Effects of Vegetarian Diets on Exercise Performance and Exercise-Induced Metabolic Changes.

By Attard Manuel

Abstract

Background: A multitude of studies have reported the potential benefits of a vegetarian diet in the general population; however, it is yet unclear whether these diets have an effect on exercise performance and whether they interact with the metabolic changes that occur as a result of exercise and the benefits derived from exercise. The most recent review paper published, which included mostly studies published pre-2004, concluded that it does not appear that these diets are either beneficial nor detrimental to exercise performance, but the lack of research available on the topic was highlighted.

Aim: To explore if recent studies have provided more evidence on whether a vegetarian diet affects exercise performance and exercise-induced metabolic changes and benefits.

Methods: A literature search using 6 electronic databases was carried out for full-text publications in the English language published from 2004 to 2013 (both years inclusive). A possible 503 hits were identified, and after checking for relevance, 10 publications were included in the review.

Results: Vegetarian diets had no effect on exercise performance compared to omnivorous diets. Although vegetarian subjects had lower baseline creatine stores compared to non-vegetarians, creatine supplementation resulted in similar improvements in physical performance in the two diet groups. Overweight subjects who adhered to calorie-restricted vegetarian diets combined with exercise derived more benefits in terms of weight loss and metabolic parameters than subjects following a calorie-restricted standard diet combined with exercise. However, at 18 months most subjects in the former group were not adhering to the vegetarian restrictions, and all initial differences in outcomes were gone. On the other hand, in type 2 diabetics, a calorie-restricted vegetarian diet was found to be better adhered to, and more efficacious for controlling diabetes, than a standard diabetic diet. In these diabetics, exercise was found to confer more benefits in the vegetarian group than in the standard group.

Conclusion: Exercise performance is not affected by a vegetarian diet; however, exercise confers more benefits to type 2 diabetics following a calorie-restricted vegetarian diet than those following a calorie-restricted conventional diabetic diet.

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Background

'Vegetarianism' is an umbrella term for a spectrum of dietary restrictions that involve the avoidance of animal products. The term is usually used in the context of lacto-ovo-vegetarianism, as this is the most common type of diet that vegetarians follow (Cox, 2000). People who follow the lacto-ovo-vegetarian diet avoid meat, poultry, fish, and other seafood but include dairy and eggs. On the other hand, people who identify themselves as vegans avoid all animal products, including eggs, dairy, gelatine, honey and animal-derived additives (Venderly and Campbell, 2006).

The reasons why individuals choose to follow a vegetarian diet are several, and include ethical, environmental and health motivations. According to the National Diet and Nutrition Survey, 2% of the British population identifies itself as vegetarian (Department of Health, 2011), while a private sector report by Key Note estimated that 6% of the population are "mainly vegetarian", with 3% being completely vegetarian (Key Note, 2012). The health benefits of a vegetarian diet in the general population are well recognized (e.g. Key *et al*. (2006)), and according to the British Dietetic Association, "well planned vegetarian diets are appropriate for all stages of life" (Garton, 2011).

Even among athletes, a subgroup of the population that has traditionally regarded meat as a crucial constituent of their diet (Folgelholm, 2003), vegetarianism is on the rise (Berning, 2000). A survey among athletes competing in the Delhi 2010 Commonwealth Games found that 13% avoided red meat and 7% were vegetarian; with more athletes from non-Western regions following a vegetarian diet (Pelly and Burkhart, 2013). Whether vegetarian diets have an effect on athletic performance is not clear. As athletes tend to have higher nutritional requirements than the general population, it is reasonable to speculate that they are at higher risk of deficiencies than non-athletes, and omitting one or more food groups may increase the likelihood of these deficiencies. On the other hand, as vegetarians tend to have higher intakes of antioxidants and phytochemicals (Li, 2014), it can be argued that vegetarian diets could attenuate the immunosuppression that athletes tend to experience (Gleeson and Williams, 2013), and this could result in less illnesses and hence less disruptions to training.

Although a vegetarian diet is indeed restrictive, the 2009 position paper of the American Dietetic Association reported that vegetarian diets are suitable even to athletes (American Dietetic Association, 2009). This topic was further elaborated on in a joint position statement by Dieticians of Canada, the American College of Sports Medicine, and the American Dietetic Association (2009). In this paper, the importance of planning the diet was emphasised, and the main points highlighted were:

1. the importance of opting for quality sources of protein, especially for vegans whose diet can be limited in lysine, threonine, tryptophan or methionine;

2. a recommendation to increase protein intake by 10% owing to the decreased digestibility of plant protein (therefore recommending a protein intake for vegetarian athletes of 1.3-1.8g/kg bodyweight/day); and

3. the importance of ensuring a good intake of energy, fat (especially essential fatty acids), vitamins B12, riboflavin, and D, calcium, iron and zinc; which may be low in plant-based diets.

This position paper also noted that research investigating interaction effects of vegetarian diets and exercise was limited. In addition, most studies suffered from small sample sizes. The majority of the studies involved lacto-ovo-vegetarian subjects, with research on veganism and exercise performance being practically non-existent, possibly due to the fact that true veganism among athletes is rare. Extrapolating what is known about vegetarians, Fuhrman and Ferreri (2010) reported that beyond the potential nutritional shortcomings of a lacto-ovo-vegetarian diet, vegan athletes are at an increased risk of being deficient in iodine and docosahexaenoic acid.

Most review papers on vegetarianism and exercise dealt with the potential nutritional deficiencies that may be met on a vegetarian diet, and gave practical advice on how to tackle these (mainly: choosing a variety of foods, using fortified foods, and supplementation); few explored the effects of such diets on sports performance or on the metabolic changes associated with exercise. In the last decade (2004-2013), just one review paper focused on the effects of vegetarian diets on sports performance, and it re-iterated what older review papers (e.g. Nieman (1999)) had reported - that there was no concrete evidence that vegetarian diets were either beneficial or detrimental to sports performance (Venderly and Campbell, 2006). This was also in agreement with what was reported in the 2009 position statement of the International Society of Sports Medicine (Borrione *et al*., 2009). Venderly and Campbell (2006) also noted that creatine supplementation in vegetarians was a topic that merited further exploration, as creatine supplementation is known to be ergogenic and vegetarians are likely to have lower creatine levels. This is because both creatine itself, and its precursor amino acids that may be used for endogenous formation (methionine, glycine and arginine), are primarily found in meat and fish (Mujika and Padilla, 1997).

With regards to the effects of vegetarian diets on exercise-induced metabolic changes, one review paper tackled the question of whether vegetarian diets have an effect on exercise-induced oxidative stress, but reported that evidence directly investigating this link was lacking (Trapp *et al*., 2010).

The aim of this review paper was therefore to explore if recent studies have provided more evidence on the question of whether a vegetarian diet affects exercise performance and exercise-induced metabolic changes; this was accomplished by looking at studies published in the last decade. It therefore focused on studies published after Venderly and Campbell (2006)'s review.

Methodology

Pubmed, Web of Knowledge, Cochrane Library, Zetoc, Wiley, and Science Direct were searched using date limits of 2004-2013 (both years inclusive). This range was chosen because the most recent review paper on vegetarian diets and exercise (Venderly and Campbell, 2006) included mainly studies from pre-2004. A search for papers published in 2014 was also carried out but at the time of searching (Jan-Feb 2014), no relevant ones were identified. Hence this year was excluded. In addition, the range chosen (previous 10 years) included studies that would be more relevant than older ones, as availability and type of vegetarian and fortified foods is rapidly changing. In addition, this range encompassed a manageable number of studies for the time frame available. The inclusion and exclusion criteria used are shown in Table 1.

The searches were done using the following search query [(exercise OR sports OR performance OR athletes OR physical activity) AND (vegetarianism OR vegetarian OR vegan OR veganism)]. As both Pubmed and Cochrane Library have the MeSH functionality, a second search was carried out in both using the query: ((((exercise[MeSH Terms]) OR sports[MeSH Terms]) OR athletes[MeSH Terms])) AND diet, vegetarian[MeSH Terms]. Full details of the search process are given in Appendix 1.

Critical appraisal tools published by the Critical Appraisal Skills Programme (2013) were used to help appraise the studies; details of these can be found in Appendix 2. A data extraction tool was built based on the format provided by the Centre for Reviews and Dissemination, University of York (2009). This tool was used to help extract and identify the key data from each study; this tool can be found in Appendix 3.

Ethics approval was obtained from London Metropolitan University in January 2014.

Table 1. Inclusion and exclusion criteria

	Inclusion Criteria	Exclusion Criteria
Population and sample size	Humans, with sample size of 2 or more.	Animal-studies. Human studies with only 1 subject (case-studies).
Intervention	Vegetarian diets and exercise (both part of the intervention).	Studies that did not include both a vegetarian diet and exercise as part of the intervention.
Control	Non-vegetarians.	No non-vegetarian control.
Outcome	Comparison of the effects of vegetarian diets vs. non-vegetarian diets on exercise performance and/or exercise-induced metabolic changes.	Results obtained for vegetarians not compared to those obtained in non-vegetarians.
Publication Type	Full text publications of original research.	Any non full-text publication (e.g. meeting abstracts). Any publication that was not original research (e.g. review papers and hypotheses). Any unpublished literature.
Language	English.	Non-English languages.
Date	2004-2013 (both years inclusive).	Pre-2004 and post-2013.

Results

Database Searches

As shown in Figure 1 below, the searches yielded a total of 503 citations. After removing duplicates, and applying the inclusion and exclusion criteria, 10 papers were identified that were included in this review.

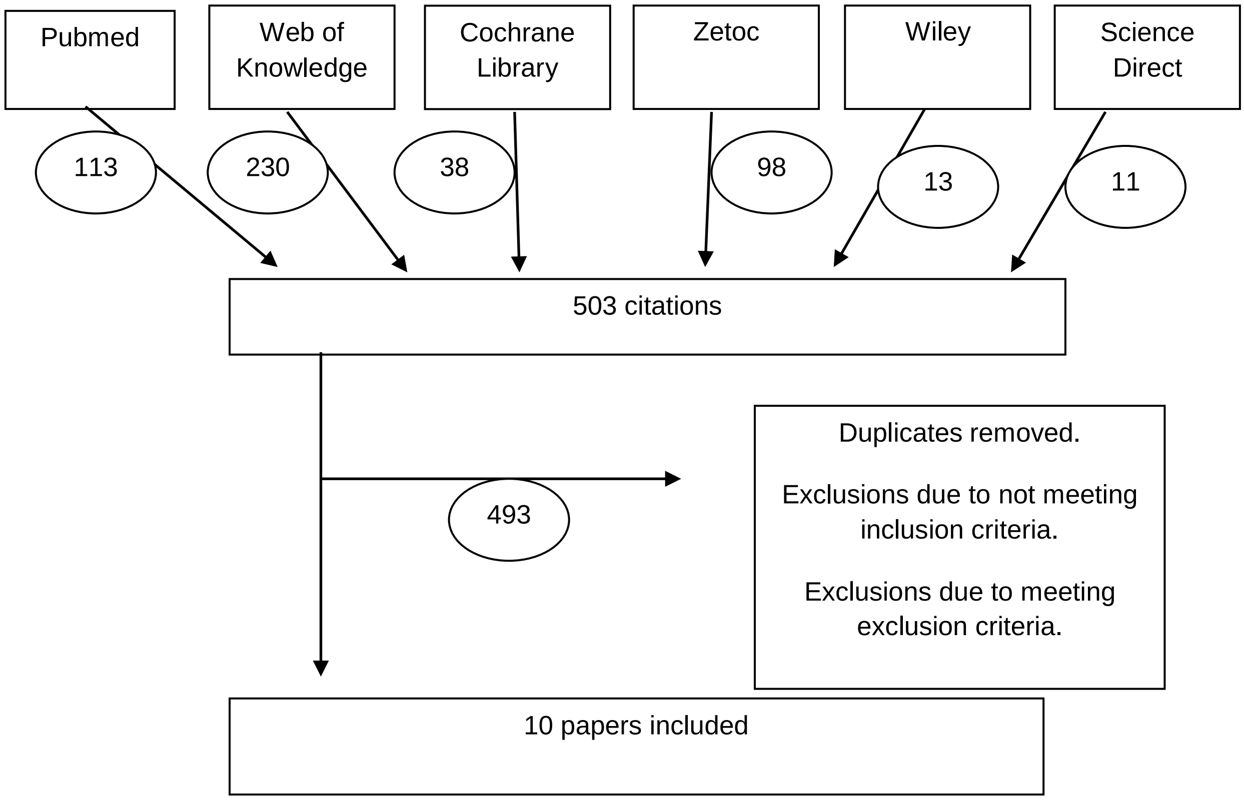

Figure 1. Summary of the searches conducted

Effects of Vegetarian Diets on Exercise Performance and Concurrent Metabolic Changes

Three papers were identified that investigated the effects of vegetarian diets on exercise performance and concurrent metabolic changes; these are summarised in Table 2 below. Vegetarian diets had no effect on performance compared to omnivorous diets (Haub *et al*. 2005; Baguet *et al*., 2011), while low-protein vegetarian diets designed to enhance alkalinity in the body lead to higher oxygen consumption during sub-maximal cycling (Hietavala *et al*., 2012).

Table 2. Summary of studies investigating the effects of vegetarian diets on exercise performance and metabolic changes

Authors & Date	Primary Aim of Research	Study Design	Subjects & Sample Size	Exposure (Diet and Exercise)	Main Outcomes	Comments
Haub *et al*. (2005)	To investigate the effects of beef- or soy-based food supplements on exercise performance and lipid parameters in older men doing RT.	Randomised open parallel trial.	21 non-vegetarian men (age 65±5 years).	All subjects were told to opt for a LOV diet. During the first 2 wks, all men received soy-based protein foods (0.6g/kg/d). In the subsequent 12 wks, 11 men continued on the soy foods whereas 10 men were given beef protein (but continuing an otherwise LOV diet). During these 12 wks, all men participated in RT.	No difference between the two groups in the improvements that occurred in muscle strength and power. The beef group experienced increased HDL (p=0.025), LDL (p=0.027) and T Chol (p=0.015), and no changes in TG, T Chol/HDL ratio or TG/HDL ratio. The soy group experienced no changes in the tested lipid parameters.	Study received financial support from the National Cattlemen's Beef Association and the Cattlemen's Beef Board, amongst others.
Baguet *et al*. (2011)	To investigate the effects of a vegetarian or mixed diet combined with sprint training on muscle carnosine content and buffering capacity.	Randomzied open parallel trial.	19 recreationally active non-vegetarian adults.	Subjects were allocated to either a LOV group (n=9) or a mixed diet group (n=10) for 5 wks. They participated in sprint training 2-3 times/wk.	No difference between the two groups in the changes in muscle carnosine content or the increase in performance. No change in *in vitro* muscle buffering capacity in any group. Carnosine synthase mRNA expression decreased significantly (p=0.023) in the LOV group while there were no sig changes in the mixed diet group.	Both groups were supplemented with 1 g creatine daily to eliminate this potential confounder.

Hietavala *et al*., (2012)	To investigate the effects of a low-protein vegetarian diet (LPVD) on blood acid-base status and aerobic cycling performance.	Crossover randomised open trial.	9 recreationally active non-vegetarian males.	Subjects followed either a LPVD or a normal diet for 4 d, then performed cycle ergometer testing, then after 10-16 d of washout (going back to their normal eating habits), they switched over to the other diet for 4 d and repeated the test.	Diet had no effect on blood acid-base status but the LPVD was associated with a higher oxygen consumption during sub-maximal cycling ($p<0.05$). VO2 max and time to exhaustion were not affected.	LPVD was not a typical vegetarian diet. Intake of protein during LPVD was 10.1 ± 0.26% and during normal diet 17.6 ± 3.0% of the total energy intake ($p=0.000$). Large inter-subject variability in the potential renal acid load of food-stuff consumed during the normal diet was reported. Energy intake was not controlled for (it was lower in the LPVD group, $p=0.033$).

RT: resistance exercise training; LOV: lacto-ovo-vegetarian; wk: week; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; T Chol: total cholesterol; TG: triglycerides; n: group size; LPVD: low-protein vegetarian diet; d: days; VO2 max: maximal oxygen uptake

Creatine Supplementation and Exercise Performance in Vegetarians

Of the studies reviewed, two investigated the effects of creatine supplementation and exercise performance in vegetarians; these are summarised in Table 3 below. There was no difference between vegetarians and omnivores in the improvements in lean-tissue gains (Burke *et al*., 2008a) and sprint cycling performance (Watt *et al*., 2004) that occurred after creatine supplementation.

Table 3. Creatine supplementation and exercise performance in vegetarians

Authors & Date	Primary Aim of Research	Study Design	Subjects & Sample Size	Exposure (Cr Supplementation & Exercise)	Main Outcomes	Comments
Watt *et al*. (2004)	To examine the effects of vegetarianism on skeletal total Cr content and Cr transporter (CreaT) gene expression prior to, and during 5d Cr supplementation.	Randomised double blind crossover trial.	Healthy males, of which 7 were VEG (4 vegans and 3 LOV) and 7 were OMNI.	VEG and OMNI were assigned Cr (0.4g/kg/d) or placebo for 5 d and after 5 wks, received the alternative treatment.	Before supplementation, total muscle Cr content was lower in VEG (p<0.05). Cr supplementation resulted in increased muscle total Cr content in both groups, but VEG achieved higher levels than OMNI (p<0.05). Basal and post-supplementation CreaT mRNA levels were not different between VEG and OMNI. Sprint cycling performance was improved after Cr supplementation (p<0.05); the improvement was similar between the groups.	VEG had been on that diet for at least 6 months prior. The 5 wks washout were not enough for the muscle Cr levels to go back to baseline in the VEG group (p<0.05).
Burke *et al*. (2008a)	To compare changes in muscle IGF-I content resulting from RT and Cr supplementation in omnivores OMNI and VEG.	Randomised double-blind parallel trial.	Healthy, recreationally active adults, of which 18 were VEG (LOV or vegan), 24 were OMNI.	Participants were supplemented either with Cr (0.25g/kg lean-tissue mass/d for 7 d and 0.06g/kg lean-tissue mass/d for 49 d) (n=22) or placebo (n=20). They engaged in a whole body RT program (repeating cycles of 3 d training, 1 d off).	Differences in lean-tissue gains in the Cr supplemented group were not different between VEG and OMNI. Results for VEG vs. OMNI for the non-supplemented group were not reported. No differences in IGF-I between OMNI and VEG (actual measurements not given).	Participants identified as VEG had been so for at least 3 years. Dietary analysis indicated that VEG were consuming fewer total calories (p<0.05) and protein (p<0.05) compared to OMNI.

Cr: creatine; VEG: vegetarians; OMNI: omnivores; LOV: lacto-ovo-vegetarians; d: day; wk: week IGF-I: insulin-like growth factor-I; RT: resistance exercise training; n: group size

Effects of Calorie-Restricted Vegetarian Diets Combined with Exercise on Weight Loss and Metabolic Parameters in Overweight Adults

Three papers were identified that investigated the effects of calorie-restricted vegetarian diets combined with exercise on weight loss and metabolic parameters, as summarised in Table 4 below. These three publications all reported data obtained from the same study (but were not duplicates as each publication reported different parts of the study). Initially, vegetarians appeared to derive more benefits than non-vegetarians on a calorie-restricted diet and exercise regimen (Burke *et al*., 2006); however, all differences between the two groups were gone at the end of the study (Burke *et al*., 2008b). When the results from both diet groups were merged, it was found that physical activity had an effect on total cholesterol even after controlling for weight change (Burke *et al*., 2007).

Table 4. Effects of calorie-restricted vegetarian diets combined with exercise on weight loss and metabolic parameters

Authors & Date	Primary Aim of Research	Study Design	Subjects & Sample Size	Exposure (Diet and Exercise)	Main Outcomes	Comments
Burke *et al*. (2006)	To compare two calorie-restricted diets: (STD-D vs. LOV-D) on weight loss efficacy and metabolic changes, and to determine effect of a chosen diet vs. an assigned diet. This publication reported the initial results (6 months) based on dietary treatment only.	Randomised open parallel trial. .	176 overweight and obese sedentary adults.	Cognitive behaviour therapy + diet (98 allocated to STD-D and 84 allocated to LOV-D) + exercise (participants were recommended to increase their physical activity, e.g. walking, gradually to 150min/d by the 6th week and thereafter to increase or at least maintain it). The study ran for 18 months: 12 months intervention and 6 months maintenance; however, this publication reports the results after the first 6 months only.	At 6 months, the LOV-D group achieved higher LDL reductions than the STD-D group (p=0.013). Changes in bodyweight, BMI, waist circumference, T Chol, HDL, TG, glucose, and insulin were not different between the two groups. Subjects in the LOV-D group reporting 100% adherence to the LOV restrictions (n=47) lost more weight (p<0.001), and had greater reductions in BMI (p<0.001), waist circumference (p=0.018), T Chol (p=0.026), LDL (p=0.034), and glucose (p=0.002) compared to those in the same group reporting <100% adherence (n=24).	Meals not provided by research teams - participants were instead educated on how to come up with suitable meals themselves. Only 12.6% of the subjects were males. Not all subjects in the LOV-D group adhered to the LOV restrictions (subjects in this group recorded consuming 0.26 meat meals per day).

Burke *et al*. (2007)	As above (same study). This publication reported the full results after 18 months, focusing on biochemical and dietary variables.	At 18 months, there were no differences between the two diet groups in terms of changes in body weight or lipids. From 0-12 months, physical activity had an effect on T Chol ($p<0.01$) even after controlling for weight change ($p=0.02$) (results of both groups combined).	Adherence in the LOV-D group to the LOV restrictions dropped with time: at 6, 12 and 18 months respectively, 61%, 53% and 36% of participants in this diet group reported complete adherence.
Burke *et al*. (2008b)	As above (same study). This publication reported the full results after 18 months, focusing on anthropometric and biochemical measures.	At 18 months, there were no differences in changes in BMI and waist circumference between the two diet groups.	As above.

STD-D: standard omnivorous diet; LOV-D: lacto-ovo-vegetarian diet; LOV: lacto-ovo-vegetarian; d: day; LDL: low-density lipoprotein cholesterol; BMI: body mass index; HDL: high-density lipoprotein cholesterol; T Chol: total cholesterol; TG: triglycerides; n: group size

Effects of Calorie-Restricted Vegetarian Diets Combined with Exercise on Insulin Sensitivity and Metabolic Parameters in Type 2 Diabetics

Two publications investigated the effects of calorie-restricted vegetarian diets combined with exercise on insulin sensitivity and metabolic parameters in type 2 diabetics; these are summarised in Table 5 below. Both were from the same study but analysed different data. The vegetarian diet was associated with better metabolic improvements than the conventional diabetic diet, with exercise augmenting these benefits (Kahleova *et al*., 2011). Vegetarian diets and exercise were both shown to result in significant changes in serum phospholipids (Kahleova *et al*., 2013).

Table 5. Effects of calorie-restricted vegetarian diets combined with exercise on insulin sensitivity and metabolic parameters in type 2 diabetics

Authors & Date	Primary Aim of Research	Study Design	Subjects & Sample Size	Exposure (Diet and EXR)	Main Outcomes	Comments
Kahleova *et al*. (2011)	To investigate the effects of calorie restricted diets (vegetarian vs. conventional diabetic diet) alone or in combination with EXR on insulin resistance, visceral fat and oxidative stress markers	Randomised open parallel clinical trial.	74 Type 2 diabetics on oral hypoglycemic agents	37 subjects were allocated to a LVG and 37 to a CDG (both calorie-restricted: -500kcal/d). Diet-only intervention for 12 wks, and diet + aerobic EXR (3/wk, 1hr each time) for the second 12 wks.	43% of participants in the LVG and 5% of participants in the CDG reduced their diabetes medication due to repeated hypoglycaemia (p<0.001). Weight loss was greater in the LVG (p=0.001). An increase in insulin sensitivity was greater in the LVG (p=0.04). After dietary intervention, visceral and subcutaneous fat were decreased in both groups (p<0.001 for both); addition of EXR resulted in further reductions in LVG only (p<0.01 and p<0.05 respectively). Total reductions in visceral and subcutaneous fat were both higher in LVG (p= 0.007 and 0.02 respectively). Vitamin C, superoxide dismuthase and reduced glutathione increased in the LVG (p=0.002, p<0.001 and p=0.02, respectively). EXR enhanced the favourable changes in superoxide dismuthase and reduced glutatione in the LVG. Resistin: in the LVG, decreased after dietary intervention, and remained reduced after the addition of EXR. In the CDG, was unchanged after dietary intervention but increased after the addition of EXR (group x time p=0.05) Changes in volume of visceral fat were strongly associated with changes in the metabolic clearance rate of glucose (r=-0.63; p<0.001).	All meals provided by researchers. At 24 wks, adherence to the prescribed diet was 'high' among 55% of the participants in the LVG and 32% in the CDG. Insulin sensitivity was calculated from the metabolic clearance rate of glucose.

Kahleova *et al*. (2013)	To investigate the role of changes in fatty acid composition of serum phospholipid in diet- and EXR-induced changes in insulin sensitivity in subjects with type 2 diabetes.	As above (same study).	Changes in serum phospholipids: • At 24 weeks linoleic acid was higher in the LVG compared to CDG (P<0.001). • Total saturated fatty acids did not change in either group following dietary intervention; after the addition of EXR, they were increased in the LVG (P<0.001) and were unchanged in the CDG. • The ratio of saturated to unsaturated fatty acids did not change in either group following dietary intervention. After the addition of EXR, it increased in LVG (P<0.001), and did not change in CDG.	As above.

EXR: exercise; LVG: lacto-vegetarian diet group; CDG: conventional diabetic diet group; d: day; wk: week

Discussion

Effects of Vegetarian Diets on Exercise Performance and Concurrent Metabolic Changes

Three studies investigated the effects of vegetarian diets on exercise performance and concurrent metabolic changes; however, none of these were carried out in actual athletes. In Haub *et al*. (2005)'s study, a lacto-ovo-vegetarian diet was prescribed for all subjects (21 older men); however, a group received soy-based protein foods while the other group received beef-based protein foods. During this time, the subjects undertook resistance-exercise training. Therefore, this study did not strictly investigate a vegetarian diet vs. an omnivorous diet; rather, it investigated the effects of protein from soy vs. beef on an otherwise vegetarian diet.

There was no difference in the increases in muscle strength and power that occurred between the two groups but there was a difference in lipid changes. While the soy group experienced no significant changes, the beef group experienced increases in high-density lipoprotein cholesterol, low-density lipoprotein cholesterol and total cholesterol. The authors stated that as the total cholesterol to high-density lipoprotein cholesterol ratio remained unchanged in the beef group, this may indicate that the health risks associated with an increase in low-density lipoprotein cholesterol and total cholesterol were possibly offset by an increase in high-density lipoprotein cholesterol. The authors speculated that the beef group actually decreased their risk of metabolic syndrome compared to the soy group. This due to the fact that although the increase in triglyceride to high-density lipoprotein cholesterol ratio in the soy group, and the decrease in the beef group, from baseline to 14 weeks was not of statistical significance, within group comparison of this change reached statistical significance. However, the sample size was small and the diets were followed for a short term, so the results need to be interpreted with caution. There was also a possibility of bias in this study, as the paper acknowledged that the research team had received financial support from the National Cattlemen's Beef Association and the Cattlemen's Beef Board, amongst others. Moreover, the study was not blinded. Furthermore, due to the particular study design, it is not possible to extrapolate the findings to a vegetarian vs. omnivorous diet comparison. At best, this study showed that a strict lacto-ovo-vegetarian diet and a lacto-ovo-vegetarian diet supplemented with beef protein produced similar improvements in muscle strength when combined with resistance training. It would have been interesting to investigate any changes in body weight/fat that occurred, but this was not reported.

In a different study, Baguet *et al*. (2011) investigated the changes in muscle carnosine content and buffering capacity in response to sprint training in subjects following either a lacto-ovo-vegetarian diet or a mixed diet. Carnosine is a dipeptide found in muscle with proton buffering capacity (Budzeń and Rymaszewska, 2013). As there is a positive correlation between muscle buffering capacity and performance during high-intensity exercise (Bishop *et al*., 2004), levels of carnosie may be correlated with performance. Carnosine is synthesized endogenously, with beta-alanine being the rate-limiting precursor (Culbertson *et al*., 2010). Like creatine, beta-alanaine is found mainly in meat, fish and poultry (Abe, 2000), and in fact long-term vegetarians tend to have lower muscle carnosine content compared to omnivores (Everaert *et al*., 2011). To isolate the effect of carnosine on performance, Baguet *et al*. (2011)'s study supplemented 1 gram of creatine per day to all subjects.

The subjects in this study were not vegetarian to start with; they only followed this diet for the duration of the study (5 weeks). It was found that carnosine synthase (the enzyme responsible for making carnosine from beta-alanaine) mRNA expression decrease significantly in the subjects following the vegetarian diet. However, muscle carnosine content and in vitro muscle buffering capacity did not change significantly in either group, and the improvement in performance that occurred was similar in the two groups. Few studies have investigated the effects of exercise on muscle carnosine content without using simultaneous beta-alanine supplementation. In a study by Mannion *et al.* (1994), 16 weeks of isokinetic quadriceps training did not result in any changes in muscle carnosine content; however, Suzuki *et al*. (2004) reported that 8 weeks of sprint training resulted in significantly elevated skeletal muscle carnosine concentration. It is therefore possible that 5 weeks was too short a duration for changes in muscle carnosine content and buffering capacity to occur; indeed, the decrease in carnosine synthase mRNA in vegetarians (probably as a result of reduced beta-alanine availability) may hint that had the study been conducted for longer, a change in carnosine content may have occurred (and possibly a drop in performance due to a decreased buffering capacity).

Other factors, other than carnosine, influence the acid-base balance of the body. Nutrition can affect this balance as different foodstuff may cause the production of acids or basis (to different extents) (Remer, 2001). The PRAL (potential renal acid load) is a measure of the potential of a food item to generate either acids or alkalis within the body (Remer et al., 2003). For example, all protein-rich foods are acid forming, while fruits and vegetables high in potassium are base-forming. Hietavala *at al*. (2012) investigated the extent to which a predominantly base-forming diet planned according to PRAL could affect the blood acid-base status and in turn, aerobic capacity during exercise (as high alkalinity is conducive to improved aerobic capacity (Oopik *et al*., 2003)). The study was a randomised crossover one, in which subjects followed both diets at different points - either a normal diet, or a low-protein vegetarian diet. In needs to be highlighted that the latter was not a typical vegetarian diet, but one that was also restricted in acid-generating foods (including all protein foods and grains). The researchers found that diet had no effect on blood acid-base status, and that actually, the low-protein vegetarian diet was associated with higher oxygen consumption during submaximal cycling, suggesting a higher energy expenditure and poorer exercise economy. However, this study did suffer from several limitations which weakened the reliability of the results, including: small sample size (9 subjects), small study duration (4 days on each diet), large inter-subject variability in the PRAL of the food-stuff consumed in the control group, and that calorie intake was not controlled for (subjects consumed significantly less calories when on the low-protein vegetarian diet). At best, this study indicated that a base-forming, low-protein vegetarian diet is not to be recommended for performance improvement.

These three studies re-iterated what previous review papers, e.g. Venderly and Campbell (2006) and Borrione *et al*. (2009), had concluded - that current evidence does not indicate that vegetarian diets are either beneficial or detrimental to exercise performance. These newer studies also suffer from the main weakness as older, similar studies: a very small sample size.

Creatine Status and Effects of Supplementation on Exercise Performance in Vegetarians

Two studies investigated creatine status and effects of its supplementation among vegetarians. Creatine is stored in muscle and promotes faster regeneration of adenosine triphosphate, which is integral for the ongoing contractility of muscle fibres (Bemben and Lamont, 2005).

Watt *at al.* (2004)'s study reported a lower basal creatine level in vegetarians; an expected result since both creatine itself and its precursor amino acids are found predominantly in meat and fish (Mujika and Padilla, 1997). Interestingly, Watt *at al.* (2004) found that 5 days of creatine supplementation at 0.4g/kg bodyweight/day resulted in the vegetarians achieving higher skeletal muscle total creatine content than omnivores supplementing with the same amount. The authors reported that it was unclear why vegetarians exhibited increased muscle accumulation ability upon ingestion of creatine. Another unexpected observation was that although the 5 week washout period was sufficient for the muscle creatine levels of supplemented omnivores to go back to baseline levels, in vegetarians muscle total creatine content remained elevated after 5 weeks, compared with pre-supplement levels. Other studies on creatine supplementation had shown that muscle creatine stores return to pre-supplement levels after 4 weeks of supplement cessation, e.g. Hultman *et al.* (1996) - however, all previous creatine supplementation studies had been carried out in omnivores.

Watt *at al.* (2004)'s study found that although sprint cycling performance was improved after creatine supplementation, the improvement was similar between the two groups. However, the data may have been affected by the washout period not being long enough for the creatine levels of vegetarians to return to baseline before the start of the placebo trial. The study also looked at the creatine transporter (CreaT), which accounts for the bulk of creatine movement into the skeletal muscle (Schoch *et al.,* 2006), and found that there was no difference between the groups in terms of CreaT mRNA levels; showing that vegetarianism does not affect the expression of the CreaT gene.

Although this study had a good design (double-blind, crossover), the sample size was very small (7 vegetarians and 7 omnivores) and all subjects were males. Of the 7 vegetarians, 4 were vegans and 3 were lacto-ovo-vegetarian. It would have been interesting if separate results were reported for the two types of vegetarians, although it is not expected that the results would have differed as creatine intake from the diet is equally absent in the two types of vegetarianism.

Similarly, Burke *et al*., (2008a)'s study reported that 8 weeks of creatine supplementation combined with resistance-exercise training in 42 adults resulted in similar lean-tissue gains among vegetarians and non-vegetarians. This study also had a vegetarian and a non-vegetarian group that did not supplement with creatine - unfortunately, the results for these groups were not reported. The study also investigated changes in muscle insulin-like growth factor-I content resulting from resistance training, and reported that there was no difference between the two diet groups. Insulin-like growth factor-I produced in skeletal muscle controls local tissue repair and remodelling (Schroeder *et al*, 2013).

During Burke *et al*., (2008a)'s study, it was reported that vegetarians consumed fewer total calories and protein, and this may have affected the results (as the results were not adjusted for calorie and protein intake). In addition, not all results obtained from the study were reported in this paper (e.g. there is no data on the lean tissue gains of unsupplemented subjects); full results were given in a separate paper (Burke *et al*., 2003) which was published outside the date cut-off for this review and was therefore not included.

From these two studies, it therefore appears that vegetarians are likely to have lower creatine stores due to a low intake of both creatine and its precursor amino acids. Supplementation can increase creatine stores and performance during high-intensity exercise, but it does not appear that vegetarians benefit more than omnivores from supplementation, as may be otherwise expected due to a lower baseline level. However, it is possible that a difference in performance was not detected simply due to the small sample size of both studies.

Effects of Calorie-Restricted Vegetarian Diets Combined with Exercise on Weight Loss and Metabolic Parameters in Overweight Adults

The PREFER trail was an 18 month study conducted to evaluate the effects of a standard calorie- and fat-restricted omnivorous diet in a 'standard behaviour treatment' (a combination of behavioural therapy, increased physical activity, and a low-calorie diet) intervention compared to a calorie- and fat-restricted lacto-ovo-vegetarian diet as part of the intervention (Burke *et al*., 2006). The study also investigated the effects of a chosen diet vs. an assigned diet, but the results of this part of the study will not be discussed as they are not relevant to this review.

The findings need to be interpreted relative to adherence, as subjects in the lacto-ovo-vegetarian diet group reported a declining compliance to the lacto-ovo-vegetarian restrictions with time. In fact, within the lacto-ovo-vegetarian diet group, complete adherence at 6, 12 and 18 months was reported to be 61%, 53%, and 36%, respectively (Burke *et al*., 2007).

Although at 6 months, only the change in low-density lipoprotein cholesterol was significantly different between the two diet groups (the lacto-ovo-vegetarian diet resulted in better reductions), it was found that subjects in the lacto-ovo-vegetarian group reporting 100% adherence at 6 months achieved better outcomes in terms of anthropometrics and metabolic parameters than those reporting less than 100% adherence (Burke *et al*., 2006). This may indicate a superiority of a lacto-ovo-vegetarian diet compared to a standard one; although it is also possible that subjects reporting 100% adherence to the lacto-ovo-vegetarian restrictions achieved better outcomes simply because they were more motivated to lose weight.

At 18 months, there was no difference between the two diet groups in terms of changes in weight or metabolic parameters (Burke *et al*., 2008b), which was not unexpected since adherence to the lacto-ovo-vegetarian recommendations had dropped significantly at this time. This was indeed a main limitation of the study, as the declining adherence hindered the ability to detect differences between the diet groups. Perhaps, with a larger sample size, it may have been possible to detect differences between the two groups even with a low adherence rate. Moreover, although the researchers collected 3-day food records at baseline and at 6 ,12 and 18 months, these only provided snapshots of what the participants were consuming and were liable to all the limitations that 3-day food records suffer from (Bergman *et al*., 1990). Furthermore, most of the subjects were females (86.93%), and when adherence to the lacto-ovo-vegetarian restrictions was analysed at 6 months, none of the 8 males in this group reported 100% adherence (Burke *et al*., 2006). In addition, most subjects in the study group were employed (93.18%). Vegetarian foods (such as imitation meats) tend to be more expensive than non-vegetarian alternatives (Key Note, 2012), and this can therefore make these diets harder to follow by financially-strained individuals.

Physical activity levels were similar between the two diet groups, and it was found that from baseline to 12 months, physical activity had an effect on total cholesterol even after controlling for weight change when the results from the two diet groups were combined (Burke *et al*., 2007). From this study, it was not possible to isolate the effect of exercise or to find out whether exercise had differential effects in the two diet groups.

This study indicated that although a vegetarian diet combined with exercise may be more beneficial for weight loss than a standard diet combined with exercise, subjects who switch to a vegetarian diet only for its weight loss benefits may not be able to adhere to it for the long term, limiting its usefulness in practice. Males may be even less likely to adhere to vegetarian diets.

Effects of Calorie-Restricted Vegetarian Diets Combined with Exercise on Insulin Sensitivity and Metabolic Parameters in Type 2 Diabetics

As the incidence of type 2 diabetes in vegetarians is considerably lower than in non-vegetarians (Criag, 2010), and considering that exercise is known to reduce insulin resistance (Fedewa *et al.*, 2014), it is reasonable to assume that combining a vegetarian diet with regular exercise may help prevent and/or control type 2 diabetes. This topic was investigated by Kahleova *et al*. (2011) in a randomised, parallel study that compared the effects of calorie-restricted A) lacto-vegetarian and B) conventional diabetic diets, alone and in combination with exercise, on insulin resistance, visceral fat and oxidative stress markers in type 2 diabetic adults. Although the sample size was rather small (74 subjects), this study benefitted from weekly meetings between the participants and investigators, the provision of all meals to the participants and a study duration that was long enough (24 weeks) to allow for metabolic changes to be apparent.

The lacto-vegetarian group experienced more fat loss, better insulin sensitivity, and higher levels of antioxidants than the control group. Addition of exercise resulted in further metabolic improvements in the lacto-vegetarian group only. It is likely that the improved insulin sensitivity in the lacto-vegetarian group was partly due to this group experiencing a greater fat loss, as fat (especially visceral fat) is known to be associated with insulin sensitivity (Vetter *et al*., 2014). Other factors of vegetarian diets that may have a benefit on insulin sensitivity are: a reduced intake of saturated fats, increased fibre intake and vegetable protein (Barnard *et al*., 2009). On the other hand, possible effects through which exercise may modulate improved insulin sensitivity is through a higher loss of fat mass (vs. lean mass) during calorie-restricted diets, morphological changes in muscle conducive to improved insulin responses, and improved control of glucose production by the liver (Dube *et al*., 2008).

In a follow up paper by the same research team, it was reported that the insulin-sensitising effects of the lacto-vegetarian diet might have been related to an increase in the proportion of linoleic acid in serum phospholipids that occurred; it was also found that addition of exercise resulted in greater changes in serum phospholipid fatty acids composition in the vegetarian group compare to the control group (Kahleova *et al*., 2013). For example, the ratio of serum saturated to unsaturated fatty acids was unchanged in the control group for the duration of the study, but increased in response to exercise in the vegetarian group. The authors reported that an increase in saturated fatty acids following exercise may be beneficial due to increased membrane stability and reduced lipoperoxidation.

Another finding of the original study was that resistin decreased after dietary intervention and remained reduced after the addition of exercise in the lacto-vegetarian group; on the other hand, it was unchanged after dietary intervention but increased after the addition of exercise in the control group (Kahleova *et al*., 2011). Resistin is an inflammatory cytokine that has been associated with insulin resistance and cardiovascular disease (Abate *et al*., 2013). Recently, it has also been suggested that resistin could be a potential biomarker for diabetes-induced periodontitis (Devanoorkar *et al*., 2014). The lacto-vegetarian group were also found to exhibit an improvement in oxidative stress markers (which was augmented by exercise). Oxidative stress is implicated in the progression of diabetes and its complications (Forbes *et al*., 2008).

Interestingly, while 32% of the subjects in the control group reported high adherence to their diet, 55% of the lacto-vegetarian subjects reported high adherence (Kahleova *et al*., 2011). While it can be argued that the lower adherence in the control group may have been partly responsible for the lower improvements seen in this group compared to the vegetarian group, the higher adherence in the vegetarian group may also mean that this diet is easier to follow than the conventional diabetic diet, thus highlighting the suitability of this diet in practice.

This study therefore indicated that a calorie-restricted lacto-vegetarian diet is more effective than a conventional calorie-restricted diabetic diet for controlling diabetes, and possibly offers better protection against complications such as cardiovascular disease. Furthermore, it may also be easier to follow and hence more practical. Addition of exercise further augments the effectiveness of a lacto-vegetarian diet.

Limitations of the Review Process

This review was constrained both in the time available for its completion and length; the former placed a limit at how rigorous the search process could be and the latter on the number of studies that could be included. Therefore, searches were limited to published literature in the English language, using 6 databases. This could have introduced bias in the included literature. In addition, unlike what is usually done for systematic reviews, expert opinion was not sought and hand-searching of journals was not carried out. Initially, no date limit was used when conducting the searches; however, this generated too many studies to be included in the allocated word count. Hence, a period of ten years was chosen to limit the number of studies.

Conclusion

Vegetarian diets were shown to result in lower creatine stores and decreased carnosine synthase mRNA expression (the latter possibly indicating that a drop in carnosine would have occurred in the long term); however, vegetarians exhibited the same performance improvements in response to exercise as omnivores. Vegetarians also derived similar benefits from creatine supplementation as non-vegetarians. Overall, the studies reviewed indicated that vegetarian diets are neither beneficial nor detrimental to exercise performance in recreationally active adults. However, a low-protein vegetarian diet designed to enhance alkalinity in the body resulted in higher oxygen consumption during sub-maximal cycling and this specific type of diet should therefore not be recommended. As none of the studies were carried out in actual athletes, the results cannot be extrapolated to this subgroup of the population, especially during competitive training when their nutritional requirements and metabolic demands would be extremely high. Moreover, all studies investigating exercise performance suffered from small sample sizes, which could have been the reason why no differences in exercise performance were found between vegetarians and omnivores.

In overweight and obese subjects, although a calorie-restricted vegetarian diet combined with exercise initially seemed to provide more benefits that a calorie-restricted omnivorous diet combined with exercise, adherence to the vegetarian recommendations dropped gradually over 18 months and any difference in outcomes between the two diet groups was gone by the end of the study. This could indicate that it may not be practical to advise opting for a vegetarian diet specifically for its weight loss benefits.

On the other hand, in type 2 diabetics, a calorie-restricted vegetarian diet was found to be better adhered to than a conventional diabetic diet, and more effective at controlling diabetes and improving risk factors for complications. Exercise augmented the benefits of a vegetarian diet to a larger extent than it did for the conventional diet. There is therefore good clinical potential for vegetarian diets among type 2 diabetics.

From the studies reviewed, it was also clear that there is still a lack of research investigating the interaction effects of vegetarian diets and exercise. In addition, all studies reviewed had small sample sizes, which reduced the ability of the studies to detect small differences between the groups. Moreover, none of the studies had a group with vegan subjects only.

The main implications for practice of this review are therefore:

1. Vegetarians concerned that their diets may impair exercise performance can be reassured that current evidence does not indicate that these diets affect performance;
2. Low-protein vegetarian diets designed to enhance alkalinity within the body do not improve exercise performance and should not be recommended for this purpose;
3. There is no benefit in recommending a calorie-restricted vegetarian diet instead of a standard calorie-restricted omnivorous diet for weight loss among obese and overweight adults, owing to a low adherence to the vegetarian restrictions in this population group; and
4. In type 2 diabetics, a calorie-restricted vegetarian diet combined with exercise produced more benefits than a traditional diabetic diet and may be better adhered to. The option to follow such a diet should therefore be discussed with type 2 diabetics, and those willing to switch to a vegetarian diet should be encouraged to do so.

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Appendix 1. Database Searches

Table 6. Details of the searches carried out

Database	Query	Limits	Number of citations
Pubmed	Search: ((((((exercise) OR sports) OR performance) OR athletes) OR physical activity)) AND ((((vegetarianism) OR vegetarian) OR vegan) OR veganism)	Date range: 01/01/2004 to 31/12/2013 Species: human Languages: English	113
Pubmed (using MeSH terms)	Search: ((((exercise[MeSH Terms]) OR sports[MeSH Terms]) OR athletes[MeSH Terms])) AND diet, vegetarian[MeSH Terms]	Date range: 01/01/2004 to 31/12/2013 Species: human Languages: English	39 - all had been picked up by previous search
Web of Knowledge	Search (Topic): ((((((exercise) OR sports) OR performance) OR athletes) OR physical activity)) AND ((((vegetarianism) OR vegetarian) OR vegan) OR veganism)	Date range: 01/01/2004 to 31/12/2013 Language: English Document types=(article or clinical trial or abstract)	230
Cochrane Library	Search using search manager: ((((((exercise) OR sports) OR performance) OR athletes) OR physical activity)) AND ((((vegetarianism) OR vegetarian) OR vegan) OR veganism)	None used during search	39 trials, of which 38 from 2004 onwards
Cochrane Library (using MeSH terms)	((((exercise[MeSH Terms]) OR sports[MeSH Terms]) OR athletes[MeSH Terms])) AND diet, vegetarian[MeSH Terms]	None used during search	13 - all had been picked up by previous search
Zetoc	Journal Searches. No OR function or parenthesis. Hence separate searches need to be done for each 2 word combination in "All fields". Searches: • Vegetarian exercise • Vegetarian sports • Vegetarian performance • Vegetarian	Date 2004-2013	Vegetarian exercise- 16 Vegetarian sports- 11 Vegetarian performance-16 Vegetarian physical- 29 Vegetarian athlete -8 Vegan exercise- 7 Vegan sports- 2 Vegan performance- 1 Vegan physical- 6 Vegan athletes- 2 Total: 98

	physical • Vegetarian athletes • Vegan exercise • Vegan sports • Vegan performance • Vegan physical • Vegan athletes		
ScienceDirect	Searched using "title, keywords, abstract": ((exercise OR sports OR performance OR athletes OR physical activity) AND (vegetarianism OR vegetarian OR vegan OR veganism))	Journals, Years 2004-2013	13
Wiley	Search: (exercise OR sports OR performance OR athletes OR physical activity) in Abstract AND (vegetarianism OR vegetarian OR vegan OR veganism) in Abstract	Years 2004-2013	11

Appendix 2. Critical Appraisal Tools

Critical Appraisal Skills Programme (CASP) Tools were used to help appraise the studies. These tools are available for free (Creative Commons license) from the Critical Appraisal Skills Programme website:

Main website: http://www.casp-uk.net/

Tools Download: http://www.casp-uk.net/#!casp-tools-checklists/c18f8

Appendix 3. Data Extraction Tool

1. General	
i. Record number	
ii. Author	
iii. Article title	
iv. Date	
v. Conflict of interest/funding	
2. Study Characteristics	
i. Primary aim of research	
ii. Study design	
iii. Sample size	
iv. Recruitment methods and inclusion and exclusion criteria	
v. Allocation/randomisation method	
3. Population Characteristics	
i. Age	
ii. Gender	
iii. Weight/BMI	
iv. Ethnicity	
v. Socio-economic status	
vi. Disease characteristics	
vii. Usual diet (e.g. lacto-ovo-vegetarian, omnivorous, etc…)	
viii. Usual exercise habits	
4. Intervention	
i. Setting of Intervention	
ii. Diet during intervention	

(including group sizes and controls)	
iii. Exercise during intervention (including group sizes and controls)	
iv. Supplementation, if any (including group sizes and controls)	
5. Outcomes	
i. Measurements taken, statistical tests, and statistical analysis	
ii. Type of analysis used in the study (e.g. intention to treat)	
iii. Number of withdrawals, exclusions, lost to follow up	
6. Additional comments	