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The effect of increased fruit and vegetable consumption on selected macronutrient and micronutrient intakes in four randomised-controlled trials

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Abstract

Fruit and vegetable (FV) intake is associated with reduced risk of a number of non-communicable diseases. Research tends to focus on antioxidants, flavonoids and polyphenols contained in FV as the main beneficial components to health; however, increasing FV may also alter overall diet profile. Extra FV may be substituted for foods thought to be less healthy, therefore altering the overall macronutrient and/or micronutrient content in the diet. This analysis merged dietary data from four intervention studies in participants with varying health conditions and examined the effect of increased FV consumption on diet profile. Dietary intake was assessed by either diet diaries or diet histories used in four FV randomised intervention studies. All food and drink intake recorded was analysed using WISP version 3.0, and FV portions were manually counted using household measures. Regression analysis revealed significant increases in intakes of energy (172 kJ (+41 kcal)), carbohydrate (+3·9 g/4184 kJ (1000 kcal)), total sugars (+6·0 g/4184 kJ (1000 kcal)) and fibre (+0·8 g/4184 kJ (1000 kcal)) and significant decreases in intakes of total fat (−1·4 g/4184 kJ (1000 kcal)), SFA (−0·6 g/4184 kJ (1000 kcal)), MUFA (−0·6 g/4184 kJ (1000 kcal)), PUFA (−0·1 g/4184 kJ (1000 kcal)) and starch (−2·1 g/4184 kJ (1000 kcal)) per one portion increase in FV. Significant percentage increases were also observed in vitamin C (+24 %) and -carotene (+20 %) intake, per one portion increase in FV. In conclusion, pooled analysis of four FV intervention studies, that used similar approaches to achieving dietary change, in participants with varying health conditions, demonstrated an increase in energy, total carbohydrate, sugars and fibre intake, and a decrease in fat intake alongside an expected increase in micronutrient intake.

Key words: Fruit and vegetable intake: Dietary intake: Randomised intervention trials

Non-communicable diseases such as CVD, cancers and diabetes are the leading causes of death, contributing to 63 % of global deaths in 2008[1]. Many of the main risk factors for such diseases (including poor diet, excess body weight and physical inactivity) are modifiable[2,3]. The dietary risk factors are high intakes of fat, particularly SFA, and low intakes of fruit and vegetables (FV)[4,5].

For the last few decades evidence has continued to emerge supporting a beneficial association between increased FV intake and risk of chronic disease. A possible mechanism for such a relationship has been attributed to their high-micronutrient intake. However, it is also postulated that FV may exert their health benefits through displacing less nutrient-dense foods from the diet thus improving the overall profile of the diet. A recent systematic review examining the effect of FV intervention studies (where FV only were increased)[6–17], on macronutrient intake recently indicated that FV interventions had additional benefits on the overall diet profile over and above increased micronutrient intake[18]. Specifically, there were increases in carbohydrate, fibre and micronutrient intakes and possible decreases in fat intakes. This systematic review also indicated that participants were substituting FV for other foods, as energy intakes did not significantly change. The studies included

Abbreviations: ADIT, Aging and Dietary Intervention Trial; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial; FV, fruit and vegetable; FVD, Fruit and Vegetable in Diabetes.

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in this systematic review were, however, heterogeneous in terms of population studied, dietary advice given, dietary assessment method used, intervention duration and how provision of the FV was achieved[18]. Although there was little heterogeneity observed in the meta-analysis, estimates were based on crude group differences, whereas an ability to conduct a similar analysis using individual-level data would be more robust.

We have conducted a number of FV intervention studies, using similar approaches to achieve dietary change, which examined a range of clinically relevant endpoints in different populations. In this analysis we merge dietary intake data from four intervention studies[19–22] conducted in participants with various health status (type 2 diabetes, hypertension, chronic obstructive pulmonary disease (COPD) and in healthy older people) and examine the effect of increased FV consumption on the overall macronutrient (energy, protein, total fat, SFA, MUFA, PUFA, total carbohydrate, sugar, starch, dietary fibre) and micronutrient (vitamin C, β-carotene) profile of the diet.

Methods

All four FV randomised intervention trials were carried out at Queen's University, Belfast. Summaries of each study design are reported in Table 1. The primary outcome results, including basic demographics and inclusion/exclusion criteria from the four studies have been reported in previously published peer-reviewed journals[19–22], therefore only dietary intake data will be presented here. The studies were conducted under the guidelines laid down in the Declaration of Helsinki. Study procedures for the Aging and Dietary Intervention Trial (ADIT), the Fruit and Vegetable in Diabetes (FVD) study and Dietary Intervention Study in COPD (DISCO) were approved by the Office for Research Ethics Committees Northern Ireland, whereas the Fruit and Vegetable Randomised Intervention Trial (FAVRIT) was approved by the Queen's University of Belfast Research Ethics Committee. Written informed consent was given by all participants involved in the studies.

Design of the dietary interventions

As previously reported[19–22], the duration of the interventions differed between studies, with one study being conducted over 16 weeks (ADIT), one study 12 weeks (DISCO) and two studies lasting 8 weeks (FVD and FAVRIT). The approaches used to deliver the dietary intervention were similar across the four intervention studies. The type and amount of FV provided to participants was based on individual FV preference and on group allocation, respectively. Participants were allowed a free choice of FV for consumption during the studies. More specifically, at the start of each study, participants were provided with a list of FV (fresh, frozen, dried, tinned or juice) that were available in the local supermarket, from which they were able to indicate their likes and dislikes of specific FV. This was subsequently used to guide the researcher responsible for purchasing the FV. Feasibility issues such as storage of FV, cooking methods and preparation of composite dishes were also discussed with the participant at the time of FV selection.

Table 1. An overview of the study design of the four fruit and vegetable (FV) intervention studies included in the pooled analysis

Study name (study year)	Primary endpoint	*N*	*n*	Duration of trial	Randomisation (portions/d)	Age range	Health status	Diet data	Follow-up visits
ADIT (2006–2008)	Immune function	82	82	16 weeks (no washout; low-FV consumers recruited)	2 or 5 (FV provided)	65–85 years	Healthy older people	Diet history	0, 6, 12 and 16 weeks
DISCO (2007–2009)	Oxidative stress and inflammation	80	77	12 weeks (no washout; low-FV consumers recruited)	2 or 5 (5 portion group, FV provided)	43–86 years	Moderate to severe COPD (FEV_1 <80 %)	Diet history	0, 6 and 12 weeks
FAVRIT (2004–2006)	Vascular function	117	97	8 weeks (+4 weeks washout; ≤1 portion FV)	1, 3 or 6 (FV provided)	40–65 years	Hypertensive	4-d diet diary	Baseline, 0, 4 and 8 weeks
FVD (2006–2008)	Vascular function	80	60	8 weeks (+4 weeks washout; ≤1 portion FV)	1 or 6 (FV provided)	40–70 years	Type 2 diabetics	7-d diet diary	Baseline, 0 and 8 weeks

N, number of participants in study; *n*, number of participants with complete dietary data; ADIT, Aging and Dietary Intervention Trial; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial; FVD, Fruit and Vegetable in Diabetes study.

A prescriptive list was not offered to participants at any stage. Moreover, participants were encouraged to consume as wide a variety of FV throughout the intervention as possible. In all of the studies, the FV were provided free of charge each week to maximise compliance with the intervention, while minimising personal expense and maximising food freshness. Compliance was further encouraged by providing participants with menu suggestions and recipes. Participants were also contacted at weekly intervals by telephone to monitor any difficulties and provide positive reinforcement.

Fruit and vegetable intakes during the interventions

The change in FV intake in each of the intervention studies has previously been reported in the main papers from these studies[19–22]. Summary details of these results are presented in Table 2. In all of the studies, participants in the high-FV intervention groups showed greater increases in FV intakes at the end of the intervention compared with the low-FV intervention groups. To deal with any variation in compliance with the intended intervention, self-reported FV intake was used rather than allocated intervention group.

Dietary intake data

In the four intervention studies, two studies (ADIT and DISCO) used a 7-d diet history approach and two studies (FAVRIT and FVD) used the self-completed diet diary approach (FAVRIT used 4-d diaries and FVD used 7-d diaries). The following sections describe each of these dietary methods.

7-d diet histories. Habitual dietary intake of participants in the ADIT and DISCO studies[20,21] was assessed by interviewer-administered diet histories at baseline and at each of the follow-up visits (Table 1). The diet history interview, which lasted approximately 1 h, captured detailed information on habitual dietary intake including main meals (breakfast, lunch, dinner) and snacks; weekday and weekend meal pattern; location and time of food consumption; food preparation methods; home-made recipes; and portion sizes. In case of FV intake, participants were asked whether the fruit or vegetables were fresh, frozen, tinned, dried or pureed. Amounts of foods were reported in household measures (e.g. one tablespoon) or natural measures (e.g. one slice). Food portion sizes[23] were also used to quantify intakes. Energy, macronutrient and micronutrient intakes from foods and beverages recorded in the diet histories were calculated using a computerised food analysis database based on UK food composition tables (WISP; Tinuviel Software).

Diet diaries. Habitual dietary intake of participants in the FAVRIT[19] and FVD study[22] was assessed using a 4-d and 7-d diet diary, respectively. To monitor compliance, diet diaries were collected at baseline and at each of the follow-up visits (Table 1). Participants recorded all food and drinks consumed over a consecutive 4-d or 7-d period (to include at least 2 weekdays and 2 weekend days) for the FAVRIT and FVD study, respectively. Details of the types of food and drink consumed including cooking methods and estimated portion sizes in household measures or as a weight recorded from food packaging were recorded. Food portion sizes[23] were also used to quantify intakes. The same computerised food analysis database, as detailed above, was used to calculate energy, macronutrient and micronutrient intakes from foods and beverages recorded in the diet diaries.

Fruit and vegetable counts. The numbers of portions of FV consumed by each participant at each time point during the intervention studies were manually counted from the self-reported diet histories and diet diaries by at least one independent researcher who was blinded to the group allocation of participants. Household measures, used throughout the diet histories and diet diaries, were used as a guideline for counts (e.g. one portion was equal to one apple, two plums, 150 ml fruit juice or three heaped tablespoons of vegetables)[24]. One average glass of fruit juice could only be counted as one portion in a day, in line with Department of Health recommendations. Three tablespoons of pulses, such as baked beans, were also only counted once per day[24]. Portion counts for the number of recording days (i.e. 4 d for the FAVRIT study and 7 d for the other three studies) were totalled and then divided by the number of days to give an average daily portion count at each time point.

Table 2. An overview of changes in fruit and vegetable intake in the four fruit and vegetable intervention studies included in the pooled analysis (Mean values, standard deviations and 95 % confidence intervals)

Study name	Randomisation (portions/d)	Baseline fruit and vegetable intake (portions/d)		Post intervention fruit and vegetable intake (portions/d)		Change in fruit and vegetable intake from baseline (portions/d)	
		Mean	SD	Mean	SD	Mean	95 % CI
ADIT	2	1·4	0·6	1·7	0·5	0·3	0·1, 0·6
	5	1·4	0·5	6·0	1·3	4·6	4·2, 5·0
DISCO	2	1·4	0·6	1·9	0·6	0·5	0·3, 0·8
	5	1·5	0·7	5·8	1·5	4·2	3·7, 4·7
FAVRIT	1	1·8	1·2	1·0	0·5	– 0·8	– 1·3, –0·3
	3	2·2	0·9	3·3	0·9	1·1	0·6, 1·6
	6	3·1	1·3	5·4	0·9	2·3	1·7, 2·8
FVD	1	2·0	1·0	1·4	0·6	– 0·6	– 1·0, –0·1
	6	2·0	1·2	5·3	1·2	3·3	2·6, 4·0

ADIT, Aging and Dietary Intervention Trial; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial; FVD, Fruit and Vegetable in Diabetes study.

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Pooling of dietary results. Owing to the intervention studies being carried out for different periods of time and having different follow-up visits (Table 1), all four studies could not be analysed in a uniform fashion. For ADIT and DISCO, week 0 and week 6 were used and compared with baseline and week 8 from FAVRIT and FVD. Week 0 and baseline were equivalent time points from these studies as both assessed the habitual dietary patterns of their participants. Weeks 6 and 8 assessed the diet of the participants during the intervention period and were sufficient in length to capture any changes which may have been made to the diet, whereas also being closest in length.

Statistical methods

Average daily dietary intake data generated from WISP-DES version 3.0 for each intervention study were transferred to SPSS version 17.0 (SPSS Inc.) for statistical analysis. Macronutrients selected for analysis were those which had been considered in a previous systematic review and meta-analysis[18]: energy (kJ (kcal)); protein (g); carbohydrate (g); total sugars (g); starch (g); total fat (g); SFA (g), MUFA (g) and PUFA (g); and dietary fibre (g), all of which were energy adjusted. Two micronutrients were selected for analysis based on their close association with FV intakes; these were vitamin C and β-carotene. β-Carotene intakes were as specified by McCance and Widdowson's food composition tables (i.e. the sum of β-carotene plus half of any α-carotene and cryptoxanthins present). Macronutrient and micronutrient intakes were adjusted for energy by dividing the respective values by the energy intake and expressing the final values in g/4184 kJ (1000 kcal). The distribution of *variables* was checked and logarithmic transformations were performed for vitamin C and β-carotene to satisfy the assumptions for regression analysis. Changes in self-reported FV portions and in macronutrient and micronutrients between week 6 or 8 and week 0 or baseline were calculated by subtracting week 6 or 8 values from week 0 or baseline values. Results for vitamin C and β-carotene are presented as percentage change. Macronutrient and micronutrient changes were then regressed on FV portion changes, the slope providing an estimate of the macronutrient and micronutrient change associated with a one portion change in FV intake. A scatter plot of energy as an example is shown in Fig. 1. Before pooling results from the four studies we assessed, in each study, if the effect of the change in FV portions on macronutrient and micronutrient intake changes varied by the sex or age of the participant. This was carried out by adding interaction terms between age/sex and change in FV intake into the regression analyses. In light of multiple testing in the absence of any prior hypothesis, these tests for interaction were assessed using a significance level of $P < 0.01$ (Bonferroni corrections for four trials × six nutrients = twenty-four comparisons). The slopes and their standard errors from the four studies were then input into RevMan version 5.1 (Nordic Cochrane Centre) and a random effects model used to pool results from the four studies. Tests for heterogeneity of slopes between studies were performed and forest plots generated. A significance level of $P < 0.05$ was used for testing the pooled results.

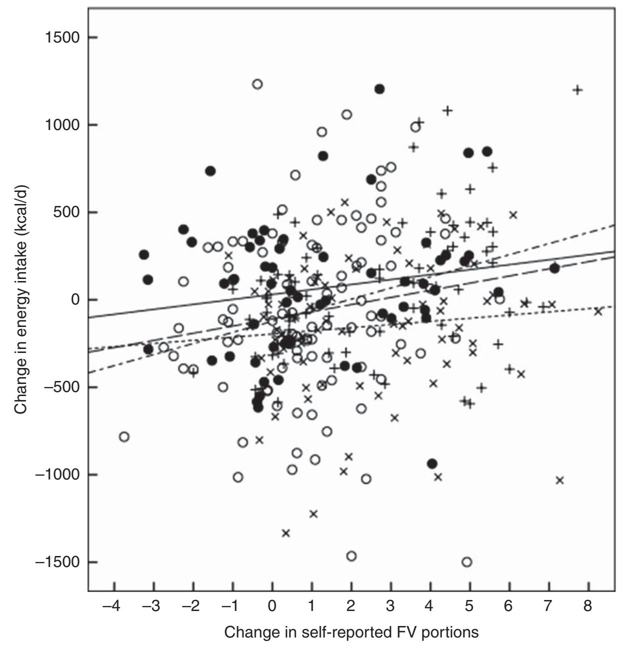

Fig. 1. Scatter plot of change in energy plotted against fruit and vegetable (FV) portion changes, the slope providing an estimate of energy intake change associated with a one portion change in FV intake. FV, fruit and vegetable. ---+---, Aging and Dietary Intervention Trial; —●—, Fruit and Vegetable in Diabetes study; ····×····, Dietary Intervention Study in COPD; - -○- -, Fruit and Vegetable Randomised Intervention Trial. To convert kcal/d to kJ/d, multiply by 4·184.

Results

In total, 359 participants completed the four FV intervention studies. However, not all participants returned fully completed diet diaries and diet histories; complete dietary data were available for 316 (88 %) of the participants (ADIT, *n* 82; DISCO, *n* 77; FAVRIT, *n* 97; FVD, *n* 60). Linear regression analyses on the individual study results found no significant interactions which would have indicated that the relationship between change in nutrients and change in self-reported FV consumption depended on age or sex. Similar interactions fitted to the pooled study data were also non-significant.

Baseline characteristics of participants

The pooled sample included 175 males and 141 females with a mean age of 61·6 (SD 9·8) years (range 40–86 years). Based on BMI classifications, 0·3 % (*n* 1) of participants were defined as underweight, 22 % (*n* 69) were normal weight, 40 % (*n* 127) were overweight and 38 % (*n* 119) were clinically obese at baseline. The mean baseline FV intake of the pooled sample of participants was 1·85 (SD 1·0) portions/d.

Change in selected macronutrients per one portion increase in fruit and vegetables

Forest plots displaying the meta-analysis for energy and macronutrients are shown in Fig. 2 and 3.

Energy (kJ (kcal)). The pooled results in Fig. 2 for energy show that a one portion increase in FV was associated with a 172

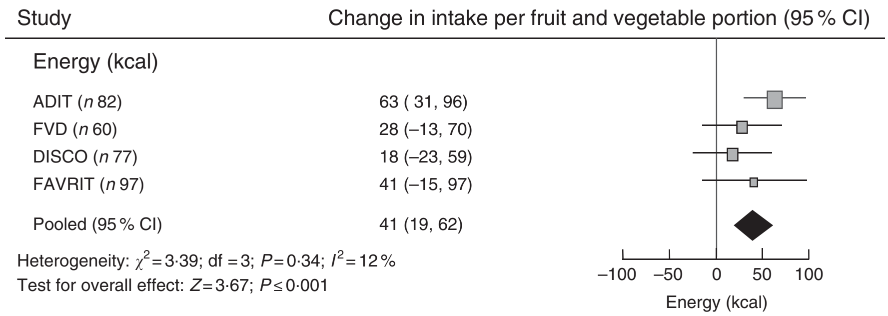

Fig. 2. Forest plots showing the pooling over four randomised-controlled trials of regression estimates of the change in energy intake per portion increase in fruit and vegetables. ADIT, Aging and Dietary Intervention Trial; FVD, Fruit and Vegetable in Diabetes; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial. To convert kcal to kJ, multiply by 4·184.

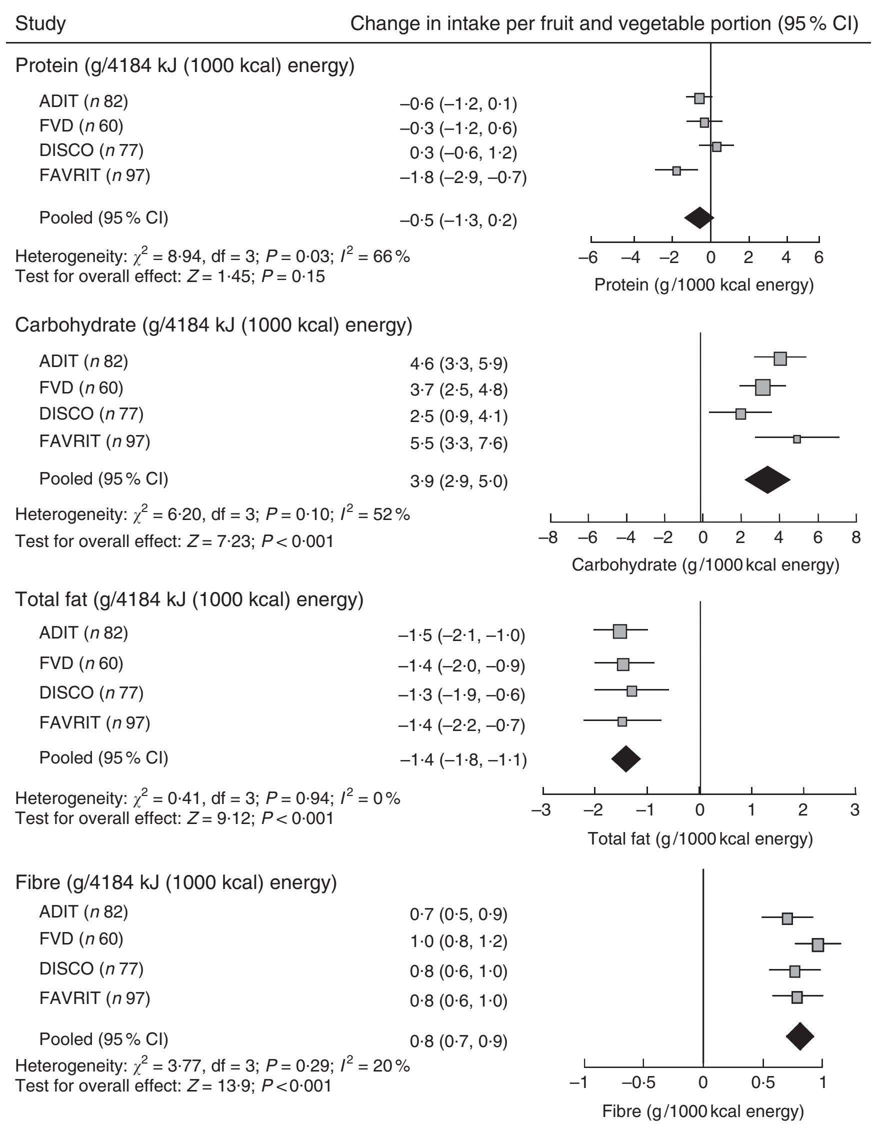

Fig. 3. Forest plots showing the pooling over four randomised-controlled trials of regression estimates of the change in protein, carbohydrate, total fat and fibre intake per portion increase in fruit and vegetables. ADIT, Aging and Dietary Intervention Trial; FVD, Fruit and Vegetable in Diabetes; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial.

(95 % CI 19, 62) kJ (41 (95 % CI 19, 62) kcal) increase in energy intake, which was statistically significant ($P < 0{\cdot}001$). There was no evidence of heterogeneity between studies ($P = 0{\cdot}34$).

Protein (g/4184 kJ (1000 kcal) energy). The pooled results in Fig. 3 show that a one portion increase in FV was associated with a 0·5 (95 % CI −1·3, 0·2) g/4184 kJ (1000 kcal) decrease in protein although this was not statistically significant ($P=0·15$). There was significant heterogeneity between studies ($P=0·03$).

Carbohydrate (g/4184 kJ (1000 kcal) energy). The change in carbohydrate intake per one portion increase in FV (shown in Fig. 3) shows the pooled estimate for all studies was 3·9 (95 % CI 2·9, 5·0) g/4184 kJ (1000 kcal), which again was statistically significant ($P<0·001$). There was little evidence of heterogeneity between studies ($P=0·10$). Significant increases in sugar (5·98 (95 % CI 4·8, 7·1) g/4184 kJ (1000 kcal)) and decreases in starch (–2·1 (95 % CI –3·1, 1·0) g/4184 kJ (1000 kcal)) were evident per one portion increase in FV (both $P<0·001$). There was little evidence of heterogeneity between studies for sugar ($P=0·06$) but significant between study heterogeneity was observed for starch ($P=0·03$).

Fat (g/4184 kJ (1000 kcal) energy). The forest plot in Fig. 3 illustrates that a one portion increase in FV was associated with –1·4 (95 % CI –1·8, –1·1) g/4184 kJ (1000 kcal) change in total fat intake, which was statistically significant ($P<0·001$). There was no evidence of heterogeneity between studies ($P=0·94$). Significant decreases in SFA (–0·58 (95 % CI –0·7, –0·4) g/4184 kJ (1000 kcal), $P<0·001$), PUFA (–0·12 (95 % CI –0·2, 0·0) g/4184 kJ (1000 kcal), $P=0·03$) and MUFA (–0·57 (95 % CI –0·70, –0·45) g/4184 kJ (1000 kcal), $P<0·001$) were observed per one portion increase in FV, with no evidence of heterogeneity between studies ($P=0·85$, 0·7, 0·48, respectively).

Fibre (g/4184 kJ (1000 kcal) energy). Fig. 3 demonstrates that the change in dietary fibre intake per one portion increase in FV was 0·8 (95 % CI 0·7, 0·9) g/4184 kJ (1000 kcal), which was also statistically significant ($P<0·001$). There was no evidence of heterogeneity between studies ($P=0·29$).

Change in selected micronutrients per one portion increase in fruit and vegetables

Vitamin C (percentage increase after adjustment for energy). Fig. 4 shows that a one portion increase in FV was associated with a 24 (95 % CI 20, 29) % increase in vitamin C intake after adjustment for energy, which was statistically significant ($P<0·001$). There was no evidence of heterogeneity between studies ($P=0·13$).

β-Carotene (percentage increase after adjustment for energy). Fig. 4 shows that the increase in *β*-carotene intake per one portion increase in FV was 20 (95 % CI 13, 27) % after adjustment for energy, which was also statistically significant ($P<0·001$). There was no evidence of heterogeneity between studies ($P=0·23$).

Discussion

This study assessed the effect of increased FV consumption on the overall macronutrient and micronutrient profile of the diet, by conducting a pooled analysis of four FV intervention studies that used similar approaches to increase FV intake in participants with differing health status (type 2 diabetes, hypertension, COPD and in healthy older people). Overall, our findings suggest that energy, carbohydrate, total sugars, fibre, vitamin C and *β*-carotene intakes increase, whereas total fat, SFA, MUFA, PUFA and starch intakes decrease when FV intakes are increased in the diet. Protein intakes were not affected by an increase in FV intake. It was found that the association between increased FV intake and change in macronutrient and micronutrient intakes did not depend on the individual study, with the majority of the meta-analyses heterogeneity tests showing no evidence of differences between studies, except for starch and protein. Regression analyses also suggest no age or sex effects (data not shown).

Energy, macronutrient and micronutrient profiles

Regression analysis on pooled data from the four intervention studies showed statistically significant changes, for all nutrients of interest per one portion increase in FV, with the exception of protein, which showed no significant change. Significant increases were observed in change in energy, carbohydrate, sugars and fibre intakes, whereas a significant decrease was observed in change in starch intake and total fat intake including SFA, MUFA and PUFA per one portion increase in FV. There was no evidence of heterogeneity between studies, with the exception of starch and protein intakes, and, despite participants having varied health status, results therefore appeared to be comparable between all four studies.

We previously conducted a systematic review and meta-analysis, examining the effect of increasing FV consumption on macronutrient and micronutrient intakes in seven intervention trials where FV intakes alone were increased[18]. The meta-analysis, which pooled data on energy, carbohydrate, fat and fibre intakes, is in line with the current results, with mean differences between groups for fibre and carbohydrate intakes being significantly increased in the intervention compared with the control groups when FV intake was increased, while mean difference between groups for fat intakes significantly decreased. However, in contrast to the current analysis, the meta-analysis found no difference in energy intake between intervention and control groups when FV were increased. Similar to the current results, the individual studies included in our previous review showed that an increase in FV intake produced a decrease in SFA and MUFA intake and had no effect on protein intake. However, unlike the current results, there was no change in PUFA intake or starch intake in the previous analysis, although this finding was only based on a limited number of studies[18] that reported these macronutrients. While the results of the meta-analysis are largely in agreement with the current study, directly comparing results is difficult as the meta-analysis only examined mean differences between groups (i.e. intervention *v.* control) during the intervention. Similar to the macronutrient profile, individual studies showed comparable outcomes to the total effect observed among all four studies in vitamin C and *β*-carotene, which is in agreement with our previous systematic review[18]. Therefore it is likely that vitamin C and *β*-carotene will increase when FV intakes are increased.

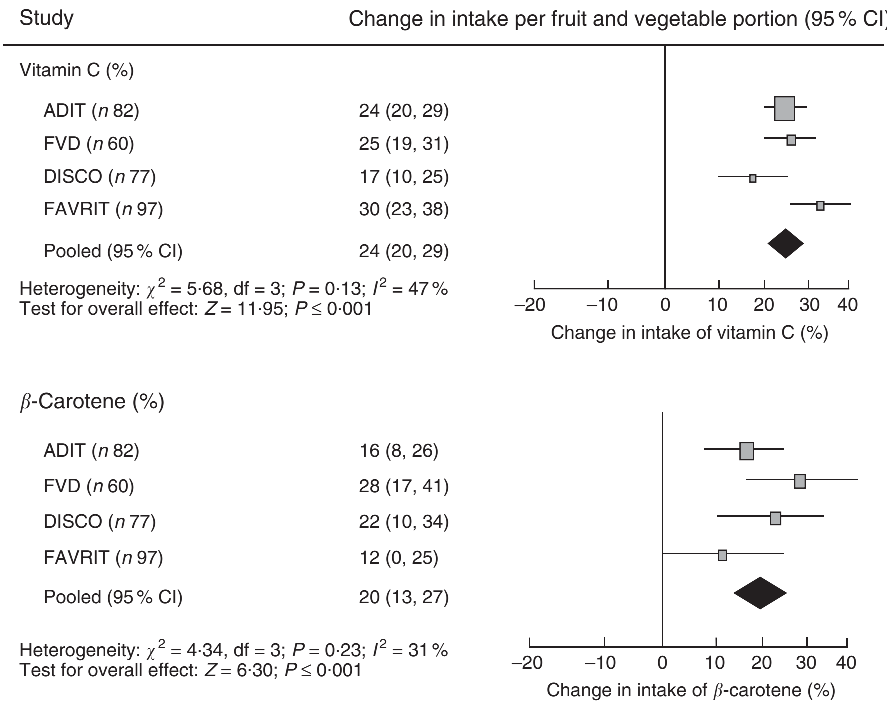

Fig. 4. Forest plots showing the pooling over four randomised-controlled trials of regression estimates of the change in vitamin C and β-carotene intake per portion increase in fruit and vegetables. ADIT, Aging and Dietary Intervention Trial; FVD, Fruit and Vegetable in Diabetes; DISCO, Dietary Intervention Study in COPD; FAVRIT, Fruit and Vegetable Randomised Intervention Trial.

Results for energy intakes are therefore inconclusive and further work is needed to examine the effect of increased FV intake on energy intakes. The different results for energy intake reported in our previous meta-analysis[18] may reflect the different statistical analysis approaches used, or the different dietary strategies used to increase FV intake in those studies, compared with those included here. There was also variation in how participants were instructed to include FV in their diets (substitution *v.* supplementation) and in the dietary assessments conducted in each study.

Overall, our findings would suggest that, in the studies analysed here, participants may have been substituting the higher fat foods in their diet for the additional FV, leading to the observed decreases in total, SFA, PUFA and MUFA intakes. However, energy, total carbohydrate and sugar intake increased. The observed increase in energy intake of 172 kJ (41 kcal) per portion increase in FV could have implications for weight gain if sustained over time. One possible explanation for the observed increase in energy and sugar intake may be related to the proportion of fruit *v.* vegetables that participants chose to incorporate into their diet; in general, a portion of fruit is more energy dense than a portion of vegetables. Participants were not specifically advised to substitute FV for other foods, as the focus of the studies was ensuring addition of FV to usual diet. However, given the current findings, public health guidance to increase FV intake should consider how best to present advice on incorporating extra portions of FV into the diet and perhaps consider the proportion of fruit *v.* vegetables to be consumed for maximum health benefits.

Strengths and limitations

There are important strengths of the current study. First, to our knowledge, this is the largest pooled analysis of FV intervention studies to examine changes in overall diet profile. Such a pooling was possible because the interventions were conducted using similar dietary change methodology (i.e. similar dietary advice given by researchers; delivery of FV on a weekly basis to participants' homes, with advice on storage and cooking). This allowed a stronger conclusion to be drawn compared with a previously published meta-analysis, where pooling of data were not conducted at an individual level, and where studies varied considerably in design and in dietary change methodology. Second, this analysis was based on pooled data from 316 participants, which is a large sample size for a dietary intervention study. Third, the dietary data were collected from participants with varying health status (i.e. healthy older people, people with diabetes, those with COPD and hypertensive patients), but results were largely homogeneous between studies. Therefore, by consuming more FV, participants, regardless of their health status, showed largely similar changes in their overall diet profile. Further analysis of the pooled data is required at the food group level. More specifically, examining FV choices and other food group choices would help ascertain if FV were being substituted for other food groups and if so, what food groups were most affected.

There were also a number of limitations. First, accuracy of the self-reported dietary data could be questioned, as participants tend to over-report FV intakes and under-report other foods perceived as being less healthy. Furthermore, it is possible that participants in the high-FV intervention groups may have over-reported FV intakes during the intervention to ensure that their intakes met the study requirements, whereas those in the low-intake intervention groups may have under-reported. Second, dietary data were collected by either diet history or diet diary, both of which can be prone to random or systematic error. For example, diet histories were interviewer led; therefore, participants may have been under pressure to respond to a certain question and not accurately consider what they would typically consume. However, with the diet diaries participants may not have recorded all foods consumed. Diet histories are retrospective whereas diet diaries record food intake at the time of consumption. Although researchers across the studies received similar training in the use of the dietary analysis software it is also possible that inconsistencies may have occurred in data entry. Third, while there was a wide age range of participants across all the intervention studies (range 40–86 years), there were no younger adults, and their response to the dietary advice given may be different. Finally, participants in each study were not restricted as to which FV they consumed. It is unknown if different changes in nutrient intake may have occurred if people incorporated, for example, more vegetables *v.* more fruit into their diet.

In conclusion, pooled regression analysis of four FV intervention studies that used similar approaches to achieve dietary change found significantly increased intakes of energy, carbohydrate, sugars and fibre and significantly decreased intakes of fat including SFA, PUFA and MUFA, and starch, with increases in FV consumption. In addition, significant increases were observed in vitamin C and β-carotene intake. The observed modest increase in energy intake associated with increased consumption of FV points to a need to guide individuals regarding the appropriate substitution of FV for other foods to ensure the impact of the overall dietary change is energy neutral.

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The authors' contributions are as follows: S. L. F., F. R. B. and C. E. N. entered diet histories and/or diet diaries into the dietary analysis programme WISP to generate dietary data for the individual studies. S. L. F. merged dietary data sets together, carried out statistical analysis and drafted the manuscript; D. R. M., J. D. E., J. S. E., M. C. M., I. S. Y. and J. V. W. were involved in the conceptualisation of the studies, developed protocols, gained ethical approval and were principal investigators for the individual studies. C. C. P. gave advice and oversight on the statistical analysis, as well as helping to draft the manuscript. C. E. N., J. V. W. and M. C. M. also helped to draft the manuscript.

The authors declare that there are no conflicts of interest.

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