Exercise Performance and Metabolism*. Lamb DR, Murray R (eds). Cooper Publishing Group: Carmel, IN, 1999.
18. Stephens FB, Constantin-Teodosiu D, New GPL. insights concerning the role of carnitine in the regulation of fuel metabolism in skeletal muscle. *J Physiol* 2007; **581**: 431–444.
19. Stephens FB, Constantin-Teodosiu D, Laithwaite D, Simpson EJ, Greenhaff PL. Insulin stimulates L-carnitine accumulation in human skeletal muscle. *FASEB J* 2006; **20**: 377–379.
20. Wall BT, Stephens FB, Constantin-Teodosiu D, Marimuthu K, Macdonald IA, Greenhaff PL. Chronic oral ingestion of L-carnitine and carbohydrate increases muscle carnitine content and alters muscle fuel metabolism during exercise in humans: the dual role of muscle carnitine in exercise metabolism. *J Physiol* 2011; **589**: 963–973.
21. Litosch I, Hudson TH, Mills I, Li SY, Fain JN. Forskolin as an activator of cyclic AMP accumulation and lipolysis in rat adipocytes. *Mol Pharmacol* 1982; **22**: 109–115.
22. Ho R, Shi QH. Forskolin as a novel lipolytic agent. *Biochem Biophys Res Commun* 1982; **107**: 157–164.
23. Godard MP, Johnson BA, Richmond SR. Body composition and hormonal adaptations associated with forskolin consumption in overweight and obese men. *Obes Res* 2005; **13**: 1335–1343.
24. Maeda H, Hosokawa M, Sashima T, Funayama K, Miyashita K. Fucoxanthin from edible seaweed, Undaria pinnatifida, shows antiobesity effect through UCP1 expression in white adipose tissues. *Biochem Biophys Res Commun* 2005; **332**: 392–397.
25. Maeda H, Hosokawa M, Sashima T, Takahashi N, Kawada T, Miyashita K. Fucoxanthin and its metabolite, fucoxanthinol, suppress adipocyte differentiation in 3T3-L1 cells. *Int J Mol Med* 2006; **18**: 147–152.
26. Abidov M, Ramazanov Z, Seifulla R, Grachev S. The effects of Xanthigen in the weight management of obese premenopausal women with non-alcoholic fatty liver disease and normal liver fat. *Diabetes Obes Metab* 2010; **12**: 72–81.

27. Borchardt RT, Huber JA. Catechol O-methyltransferase. 5. Structure-activity relationships for inhibition by flavonoids. *J Med Chem* 1975; **18**: 120–122.
28. Dulloo AG, Duret C, Rohrer D, Girardier L, Mensi N, Fathi M *et al*. Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. *Am J Clin Nutr* 1999; **70**: 1040–1045.
29. Rumpler W, Seale J, Clevidence B, Judd J, Wiley E, Yamamoto S *et al*. Oolong tea increases metabolic rate and fat oxidation in men. *J Nutr* 2001; **131**: 2848–2852.
30. Berube-Parent S, Pelletier C, Dore J, Tremblay A. Effects of encapsulated green tea and Guarana extracts containing a mixture of epigallocatechin-3-gallate and caffeine on 24 h energy expenditure and fat oxidation in men. *Br J Nutr* 2005; **94**: 432–436.
31. Gregersen NT, Bitz C, Krog-Mikkelsen I, Hels O, Kovacs EM, Rycroft JA *et al*. Effect of moderate intakes of different tea catechins and caffeine on acute measures of energy metabolism under sedentary conditions. *Br J Nutr* 2009; **102**: 1187–1194.
32. Hursel R, Viechtbauer W, Dulloo AG, Tremblay A, Tappy L, Rumpler W *et al*. The effects of catechin rich teas and caffeine on energy expenditure and fat oxidation: a meta-analysis. *Obes Rev* 2011; **12**: e573–e581.
33. Harada U, Chikama A, Saito S, Takase H, Nagao T, Hase T *et al*. Effects of the long term ingestion of tea catechins on energy expenditure and dietary fat oxidation in healthy subjects. *J Health Sci* 2005; **51**: 248–252.
34. Auvichayapat P, Prapochanung M, Tunkamnerdthai O, Sripanidkulchai BO, Auvichayapat N, Thinkhamrop B *et al*. Effectiveness of green tea on weight reduction in obese Thais: a randomized, controlled trial. *Physiol Behav* 2008; **93**: 486–491.
35. Chantre P, Lairon D. Recent findings of green tea extract AR25 (Exolise) and its activity for the treatment of obesity. *Phytomedicine* 2002; **9**: 3–8.
36. Nagao T, Hase T, Tokimitsu I. A green tea extract high in catechins reduces body fat and cardiovascular risks in humans. *Obesity (Silver Spring)* 2007; **15**: 1473–1483.
37. Hill AM, Coates AM, Buckley JD, Ross R, Thielecke F, Howe PR. Can EGCG reduce abdominal fat in obese subjects? *J Am Coll Nutr* 2007; **26**: 396S–402S.
38. Nagao T, Komine Y, Soga S, Meguro S, Hase T, Tanaka Y *et al*. Ingestion of a tea rich in catechins leads to a reduction in body fat and malondialdehyde-modified LDL in men. *Am J Clin Nutr* 2005; **81**: 122–129.
39. Wang H, Wen Y, Du Y, Yan X, Guo H, Rycroft JA *et al*. Effects of catechin enriched green tea on body composition. *Obesity (Silver Spring)* 2010; **18**: 773–779.
40. Diepvens K, Kovacs EM, Nijs IM, Vogels N, Westerterp-Plantenga MS. Effect of green tea on resting energy expenditure and substrate oxidation during weight loss in overweight females. *Br J Nutr* 2005; **94**: 1026–1034.
41. Di Pierro F, Menghi AB, Barreca A, Lucarelli M, Calandrelli A. Greenselect Phytosome as an adjunct to a low-calorie diet for treatment of obesity: a clinical trial. *Altern Med Rev* 2009; **14**: 154–160.
42. Hursel R, Viechtbauer W, Westerterp-Plantenga MS. The effects of green tea on weight loss and weight maintenance: a meta-analysis. *Int J Obes (Lond)* 2009; **33**: 956–961.
43. Lee MS, Kim CT, Kim Y. Green tea (-)-epigallocatechin-3-gallate reduces body weight with regulation of multiple genes expression in adipose tissue of diet-induced obese mice. *Ann Nutr Metab* 2009; **54**: 151–157.
44. Chen N, Bezzina R, Hinch E, Lewandowski PA, Cameron-Smith D, Mathai ML *et al*. Green tea, black tea, and epigallocatechin modify body composition, improve glucose tolerance, and differentially alter metabolic gene expression in rats fed a high-fat diet. *Nutr Res* 2009; **29**: 784–793.
45. Kim HJ, Jeon SM, Lee MK, Jung UJ, Shin SK, Choi MS. Antilipogenic effect of green tea extract in C57BL/6J-Lep ob/ob mice. *Phytother Res* 2009; **23**: 467–471.
46. Achten J, Gleeson M, Jeukendrup AE. Determination of the exercise intensity that elicits maximal fat oxidation. *Med Sci Sports Exerc* 2002; **34**: 92–97.
47. Achten J, Jeukendrup AE. Maximal fat oxidation during exercise in trained men. *Int J Sports Med* 2003; **24**: 603–608.
48. Shimotoyodome A, Haramizu S, Inaba M, Murase T, Tokimitsu I. Exercise and green tea extract stimulate fat oxidation and prevent obesity in mice. *Med Sci Sports Exerc* 2005; **37**: 1884–1892.
49. Murase T, Haramizu S, Shimotoyodome A, Nagasawa A, Tokimitsu I. Green tea extract improves endurance capacity and increases muscle lipid oxidation in mice. *Am J Physiol Regul Integr Comp Physiol* 2005; **288**: R708–R715.
50. Murase T, Haramizu S, Shimotoyodome A, Tokimitsu I, Hase T. Green tea extract improves running endurance in mice by stimulating lipid utilization during exercise. *Am J Physiol Regul Integr Comp Physiol* 2006; **290**: R1550–R1556.
51. Venables MC, Hulston CJ, Cox HR, Jeukendrup AE. Green tea extract ingestion, fat oxidation, and glucose tolerance in healthy humans. *Am J Clin Nutr* 2008; **87**: 778–784.
52. Ota N, Soga S, Shimotoyodome A, Haramizu S, Inaba M, Murase T *et al*. Effects of combination of regular exercise and tea catechins intake on energy expenditure in humans. *J Health Sci* 2005; **51**: 233–236.
53. Eichenberger P, Colombani PC, Mettler S. Effects of 3-week consumption of green tea extracts on whole-body metabolism during cycling exercise in endurance-trained men. *Int J Vitam Nutr Res* 2009; **79**: 24–33.
54. Ichinose T, Nomura S, Someya Y, Akimoto S, Tachiyashiki K, Imaizumi K. Effect of endurance training supplemented with green tea extract on substrate metabolism during exercise in humans. *Scand J Med Sci Sports* 2010; **21**: 598–605.
55. NAoSIo (ed.). *Dietary Reference Intakes: Recommended Intakes for Individuals Medicine*. The National Academies Press: Washington, D.C., 2005.
56. Anderson RA, Kozlovsky AS. Chromium intake, absorption and excretion of subjects consuming self-selected diets. *Am J Clin Nutr* 1985; **41**: 1177–1183.
57. Evans GW. The effect of chromium picolinate on insulin controlled parameters in humans. *Int J Biosoc Med Res* 1989; **11**: 163–180.
58. Clancy SP, Clarkson PM, DeCheke ME, Nosaka K, Freedson PS, Cunningham JJ *et al*. Effects of chromium picolinate supplementation on body composition, strength, and urinary chromium loss in football players. *Int J Sport Nutr* 1994; **4**: 142–153.
59. Hallmark MA, Reynolds TH, DeSouza CA, Dotson CO, Anderson RA, Rogers MA. Effects of chromium and resistive training on muscle strength and body composition. *Med Sci Sports Exerc* 1996; **28**: 139–144.
60. Hasten DL, Morris GS, Ramanadham S, Yarasheski KE. Isolation of human skeletal muscle myosin heavy chain and actin for measurement of fractional synthesis rates. *Am J Physiol* 1998; **275**: E1092–E1099.
61. Lukaski HC, Bolonchuk WW, Siders WA, Milne DB. Chromium supplementation and resistance training: effects on body composition, strength, and trace element status of men (see comments). *Am J Clin Nutr* 1996; **63**: 954–965.

62. Lukaski HC, Siders WA, Penland JG. Chromium picolinate supplementation in women: effects on body weight, composition, and iron status. *Nutrition* 2007; **23**: 187–195.
63. Stearns DM, Belbruno JJ, Wetterhahn KE. A prediction of chromium(III) accumulation in humans from chromium dietary supplements. *FASEB J* 1995; **9**: 1650–1657.
64. McCarty MF. Chromium(III) picolinate (letter). *FASEB J* 1996; **10**: 365–369.
65. Park Y, Albright KJ, Liu W, Storkson JM, Cook ME, Pariza MW. Effect of conjugated linoleic acid on body composition in mice. *Lipids* 1997; **32**: 853–858.
66. Rahman SM, Wang Y, Yotsumoto H, Cha J, Han S, Inoue S *et al*. Effects of conjugated linoleic acid on serum leptin concentration, body-fat accumulation, and beta-oxidation of fatty acid in OLETF rats. *Nutrition* 2001; **17**: 385–390.
67. Houseknecht KL, Vanden Heuvel JP, Moya-Camarena SY, Portocarrero CP, Peck LW, Nickel KP *et al*. Dietary conjugated linoleic acid normalizes impaired glucose tolerance in the Zucker diabetic fatty fa/fa rat. *Biochem Biophys Res Commun* 1998; **244**: 678–682.
68. Malpuech-Brugère C, Verboeket WP, Mensink RP, Arnal MA, Morio B, Brandolini M *et al*. Effects of two conjugated linoleic acid isomers on body fat mass in overweight humans. *Obes Res* 2004; **12**: 591–598.
69. Gaullier JM, Halse J, Hoivik HO, Hoye K, Syvertsen C, Nurminiemi M *et al*. Six months supplementation with conjugated linoleic acid induces regional-specific fat mass decreases in overweight and obese. *Br J Nutr* 2007; **97**: 550–560.
70. Gaullier JM, Halse J, Hoye K, Kristiansen K, Fagertun H, Vik H *et al*. Conjugated linoleic acid supplementation for 1 year reduces body fat mass in healthy overweight humans. *Am J Clin Nutr* 2004; **79**: 1118–1125.
71. Whigham LD, Watras AC, Schoeller DA. Efficacy of conjugated linoleic acid for reducing fat mass: a meta-analysis in humans. *Am J Clin Nutr* 2007; **85**: 1203–1211.
72. Park Y, Albright KJ, Storkson JM, Liu W, Cook ME, Pariza MW. Changes in body composition in mice during feeding and withdrawal of conjugated linoleic acid. *Lipids* 1999; **34**: 243–248.
73. West DB, Blohm FY, Truett AA, DeLany JP. Conjugated linoleic acid persistently increases total energy expenditure in AKR/J mice without increasing uncoupling protein gene expression. *J Nutr* 2000; **130**: 2471–2477.
74. Ryder JW, Portocarrero CP, Song XM, Cui L, Yu M, Combatsiaris T *et al*. Isomer-specific antidiabetic properties of conjugated linoleic acid. Improved glucose tolerance, skeletal muscle insulin action, and UCP-2 gene expression. *Diabetes* 2001; **50**: 1149–1157.
75. Belury MA, Mahon A, Banni S. The conjugated linoleic acid (CLA) isomer, t10c12-CLA, is inversely associated with changes in body weight and serum leptin in subjects with type 2 diabetes mellitus. *J Nutr* 2003; **133**: 257S–260S.
76. Blankson H, Stakkestad JA, Fagertun H, Thom E, Wadstein J, Gudmundsen O. Conjugated linoleic acid reduces body fat mass in overweight and obese humans. *J Nutr* 2000; **130**: 2943–2948.
77. Smedman A, Vessby B. Conjugated linoleic acid supplementation in humans – metabolic effects. *Lipids* 2001; **36**: 773–781.
78. Riserus U, Vessby B, Arnlov J, Basu S. Effects of cis-9,trans-11 conjugated linoleic acid supplementation on insulin sensitivity, lipid peroxidation, and proinflammatory markers in obese men. *Am J Clin Nutr* 2004; **80**: 279–283.
79. Riserus U, Vessby B, Arner P, Zethelius B. Supplementation with trans10cis12-conjugated linoleic acid induces hyperproinsulinaemia in obese men: close association with impaired insulin sensitivity. *Diabetologia* 2004; **47**: 1016–1019.
80. Rutherford JA, Spriet LL, Stellingwerff T. The effect of acute taurine ingestion on endurance performance and metabolism in well-trained cyclists. *Int J Sport Nutr Exerc Metab* 2010; **20**: 322–329.
81. Galloway SD, Talanian JL, Shoveller AK, Heigenhauser GJ, Spriet LL. Seven days of oral taurine supplementation does not increase muscle taurine content or alter substrate metabolism during prolonged exercise in humans. *J Appl Physiol* 2008; **105**: 643–651.
82. Jester I, Grigereit A, Bernhardt M, Heil S, Banzer W. Effects of ingesting a taurine-enriched, caffeine containing drink on performance and haemodynamics in acyclic trained athletes. *Amino Acids* 1997; **13**: 72–73.