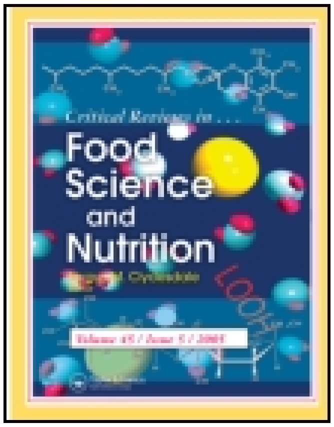

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Effects of Vegetable Consumption on Weight Loss: A Review of the Evidence with Implications for Design of Randomized Controlled Trials

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Effects of Vegetable Consumption on Weight Loss: A Review of the Evidence with Implications for Design of Randomized Controlled Trials

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Vegetable consumption is a key strategy in many weight loss programs but establishing the evidence that vegetable consumption per se assists with weight loss may be difficult. Creating a dietary energy deficit involves the whole diet, so research on the effects of vegetables may need to consider the whole-dietary model. The aims of this review were to examine the evidence on whether a higher vegetable consumption resulted in greater weight loss in overweight adults (compared to lower intakes) in view of a critique study designs with respect to their potential impact on outcomes. Using the PubMed search engine, a systematic review of randomized controlled trials (RCTs) published in the period 1988 to 2011 was conducted. Of the 16 RCTs scrutinized, five reported greater weight loss, nine no difference, one showed weight gain, and one reported a positive association between weight loss and high vegetable consumption. Trials which showed beneficial effects compared a healthy high vegetable diet with a control diet based on usual consumption patterns, and/or included behavioral support and counseling. On face value, the evidence reviewed appeared inconclusive but closer examination of study designs exposed important implications for RCTs that examine effects of foods on weight loss.

Keywords Vegetables, weight loss, evidence

INTRODUCTION

Vegetables retain a key position in cultural cuisines and their consumption is recommended in national dietary guidelines (NHMRC, 2012; U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010). While evidence for protective effects against cardiovascular disease have been known for some time (Ness and Powles, 1997), the situation with vegetable consumption and obesity is less clear, as it is for all foods. This is because overconsumption of food generally leads to obesity. The full report of the 2010 Dietary Guidelines for American attributed an evidence grade of "moderate" for a modest association between increased fruit and vegetable intake and lower body weight with a trend toward decreased weight gain over five years or more in middle adulthood. However, the evidence on the efficacy of increased fruit and vegetable consumption in weight loss diets was seen as inconclusive (U.S. Department of Agriculture, 2010).

Eating less food is an obvious strategy for weight loss but knowing which foods to consume to support overall health with weight management is a current imperative. Determining the value of each food in the total diet requires a systematic approach to evaluating the evidence and proving effects. Consistent results from randomized controlled trials (RCTs) provide the highest form of evidence for practice (National Health and Medical Research Council, 1999). Heterogeneity in study design, however, can weaken the ability to generalize across studies. Much of the evidence on effects of food consumption comes from observational studies that examine the association between food consumption patterns and health outcomes. RCTs directly examine the effect by comparing outcomes between a control and intervention diet, where the intervention diet contains the dietary variable of interest.

Food-based RCTs, however, present with substantial design challenges (Ludwig and Ebbeling, 2010), and even more so with examining weight loss outcomes given that weight is sensitive

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to the total diet. In addition, it is likely that short-term effects on weight loss may be effective from a range of dietary means, but the long-term effects have the greater health significance (Sacks et al., 2009). The content of the background diet can confound results because it may interfere with the ability to attribute effects to the dietary variable of interest. Likewise, the strategy for implementing the dietary trial (e.g., providing forms of dietary advice with or without food provisions) will influence what participants actually eat. Poor adherence to study dietary targets may render the study futile in answering the question. The aims of this review were to examine the evidence on whether a higher vegetable consumption resulted in greater weight loss in overweight adults (compared to lower intakes) in view of a critique study designs with respect to their potential impact on outcomes.

METHODS

The review was conducted with reference to frameworks for establishing evidence for practice provided by the Australian National Health and Medical Research Council (National Health and Medical Research Council, 2009). Using the PICO format, the Population was defined as overweight adults, the Intervention as vegetable intakes, the Comparator as high versus low vegetable intake and the Outcome as weight loss. The review addressed the question, "Does a higher intake of vegetables result in greater weight loss in overweight adults than a lower level of consumption?"

The primary search was conducted in 2009 (Fig. 1) and a follow-up search was conducted in 2011. Using the PubMed database and limiting outputs to human studies reported in English since 1988, the first review involved a first-pass search which produced 16,000 papers using the single keyword vegetable*. Adding weight* as a second keyword reduced this to 1810 papers. Adding further limitations for clinical trials, meta-analysis, RCTs, and reviews narrowed the database to 758 papers. Limiting studies to those on human adults resulted in 408 papers. These papers were then examined in full using the inclusion and exclusion criteria. Reference lists and citations of included studies were also checked to identify additional papers missed in the search. *Inclusion criteria* were studies involving adult overweight subjects, RCTs, studies measuring body weight as a primary outcome, and trials that included vegetable consumption in the primary intervention. *Exclusion criteria* were studies lacking an RCT design, studies where vegetable consumption was not noted in the dietary intervention, and trials where vegetables were not treated as a whole food. Applying these criteria reduced the database to 148 studies which were reviewed to identify 12 RCTs for detailed analysis as befitting the review question. In 2011 a further PubMed search was conducted for the period 2008 to 2011 using the keyword vegetable*. This produced 3481 papers. Adding weight* as a keyword reduced this to 549. Further limiting the search to clinical trials, meta-analysis, RCTs, and reviews and studies that only referred to adult subjects reduced this number to 95 papers. Hand searching of these papers produced a further four eligible studies (five papers, with one study reporting the six-month intervention and 12-month follow-up data). Combined with the original 12 RCTs, this produced a total of 16 RCTs for critical appraisal.

Each trial was analyzed in terms of their characteristics: profile of the study population (including study context, sample size, sex, and BMI), intervention and control diets, duration of intervention, and effects on weight loss. Comparisons were then made between trial designs that showed a positive effect from vegetable consumption with those that did not.

RESULTS

Of the 16 RCTs scrutinized, five reported greater weight loss effects from an intervention group targeting higher vegetable intake compared to a control group (Azadbakht et al., 2005; Burke et al., 2007; Ello-Martin et al., 2007; Svendsen et al., 2007; Shenoy et al., 2010) (Table 1), nine found no difference (Nowson et al., 2004; Gardner et al., 2005; Thomson et al., 2005; Whybrow et al., 2006; Rodriguez-Rodriguez et al., 2008; Saquib et al., 2008; Jenkins et al., 2009; Tanumihardjo et al., 2009; Lapointe et al., 2010b) (Table 2), and one showed weight gain (Djuric et al., 2002) (Table 3). Another study applied a cohort analysis to the trial and demonstrated an association between increased consumption of vegetables with greater weight loss (Sartorelli et al., 2008) (Table 3). On face value, the body of studies appears to present an inconclusive result. Nevertheless, there was substantial heterogeneity in study design, in particular with respect to vegetable dose and background diet.

Description of Trials

Study populations: Reports from 16 RCTs conducted in the period 2002 to 2011 (Djuric et al., 2002; Nowson et al., 2004; Azadbakht et al., 2005; Gardner et al., 2005; Thomson et al., 2005; Whybrow et al., 2006; Burke et al., 2007; Ello-Martin et al., 2007; Svendsen et al., 2007; Rodriguez-Rodriguez et al., 2008; Saquib et al., 2008; Sartorelli et al., 2008; Jenkins et al., 2009; Tanumihardjo et al., 2009; Lapointe et al., 2010b; Shenoy et al., 2010) were examined in detail (Table 1). They represented studies in eight different countries with sample sizes ranging from 49 to 100 (n = 11), 101 to 250 (n = 4), and >2000 (n = 1). Seven of the studies involved only females. BMI values of the study samples ranged from 23 to 38 kg·m^{-2}. The median BMI was around 28 kg·m^{-2}. which is in the overweight range (World Health Organization, 2011).

Intervention and control diets: Most of the interventions included a higher proportion of vegetables in the context of a healthy background diet (Djuric et al., 2002; Nowson et al., 2004; Azadbakht et al., 2005; Gardner et al., 2005; Thomson et al., 2005; Burke et al., 2007; Ello-Martin et al., 2007; Svendsen et al., 2007; Saquib et al., 2008; Sartorelli et al., 2008;

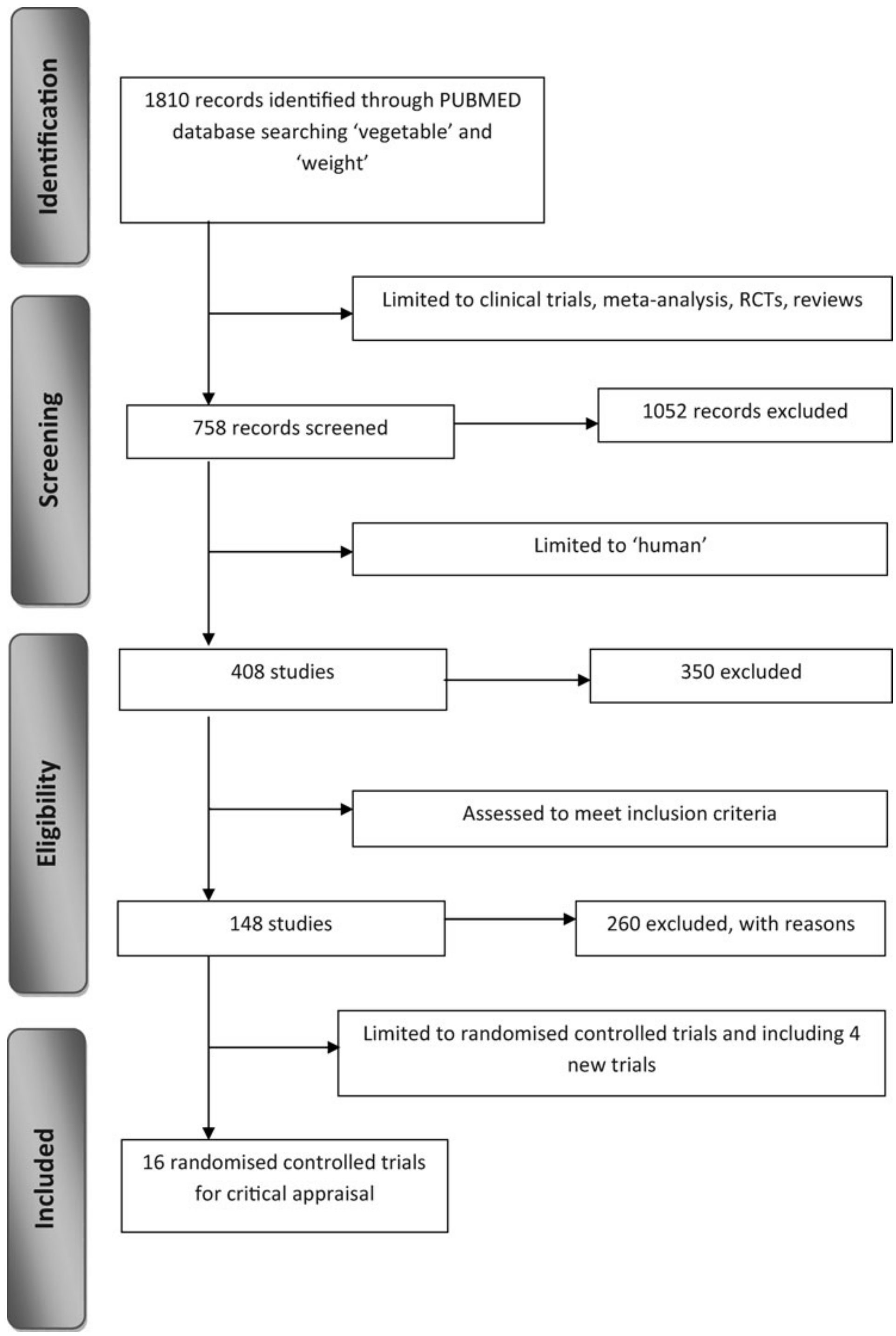

Figure 1 Search strategy flow diagram.

Tanumihardjo et al., 2009; Shenoy et al., 2010; Lapointe et al., 2010a, 2010b). The healthy background diet was defined by various means. For the intervention, four studies used the DASH diet framework (including five serves vegetables/day) (Nowson et al., 2004; Azadbakht et al., 2005; Burke et al., 2007; Shenoy et al., 2010), others specifically targeted high fruit and vegetable consumption (Djuric et al., 2002; Gardner et al., 2005; Thomson et al., 2005; Whybrow et al., 2006; Ello-Martin et al., 2007; Svendsen et al., 2007; Rodriguez-Rodriguez et al., 2008; Sartorelli et al., 2008; Saquib et al., 2008; Jenkins et al., 2009; Tanumihardjo et al., 2009; Shenoy et al., 2010; Lapointe et al., 2010a, 2010b), and one study provided participants with fruit and vegetables to consume in their usual diets (Whybrow et al., 2006). The nature and extent of dietary advice varied, with more

Table 1 RCTs on vegetables consumption and weight loss 1998 to 2010—Positive effects

Study population	Intervention diet(s)	Control diet	Duration	Results	Reference(s)
Iranian TLGS participants $n = 116$ (82 F, 34 M) MetS BMI = 29.7 ± 10 kg·m^{-2}.	DASH diet (including five serves vegetables/day) Energy deficit diet (-500 kJ)	Usual diet (assumed three serves vegetables/day)	six months	Greater weight loss with DASH diet compared to the control (-16 kg for M and -14 kg for F; $P < 0.001$) Greater weight loss with energy deficit diet compared to control (-13 kg for M and -12 kg for F; $P < 0.05$)	Azadbakht et al. (2005)
Australian $n = 241$ (134 F, 107 M) BMI = 30.0 ± 2.7 kg·m^{-2}.	DASH diet (including five serves vegetables/day)	Usual diet (approx. three serves vegetables/day)	four months	Greater weight loss with DASH diet compared to control (-2.8 kg; $P <$ 0.001)	Burke et al. (2007) —
American (USA) $n = 71$ (F) BMI = 33.3 ± 0.4 kg·m^{-2}.	Lower fat + FV (approx. 400 g FV/day)	Lower fat (LF) (approx. 300 g FV/day)	12 months	Greater weight loss in LF+FV compared to LF group (-1.5 kg; $P < 0.01$)	Ello-Martin et al. (2007) —
Norwegian $n = 138$ (35 F, 103 M) BMI = 36.7 ± 5.8 kg·m^{-2}.	Healthy diet(targeting ≥400 g/day vegetables and ≥300 g/day fruit)	Usual diet	three months	Greater weight loss from healthy diet (-2 kg; $P <$ 0.001)	Svendsen et al. (2007) —
USA (ethnically diverse) $n = 81$ (59 F, 22 M) BMI = 37.8 ± 4.9 kg·m^{-2}	8 fluid ozs. of low Na vegetable juice/day + DASH diet 16 fluid ozs. of low Na vegetable juice/day + DASH diet	No vegetable juice/day + DASH diet	12 weeks	Subjects consuming ≥ one serve of vegetable juice lost more weight than those who did not	Shenoy et al. (2010)

TLGS, Tehran lipid and glucose study; M, male; F, female.

specific advice limiting energy intakes. Given that weight loss results from a lowering of energy intake, there would have been a number of ways in which these strategies may have influenced this behavior (or not).

Duration of intervention: The period of intervention was four weeks to four years, but just over half of the studies were conducted for at least six months. Eleven of the studies were conducted over periods of four weeks to six months (Nowson et al., 2004; Azadbakht et al., 2005; Gardner et al., 2005; Whybrow et al., 2006; Burke et al., 2007; Svendsen et al., 2007; Rodriguez-Rodriguez et al., 2008; Sartorelli et al., 2008; Jenkins et al., 2009; Lapointe et al., 2010b; Shenoy et al., 2010), with two papers reporting 12-month data (Djuric et al., 2002; Ello-Martin et al., 2007), two reporting 18-month data (Tanumihardjo et al., 2009; Lapointe et al., 2010a), and two reporting a four-year follow-up (Thomson et al., 2005; Saquib et al., 2008). Thus there was evidence of short- and long-term effects, although the extent of intervention would vary across these periods.

Comparisons Between Trials

Study populations: There did not appear to be any particular regional pattern as to whether a study would show an effect or not. A greater weight loss in the intervention groups with higher vegetable consumption was found in different population groups. Positive effects were seen in studies from four regions of the globe: Iran (Azadbakht et al., 2005), Australia (Burke et al., 2007), USA (Ello-Martin et al., 2007; Shenoy et al., 2010), and Norway (Svendsen et al., 2007).

Intervention and control diets: A feature of the studies that showed a positive effect was the attention to the whole diet in the intervention model. The DASH diet framework was used in three of these studies (Azadbakht et al., 2005; Burke et al., 2007; Shenoy et al., 2010). The DASH diet stipulates the number of serves of staple food groups [vegetables, fruits, wholegrains, lean meats, low fat dairy foods (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010)] in a total diet, including five serves of vegetables/day. In two of these studies, the control diets were based on "usual intake" and this was assumed to be three serves vegetables per day (based on population surveys) which meant a difference between groups of two serves/day (Azadbakht et al., 2005; Burke et al., 2007). Both studies had low dropout rates (0 and 20%, respectively) and assessed dietary intakes to confirm the control diet intake of 3 and 2.7 serves vegetables/day, respectively. Their intervention intakes were below target, but higher than controls at 4.4 and 3.1 serves per day, respectively. The Iranian study included a second intervention diet of 500 kJ energy deficit (Azadbakht et al., 2005). While this group consumed less legumes than the DASH diet group, they reported consuming 4.1 serves vegetables per day and lost more weight than the controls ($P < 0.05$), but the DASH diet produced a greater weight loss ($P < 0.05$). The third study used a calorie deficit DASH diet for both the intervention and control groups, but were given vegetable juice in the intervention diets. This study found those who received the vegetable juice lost more weight than the control ($P < 0.05$) and those not consuming the vegetable juice reported a significantly lower vegetable intake ($P = 0.002$) (Shenoy et al., 2010).

Table 2 RCTs on vegetables consumption and weight loss 1998 to 2010—No effect

Study population	Intervention diet(s)	Control diet	Duration	Results	Reference(s)
Australian $n = 94$ (38 F, 56 M) BMI $= 29.0 \pm 3.8$ kg·m^{-2}.	DASH diet (including 5 serves vegetables/day) Low Na High K (LNHK) (including 5 serves vegetables/day) High Ca (HC) (no specification for vegetables)	Low Ca / Low K (including three serves vegetables)	two × four weeks	No difference in weight between DASH and control. Greater weight loss between LNHK and control (-0.4 kg; $P < 0.05$) Greater weight gain between HC and control ($+0.9$ kg; $P < 0.001$)	Nowson et al. (2004)
USA WHEL study participants $n = 2718$ (All F) BMI $= 27.3 \pm 6.3$ kg·m^{-2}.	Healthy diet (including ≥5 serves vegetables)	Usual diet	four years	Greater weight loss with healthy diet after one year (-0.05 kg; $P < 0.0001$) No difference after four years.	Saquib et al. (2008)
American (USA) WHEL study participants $n = 97$(F) BMI $= 26.7 \pm 4.5$ kg·m^{-2}.	Low fat diet (including eight serves fruit and vegetables/day)	General dietary advice for cancer prevention	four years	No difference between groups in body weight change	Thomson et al. (2005)
American (USA) $n = 120$ (60 F, 60 M) BMI $= 26.5 \pm 3$ kg·m^{-2}.	Low fat plus (including 10 serves vegetables/day)	Low fat (including two serves vegetables/day)	four weeks	No difference between groups in body weight change	Gardner et al. (2005)
Spanish $n = 49$ (F) BMI $= 28.5 \pm 2.8$ kg·m^{-2}.	20% energy deficit Vegetable diet (including 4.5 serves vegetables/day)	20% energy deficit Cereal diet (including 3.5 serves vegetables/day)	six weeks	No difference between groups in body weight change	Rodriguez- Rodriguez et al. (2008)
Scotland (UK) $n = 62$ (28 F, 34 M) BMI $= 23.7 \pm 2.7$ kg·m^{-2}.	300 g fruit and vegetables provided 600 g fruit and vegetables provided	No food supplements	two months	No difference between groups in body weight change	Whybrow et al. (2006)
USA $n = 60$ (44 F, 16 M) BMI $= 33.7 \pm 3.8$ kg·m^{-2} (Hi Vegetable); 33.3 ± 3.5 kg·m^{-2} (Reduction)	High vegetable (≥ eight serves/day) and moderate fruit (—two to three serves/day) consumption (Hi Vegetable)	Energy- and fat-reduction diet (Reduction)	18 months	Hi Vegetable group lost weight after three months ($P = 0.0087$), but did not maintain weight loss at 12 and 18 months. Control group lost weight at three months ($P < 0.0001$) and maintained weight loss at 12 and 18 months.	Tanumihardjo et al. (2009)
Canadian $N = 68$ (All F)	Positive messages to promote fruit and vegetable intake (Hi FV)	Restrictive messages to decrease fat intake (Lo FAT)	six months	Hi FV weight loss: -1.6 ± 2.9 kg ($P = 0.0004$) Lo FAT weight loss: -3.5 ± 2.9 kg ($P < 0.0001$) Lo FAT group lost more weight than Hi FV group from 0 to 6 months ($P = 0.01$)	Lapointe et al. (2010b)
Canadian $N = 68$ (All F) Weight $= 85.8 \pm 8.9$ kg (Lo FAT); 85.0 ± 8.9 kg (Hi FV)	Positive messages to promote fruit and vegetable intake (Hi FV)	Restrictive messages to decrease fat intake (LOFAT)	six-month intervention 12-month follow-up	No difference between groups in body weight change at 12-month follow-up	Lapointe et al. (2010a)
Canada/USA (ethnically diverse) $n = 47$ (26 F, 18 M) BMI $= 31.0 \pm 2.4$ kg·m^{-2} (High CHO); 30.6 ± 2.9 kg.m^{-2} (Low CHO)	40% energy deficit low CHO plant-based diet (low CHO: 26%, high vegetable protein: 31%, and vegetable oil: 43%)	40% energy deficit high CHO lacto-ovo vegetarian diet (58% CHO, 16% protein and 25% fat)	four weeks	No difference between groups in body weight change	Jenkins et al. (2009)

Table 3 RCTs on vegetables consumption and weight loss 1998 to 2010—Other effect

Study population	Intervention diet(s)	Control diet	Duration	Results	Reference(s)
American (USA) NABH study participants $n = 97$ (F) BMI: not specified Weight = 150 ± 30 lbs	Low fat (LF) High fruit and vegetable (HFV) Low fat–high FV (including nine serves vegetables and fruit/day)	Usual diet (approx. two serves FV/day)	12 months	Weight loss with LF: −11 lb ($P < 0.05$) Weight gain with HFV: +4 lb ($P < 0.05$) No change with LFHFV No change Control Diet	Djuric et al. (2002)
Brazilian Diabetes prevention trial participants $n = 80$ (61 F, 19 M) BMI = 28.7 ± 2.5 kg·m^{-2}.	Healthy diet (including five serves vegetables/day)	Usual diet	six months	Increased consumption of vegetables associated with greater weight loss (CI-0.00497; −0.008, −0.002)	Sartorelli et al. (2008)

While the DASH diet was not stipulated in other studies showing a positive effect, the same principles applied. In the 12-month American study (Ello-Martin et al., 2007), participants were given detailed instructions on the types and amounts of all foods to consume in a total diet model. Substantial behavioral support was provided through group and individual sessions, but the intervention group was given more information on alternatives to high fat foods (i.e., fruits and vegetables) compared to the control group. The intervention group in the three-month Norwegian trial (Svendsen et al., 2007) received 6 to 10 group support sessions in addition to the individual dietary advice provided to the control group. Both these trials assessed differences in vegetable intakes at the completion of the study (intervention vs. control = 416 vs. 302 g and 457 vs. 238 g, respectively) and produced relatively low dropout rates (27 and 7%, respectively).

Thus a key finding of this analysis was that studies that were able to show an effect from a higher vegetable intake paid particular attention to the total diet (including energy intakes), and focused on healthy diet models based on defined food groups in the high vegetable diets groups. They also confirmed a higher vegetable consumption in the intervention groups. To confirm this observation, we examined the dietary prescription detail of trials that failed to show an effect. In one study, no attempt was made to change the usual diet in the control and intervention groups, but moderate and high quantities of fruit and vegetables were provided to the intervention participants (Whybrow et al., 2006). A higher fruit and vegetable consumption was found compared to the control group in the two intervention groups (207 vs. 451 vs. 640 g/day, respectively), but no other effects, (and the dropout rate was moderate at 34%).

The lack of control on energy intakes might also explain the result from a crossover study with two DASH diet periods and two control (low vegetable) diet periods. In this study with a low dropout rate (3%), participants reported difficulty in consuming the amount of food (Nowson et al., 2004) and the proportion of dietary carbohydrate reported for the test diet period which was less than in the DASH study itself (Appel et al., 1997). Importantly though, the reported energy intake was higher in the DASH diet period compared to the control (1.4 MJ; $P < 0.001$). It should also be noted that the primary outcome for this study was change in blood pressure, not weight (Nowson et al., 2004). In this study, a second intervention group (low sodium and high potassium) that also included five serves of vegetables/day did produce a weight loss effect compared to the control (−0.4 kg; $P < 0.05$), but that may have reflected a tighter dietary prescription in that arm of the study. Since weight loss effects are dependent on energy deficit, a focus on energy control appears to be necessary

A second group of trials that did not show effects compared high vegetable diets with control diets that were also well controlled for energy intake. In one four-week trial, both the intervention and control diets were tightly controlled, food was provided, and almost total compliance was achieved, with a low dropout rate (4%) (Gardner et al., 2005). In this trial, both diets were designed to provide the same levels of energy, total and saturated fat, protein, carbohydrate, and cholesterol, but the intervention diet contained much greater amounts of vegetables (10 vs. 2 serves), wholegrains, and legumes. There was no difference between groups in weight loss, but the intervention diet produced greater reductions in total and LDL cholesterol levels ($P < 0.05$). Another trial was a six-week intervention where both diets had a 20% energy deficit and the control emphasized cereals rather than vegetables (Rodriguez-Rodriguez et al., 2008). Differences in vegetable consumption were measured (control 3.48 serves/day; NS from baseline; intervention 4.84 serves/day vs. 2.94 at baseline; $P < 0.01$) and the dropout rate was mild (17%). There were some noted differences in micronutrient status reflecting the food sources. Likewise, a more recent study comparing plant-based low carbohydrate diet with a high carbohydrate lacto-ovo vegetarian diet found a similar weight loss effect with study foods providing 60% of calorie requirements (Jenkins et al., 2009). In all of these studies, energy intakes were constrained to a similar extent in both the control and high vegetable diets.

Thus where both the control and intervention diets focus on healthy eating patterns and control for energy intakes, a difference in weight loss is not likely to be seen. This is logical as weight loss is contingent on control of energy intake. A high vegetable intake may have a further influence on weight if it causes even greater reduction in energy intake, possibly through increased satiety [an effect possibly seen in the Shenoy study (Shenoy et al., 2010)]. Higher vegetable intake may also modify the total dietary fat and fiber content and have effects on blood lipids. Vegetables may also deliver phytochemical that may have a positive effect on the inflammatory status of the person. These latter effects may not be associated with weight loss but could improve overall health status.

A third group of trials were all longer-term behavioral interventions targeting changes in dietary patterns. These studies focus more on general dietary advice strategies rather than specific individualized dietary advice with attention to all food groups. A recent Canadian trial comparing positive messages to promote fruit and vegetables versus eat less fat found the low fat strategy more effective at six months (Lapointe et al., 2010b), but there was no difference between groups at the 12-month follow-up (Lapointe et al., 2010a). This was similar to a previous US trial that found both the high vegetable and low fat advice strategy effective at three months, but better maintained at 12 and 18 months by the low fat strategy (Tanumihardjo et al., 2009).

The remaining studies were analyses conducted within larger trials, such as the Women's Healthy Eating and Lifestyle (WHEL) (Thomson et al., 2005; Saquib et al., 2008) and Nutrition and Breast Health (NABH) (Djuric et al., 2002) studies and the Brazilian Diabetes prevention trial (Sartorelli et al., 2008), comparing healthy diets (significantly containing vegetables) with usual diet. Two studies assessed outcomes after four years in participants recruited from the WHEL cancer prevention trial (Thomson et al., 2005; Saquib et al., 2008). At this stage, the behavioral support took the form of telephone counseling and monthly cooking classes (S) or quarterly phone calls (T). In the Saquib et al. study (2008), the intervention group had increased its daily vegetable intake by 2.7 serves at one year and 2.3 serves at four years. A greater weight loss in the intervention group was observed after one year (−0.05 kg; $P < 0.001$) but not after four years. In the Thomson et al. study (2005), compared to virtually no change in the control group, the intervention group demonstrated an initial increase in daily serves of fruits and vegetables consumed after six months which declined with time (4.7 at baseline, 8.4 at six months, 7.3 at 12 months, and 5.3 at 48 months). This pattern concurred with the intensity of the dietary support. The dropout rates were also higher (15 and 32% S) as would be expected for the longer-term follow-up. Within the NABH trial, the 12-month dietary study (Djuric et al., 2002) found a low fat dietary advice strategy to be the most effective for weight loss (−111 b, $P < 0.05$), but that advice to increase a food intake (even if it is fruit and vegetables) resulted in weight gain (+41 b, $P < 0.05$). When the negative diet message (low fat) was combined with a positive one (increase F&V), then weight maintenance was seen. Within the Brazilian Diabetes prevention trial, the authors of the dietary study (Sartorelli et al., 2008) applied a different form of analysis to examine the association between increased vegetable consumption and weight loss. In this way, they were able to show a positive effect of vegetable consumption on weight loss (CI: 0.00497; −0.008, −0.002).

Duration of Intervention

The studies that showed a difference in effects were designed specifically to test the effects of a high vegetable consumption and were conducted between three and 12 months. Shorter-term studies tended to have tight controls on energy intake in both the control and intervention groups, and longer-term studies tended to be behaviorally focused and opportunistic. In the latter case, the analysis was more observational in nature and there were likely to be confounding factors that would be difficult to overcome in specifically exposing the effects of vegetable consumption.

DISCUSSION

On face value, this review confirmed an inconclusive position on the effect of vegetable consumption on weight loss. Trials of various durations were located from across the world, involving essentially overweight populations, but with variations in study design. A key finding was that studies that were able to show a desirable effect paid particular attention to the total diet (including energy intakes), and focused on healthy diet models based on defined food groups in the high vegetable diets groups. These studies also confirmed a higher vegetable consumption in the intervention groups. Secondly, it appeared that dietary strategies that focus on the behavioral choices of low fat eating or eating more vegetables do not necessarily test the effects of high vegetable consumption. These are behavioral strategies rather than "whole of diet" prescriptions that enable a focus on individual food groups. Finally, behavioral interventions can also be found embedded in larger disease-focused studies. They provide an opportunity to make observations on effects of vegetable consumption in that context but are not specifically designed to test the effects of a high vegetable consumption on weight loss outcomes.

Notwithstanding weight loss effects, where energy intake is controlled in both the intervention and control diets, improvements in other related health variables (lipids and micronutrient status) can be seen. This suggests that more subtle outcomes might deserve greater attention in food-based studies in overweight populations. In our own research, we find that when we provide structured dietary advice to both the control and intervention arms, we do not see a difference in overall energy intakes and subsequent weight loss (Tapsell et al., 2004; Tapsell et al., 2009; Tapsell et al., 2010). However, we do see a difference in other risk factor variables that may reflect dietary attributes other than total energy. For example, in our trials (Tapsell et al., 2004; Tapsell et al., 2009) including walnuts in the diet model resulted in a substitution of saturated fat (SFA) with polyunsaturated fat (PUFA) which may have influenced other risk factors associated with the metabolic syndrome. A recent meta-analysis has shown that replacing dietary SFA with PUFA is important in reducing risk of coronary heart disease (Mozaffarian et al., 2010).

Given that weight loss is dependent primarily on total dietary energy, there are substantial implications for RCT design. While studies that control for dietary patterns (structured advice vs. usual diet) may produce differences in weight loss, studies that control for individual foods (structured advice with test food vs. structured advice with control food) might elucidate more subtle effects on related disease risk factors. The DASH diet background may have a particular profile that results in more effective weight loss than a simple energy deficit diet, but as the authors of one of the studies (Azadbakht et al., 2005) noted, one of the limitations of this "whole of diet" research is that it cannot clearly differentiate between individual foods and the sum of the parts in diet.

When food is simply added to usual intakes, it is not surprising that weight loss effects are not seen. This was the case in a vegetable supplementation study (Whybrow et al., 2006), where both the control and intervention groups applied a "usual diet" framework. It is important to note that this group had a lower BMI (23.7 $\pm$ 2.7 kg$\cdot$m^{-2}.), compared to the others ($\sim$26–36 kg$\cdot$m^{-2}.). This design may be useful in seeing if supplementation had any behavioral effect on total intake (e.g., by displacing other foods or increasing satiety). This did not appear to be the case, at least not in a less overweight group. Where we have used supplemental foods and advised participants to replace other foods with the supplements in a "usual diet" framework, we have found that providing supplemental foods increased overall energy intake and introduced a confounder of weight gain (Murphy et al., 2007). This was also the case in another of the studies reviewed here (Djuric et al., 2002), where the arm receiving advice to consume large amounts of fruit and vegetables produced weight gain. In the end, it is not vegetable consumption *per se* that affects weight loss, but total dietary energy. This is an important distinction that needs to be drawn in RCTs for foods. Under certain dietary conditions increased vegetable consumption may support weight loss but they also deliver components that may have protective effects on disease risk factors.

In a recent multicentre trial of various dietary prescriptions for weight loss, it was found that no difference between diet groups could be found in the long term, however, dietary targets were not reached in many cases (Sacks et al., 2009). In order to answer the question, does a higher intake of vegetables produce a greater weight loss, it is necessary to know that the trials produced a different intake between comparative groups. In the studies we reviewed, these differences were confirmed, although the intakes at the end of the intervention were not always as high as intended. The serve sizes varied between but not within studies, and most studies did not specify the types of vegetables used. Both of these factors may benefit from further research in exposing greater detail on the effects of vegetable consumption. Where longer-term follow-up (four years) was reported, the lack of effects may have been due to the reported decline in vegetable intake (Thomson et al., 2005; Saquib et al., 2008). The reason for the decline in intakes may have to do with the extent of support for behavior change. In this case, we can only say that the advice strategy, not higher vegetable consumption itself, failed to show a long-term effect.

In the two long-term studies reviewed here (Thomson et al., 2005; Saquib et al., 2008), the reduction in contact and change in nature of behavioral support between the early and later stages of the intervention are likely to explain the difference in intakes and thereby effects seen at one year vs. four years. The detailed behavioral support for the intervention groups in which positive effects were seen (Ello-Martin et al., 2007; Svendsen et al., 2007) was also likely to assist in those studies being able to produce effects due to high levels of compliance to the study diets. Given the complexity of dietary change and the need for a good understanding of food attributes, behavioral support and dietary counseling is an important element of dietary intervention design. In other major dietary intervention trials, effects seen reflect the intensive dietary counseling and advice provided to participants (Zazpe et al., 2008). In our review of the literature, successful trials were able to demonstrate effects at 3, 4, 6, and 12 months. In our own trials, we have consistently shown significant effects in the first intensive period of intervention (Tapsell et al., 2004; Tapsell et al., 2009; Tapsell et al., 2010), but with a waning after six months when contact is less intense. We suggest that the true effects of diet can be established within a couple of months with strong support, and that any recidivism is likely to be due to changes in food choice. Future studies may need to focus attention on behavioral support in the later stages of longer-term studies so that effect of the dietary model is not confused with efficacy of the treatment advice.

On face value, there is some evidence that a healthy diet higher in vegetables may be conducive to weight loss in overweight adults. In the studies reviewed better weight loss was consistently found in higher vegetable (and otherwise healthy) intervention diets compared to "usual diets." This effect was seen regardless of the considerable variation in the manner in which weight loss results were reported and analyzed. Factors over and above weight loss are of clear interest in dietary studies, given that in addition to weight loss (Thomson et al., 2005; Ello-Martin et al., 2007; Rodriguez-Rodriguez et al., 2008; Saquib et al., 2008; Sartorelli et al., 2008), the outcomes analyzed for the studies reviewed here ranged from multiple features of the metabolic syndrome (Azadbakht et al., 2005; Burke et al., 2007; Svendsen et al., 2007), weight loss and dietary compliance (Djuric et al., 2002; Whybrow et al., 2006), plasma lipids (Gardner et al., 2005), and blood pressure (Nowson et al., 2004). Given that the primary outcome was not always weight loss, the main reported result for our purposes was the weight loss compared to baseline and/or comparative group. We have found that even with isocaloric dietary advice strategies, weight loss results from dietary intervention (Tapsell et al., 2004; Tapsell et al., 2009; Tapsell et al., 2010), so greater confidence would be expected where results are presented with significant time X group effects. This may not always do justice to the research, however. In their study of participants in a Diabetes prevention trial, Sartorelli et al. (Sartorelli et al., 2008) argued for the value of presenting the analysis on the total group data, exposing the relationship between increased vegetable consumption and greater weight loss. This was in consideration of the substantial problems with drop outs and lack of compliance in conducting food-based dietary interventions under free living conditions. This is an important issue and has implications for publication bias, given the increasing requirement to register clinical trials and address study attributes as outlined in the CONSORT statement (Schulz et al., 2011). To this end, we also acknowledge the limitations of our review in that we did not formally apply critical appraisal methods outlined in the Cochrane or PRISMA approaches (Moher et al., 2009), however, the focus of this review was to highlight issues of study design rather than establish an evidence statement for practice where risk of bias is a critical consideration. Indeed, we may have uncovered another form of bias that may require more detailed attention.

CONCLUSION

This review found evidence that a higher vegetable consumption in a healthy diet may prove beneficial for weight loss in overweight adults from Western populations when the trial compares a healthy high vegetable diet with a control diet based on usual consumption patterns, and where behavioral support and counseling are provided throughout the period of the study. Changes in dietary intakes need to be confirmed by dietary assessment techniques, and there are challenges for considering how the results might best be analyzed and presented. This is because body weight is dependent on total energy intake, but more subtle effects related to the pathology of overweight (such as effects on lipids, blood pressure, and other biomarkers) may help to differentiate the benefits of single foods that would otherwise appear to have a real place in a healthy weight loss diet.

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