British Journal of Nutrition (2020), 123, 951–958 doi:10.1017/S0007114520000112

Baseline diet modifies the effects of dietary change

R. T. Pickering, M. L. Bradlee, M. R. Singer and L. L. Moore*

Preventive Medicine & Epidemiology, Department of Medicine, Boston University School of Medicine, Boston, MA 02118, USA

(Submitted 2 July 2019 – Final revision received 9 January 2020 – Accepted 13 January 2020 – First published online 21 January 2020)

Abstract

The Dietary Approaches to Stop Hypertension (DASH) eating pattern has been shown to reduce blood pressure (BP) in previous clinical trials. In the PREMIER study, an established behavioural intervention, with or without DASH, promoted greater weight loss than an advice-only control group, but effects of the DASH intervention on BP were weaker. In these analyses, PREMIER data were used to evaluate whether change in dairy product or fruit and vegetable (FV) intake during the first six intervention months impacted changes in weight and/or BP. Study participants were classified as having low or high intakes of dairy products (<1·5 *v.* ≥1·5 servings/d) and FV (<5 *v.* ≥5 servings/d) at baseline and 6 months. For dairy products, in particular, participants with higher baseline intakes tended to decrease their intakes during the intervention. In these analyses, subjects consuming <1·5 dairy servings/d at baseline whose intake increased during the intervention lost more weight than those whose intake decreased or remained low throughout (10·6 *v.* 7·0 pounds (4·8 *v.* 3·2 kg) lost, respectively, $P = 0{\cdot}002$). The same was true for FV intake (11·0 *v.* 5·9 pounds (5·0 *v.* 2·7 kg) lost, $P < 0{\cdot}001$). We also found synergistic effects of dairy products and FV on weight loss and BP reduction. Specifically, subjects who increased their intakes of dairy products and also consumed ≥5 servings of FV/d lost more weight and had greater reductions in BP than other groups; in addition, higher FV intakes had the greatest benefit to BP among those consuming more dairy products. These results provide evidence that the DASH pattern was most beneficial to individuals whose baseline diet was less consistent with DASH.

Key words: Dietary Approaches to Stop Hypertension diet: PREMIER study: Weight loss: Hypertension

British Journal of Nutrition

Hypertension is exceedingly common among US adults[1] and is a well-known risk factor for CVD[2,3], contributing to nearly half of all cardiovascular deaths in the USA[4]. Primary prevention of hypertension focuses on key lifestyle strategies including weight reduction, Na restriction, increased physical activity, moderation of alcohol intake and other dietary modifications[5].

The Dietary Approaches to Stop Hypertension (DASH), characterised by higher intakes of fruits and vegetables (FV) and low-fat dairy products, have been shown to have blood pressure (BP)-lowering effects in clinical trial settings.[6] Since the initial DASH clinical trial, other studies have confirmed the beneficial effects of DASH on BP and cardiovascular risk in different population groups[7–9]. Recently, a small randomised cross-over study compared a standard DASH pattern with low-fat dairy foods with a full-fat DASH pattern and found comparable reductions in BP[10].

The PREMIER clinical trial was designed to test the BP-lowering effects of two interventions among individuals with pre-hypertension or stage 1 hypertension, one of which included standard lifestyle modifications, while the other also added a DASH dietary intervention[11]. Both interventions were designed to promote weight loss, and both led to reductions in BP, compared with an advice-only control group[12]; the intervention including DASH had a slightly greater beneficial effect on weight loss and systolic BP (SBP) and diastolic BP (DBP) reduction. Subsequent secondary analyses suggested that plant rather than animal protein in the PREMIER diets was linked with greater BP-lowering effects[13]. In those analyses, the effect of dairy products on BP outcomes was null, while FV intakes were beneficial. These analyses did not account for baseline dietary patterns.

The selection of the population at risk is a crucial element for any clinical trial since beneficial treatment effects are likely to be greater among individuals at higher risk for the outcome. For example, exercise interventions are likely to provide greater benefit for sedentary individuals who are at higher risk for CVD and other disorders than for those who are already exercising regularly. In these analyses, we hypothesised that baseline intakes of dairy products and FV in PREMIER might have impacted the effects of the DASH intervention on weight and BP in that study. Specifically, we explored whether changes in the level of dairy products and FV intake during the

Abbreviations: BP, blood pressure; DASH, Dietary Approaches to Stop Hypertension; DBP, diastolic blood pressure; FV, fruits and vegetables; SBP, systolic blood pressure.

* **Corresponding author:** L. L. Moore, fax +1 617 358 5677, email llmoore@bu.edu

initial 6-month exposure period in the PREMIER study were associated with changes in weight and BP during the intervention period.

Methods

Original study

The PREMIER study was a randomised multicentre clinical trial that was designed to compare the BP-lowering effects of two comprehensive non-pharmacological lifestyle interventions (a standard 'lifestyle' intervention and the 'lifestyle plus DASH' intervention) with an advice-only control group. Details of the study design have been previously published[11]. Begun in 2000, the study recruited 810 men and women (34 % African American) from four study centres (Baltimore, MD; Baton Rouge, LA; Durham, NC and Portland, OR). Eligible subjects were adults at least 25 years of age with a BMI between 18·5 and 45·0 kg/m^2 with pre-hypertension (SBP 120–139 mmHg or DBP 80–89 mmHg) or untreated stage 1 hypertension (SBP 140–159 mmHg or DBP 90–95 mmHg) based on mean BP from three screening visits. The primary intervention period was 6 months. Since the present analyses are based on dietary change, those who were missing dietary data at 6 months were excluded (*n* 119). In addition, nineteen subjects with missing activity data at 6 months and seven subjects with missing weight measures at 6 months were excluded, leaving data for 665 of the original 810 study participants. These data were obtained from the National Heart, Lung, and Blood Institute Biologic Specimen and Data Repository Information Coordinating Center (BIOLINCC).

In the PREMIER study, both intervention arms employed an identical series of group and individual sessions to facilitate adoption of lifestyle changes and skills to achieve the intervention goals, while the advice-only group (control) also targeted weight loss and physical activity but without the behavioural intervention. The lifestyle intervention targeted the following behaviour changes: (1) reduce weight by 7 kg (about 15 lbs) or more if overweight; (2) limit daily Na intake to 100 mmol or less; (3) limit fat intake to 30 % of energy content intake or less; (4) engage in 180 min/week (or its equivalent) of moderate physical activity and (5) limit alcohol intake to no more than one ounce of ethanol per d for men and no more than 0·5 ounce/d for women. Finally, the lifestyle plus DASH intervention added advice on a DASH-style eating pattern (9–12 servings/d of FV, 2–3 servings/d of low-fat dairy products, reduced intakes of saturated and total fat) to the behavioural intervention.

Trained telephone interviewers assessed diet among study participants using unannounced 24-h recalls. Two recalls (one weekday and one weekend) per participant were collected at baseline and 6 months. Intakes of total energy, nutrients and food groups (from both whole foods and composite food ingredients) were calculated at the Diet Assessment Center of Pennsylvania State University using the Nutrition Data System, version NDS-R 1998 (University of Minnesota). In this way, servings/d of dairy products (milk, yogurt and cheese) as well as FV were calculated. Total dairy product intake included both full-fat and reduced-fat dairy products, although study recommendations were for consumption of low-fat dairy products.

BP was measured by trained and certified individuals following a standardised protocol and using a random zero sphygmomanometer and an appropriate-sized cuff. Two separate measures were taken with at least 30 s between measurements. The means of the two SBP and DBP measures were calculated as well as the mean of two measures of weight (to the nearest 0·25 pound (0·11 kg)) using a calibrated digital scale. Weight, SBP and DBP from the baseline and 6-month follow-up visits are used in these analyses.

Two measures of height to the nearest 0·1 cm were taken using a calibrated wall-mounted stadiometer. BMI was calculated as weight, in kg, divided by the square of height, in metres. Physical activity was assessed by means of a standardised 7-d physical activity recall[14,15]. Each subject's self-reported daily activities were categorised as light, moderate, hard or very hard, and the number of minutes spent in activities of various intensity levels was used to derive each individual's estimated average daily energy expenditure for the previous week.

Statistical analysis

We first estimated mean baseline intakes of dairy products and FV in the two original PREMIER intervention groups and the control group as well as mean change in intake from baseline to 6 months (i.e. mean intake at 6 months minus mean baseline intake). Change in weight, SBP and DBP was calculated in the same manner.

Since the recommended intakes of dairy products in the DASH intervention were 2 or more servings/d, we initially classified dairy product intake as follows: <1, 1–<2 and ≥2 servings/d. However, only 22 % of subjects at baseline consumed at least 2·0 servings/d and only 28 % consumed that amount during the intervention. For FV, recommended intakes were 9 or more servings/d. However, since only twenty-five subjects at baseline consumed that amount, we chose to use the following cut-off values: <3, 3–<5 and ≥5 servings/d. Finally, to improve statistical power, we chose to dichotomise dietary intakes based on information from sensitivity analyses as follows: <1·5 *v.* ≥1·5 servings of dairy products per d and <5 *v.* ≥5 servings of FV per d.

These dichotomous categorisations were used to classify intake simultaneously during the baseline and intervention periods. For example, four exposure categories for FV intake were defined as follows: (1) low baseline (<5·0 servings)/low intervention (<5·0 servings) intake, (2) low baseline (<5·0 servings)/high intervention (≥5·0 servings), (3) high baseline/low intervention and (4) high baseline/high intervention. Those with low intakes of FV at both baseline and 6 months (low/low) served as the referent group. Those in the low/high groups were those who increased their FV intake during the intervention. The same approach was used to consider baseline/intervention dairy product intakes.

We used ANCOVA to compare the mean weight loss in three groups (low/high, high/low and high/high) compared with the referent groups (low/low). These models were to derive the

British Journal of Nutrition

adjusted mean weight loss controlling for confounding by factors (age, sex, race and physical activity) found to change the mean differences by 5 % of more. Factors that led to no change in the adjusted means were dropped from the final models. This included both non-dietary factors (i.e. height, education, pack-years of smoking) and dietary factors such as intervention intakes of minerals (i.e. Na, K, Ca and Mg), protein foods (i.e. meats, eggs, poultry and fish), sweets and snacks, total grains, and nuts, beans, and soya. Similar analyses were used to evaluate change in SBP and DBP.

Results

Table 1 shows the characteristics of subjects in the PREMIER trial according to baseline intakes of dairy products and FV. Fewer African Americans were in the highest categories of intake for both food groups. Those with the highest baseline intakes of dairy products consumed more saturated fat but not more total fat, while both total fat and saturated fat intakes were inversely associated with FV consumption. Despite randomisation, there were some apparent differences in baseline dairy product intake

Table 1. Baseline characteristics of PREMIER subjects according to baseline intake of dairy products and fruits and vegetables
(Mean values and standard deviations; numbers and percentages)

	Baseline dairy product intake (servings/d)						Baseline fruit and vegetables (servings/d)					
Subject characteristics	<1 (*n* 278)		1–<2 (*n* 238)		≥2 (*n* 149)		<3 (*n* 232)		3–<5 (*n* 224)		≥5 (*n* 209)	
Age												
≤40 years												
n	34		35		19		43		31		14	
%	12·2		14·7		12·8		18·5		13·8		6·7	
41–55 years												
n	169		138		90		148		130		119	
%	60·8		58·0		60·4		63·8		58·0		56·9	
≥56 years												
n	75		65		40		41		63		76	
%	27·0		27·3		26·8		17·7		28·1		36·4	
Sex, female												
n	184		147		76		154		145		108	
%	66·2		61·8		51·0		66·4		64·7		61·7	
Race, African American												
n	132		63		21		94		75		47	
%	47·5		26·5		14·1		40·5		33·5		22·5	
Intervention assignment												
Control												
n	95		76		52		84		77		62	
%	34·2		31·9		34·9		36·2		34·4		29·7	
Lifestyle												
n	103		69		47		73		77		69	
%	37·1		29·0		31·5		31·5		34·4		33·0	
Lifestyle plus DASH												
n	80		93		50		75		70		78	
%	28·8		39·1		33·6		32·3		31·3		37·3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Dairy products (servings/d)	0·47	0·31	1·43	0·29	2·90	0·92	1·25	1·10	1·35	1·03	1·50	1·04
Fruits and vegetables (servings/d)	3·91	2·23	4·2	2·36	4·63	2·37	1·89	0·78	4·06	0·59	6·84	1·79
Energy intake (kcal)*	1776	538	1948	582	2314	682	1839	586	1926	661	2124	584
% Energy content from fat	33·4	7·8	32·7	7·3	33·0	7·7	35·6	7·2	32·7	7·1	30·7	7·7
% Energy content from saturated fat	10·2	3·1	10·9	2·7	12·1	3·7	11·9	3·0	10·9	3·0	9·8	3·2
% Energy content from carbs	51·4	10·5	51·6	8·3	51·1	9·1	48·9	9·1	51·6	9·2	54·1	9·4
% Energy content from protein	15·3	4·4	15·9	3·7	16·3	3·3	15·3	4·2	15·8	3·6	16·2	4·0
Na (mg)	2923	1100	3091	1085	3595	1427	3056	1135	3055	1282	3304	1174
K (mg)	2279	808	2602	799	3287	978	1967	663	2573	779	3385	743
K:Na ratio	0·86	0·39	0·92	0·40	1·03	0·50	0·70	0·32	0·94	0·35	1·14	0·47
Weight (lbs)†	208	39	208	40	213	42	211·9	39·6	206·2	39·0	209·6	42·5
BMI (kg/m^2)	33·2	5·7	32·7	5·5	32·8	5·8	33·8	5·7	32·8	5·4	32·3	5·8
SBP (mmHg)	134·4	9·5	134·4	9·6	135·8	9·6	134·5	9·4	135·0	9·9	134·7	9·5
DBP (mmHg)	84·1	4·1	84·7	4·1	84·9	4·1	84·6	4·0	84·4	4·2	84·6	4·1
Physical activity (min/week)‡	193	237	240	411	237	254	240	383	188	288	230	246

carbs, Carbohydrates; SBP, systolic blood pressure; DBP, diastolic blood pressure.
* To convert kcal to kJ, multiply by 4·184.
† To convert pounds to kg, multiply by 0·453592.
‡ Moderate to vigorous physical activity.

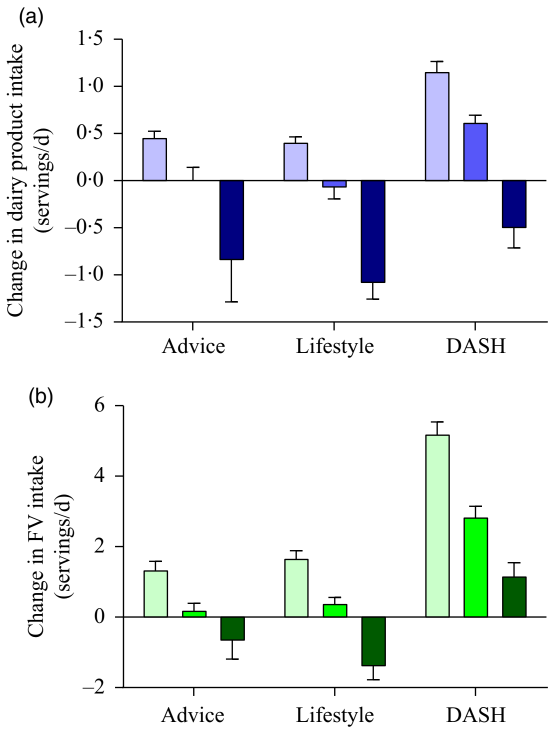

Fig. 1. Changes in dairy product and fruit and vegetable (FV) intake according to baseline intake in each intervention group. (a) Changes in dairy product intake according to baseline dairy product intake in the three intervention groups. (b) Changes in FV intake according to baseline FV intake in the three intervention groups. Data are mean changes with their standard errors. (a) ▭, <1 serving; ▭, 1–<2 servings; ▭, ≥2 servings; (b) ▭, <3 servings; ▭, 3–<5 servings; ▭, ≥5 servings. DASH, Dietary Approaches to Stop Hypertension.

across the original PREMIER intervention group assignments. In particular, those with the lowest baseline dairy product intakes were least likely to be assigned to the DASH intervention group, a finding that could have led to confounding of the original results if baseline intake is a determinant of response to the intervention.

Fig. 1 shows changes in dairy products and FV intakes (from baseline to 6 months) in each assigned PREMIER intervention group, stratifying by baseline intake. For example, those with the lowest baseline dairy product intakes (<1 serving/d) in the 'advice-only' (control) group increased their dairy product intakes by 0·46 servings/d, while those with higher baseline intakes (≥2 servings/d) decreased their intakes by 0·85 servings/d. The same pattern was evident in all three intervention groups – those with lower baseline intakes increased consumption and those with higher baseline intakes reduced consumption. The same was not the case for FV intake where those in the DASH intervention group who already were consuming at least 5 servings/d still increased their intakes by an additional 1·44 servings/d.

Fig. 2 shows changes in weight and BP according to intakes of dairy products and FV during the intervention period. For example, panel A shows that those consuming ≥2 servings of dairy products or ≥5 servings of FV during the intervention had statistically significantly greater weight loss than those

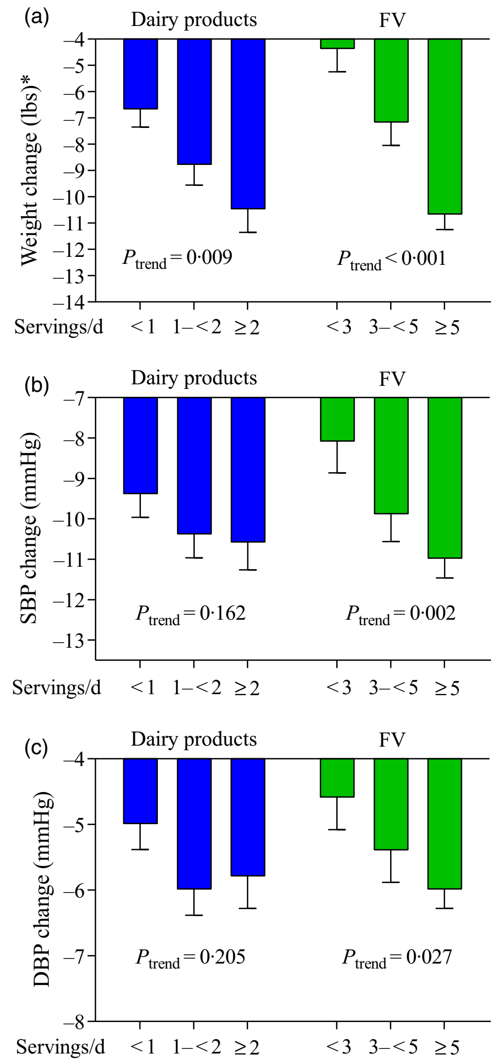

Fig. 2. Changes in weight and blood pressure according to intervention intakes. Changes in weight (a), systolic blood pressure (SBP) (b) and diastolic blood pressure (DBP) (c) according to intervention intakes of dairy products or fruits and vegetables (FV). Data are mean differences from baseline with their standard errors. Mean differences are adjusted for age, sex, race and physical activity. * To convert pounds to kg, multiply by 0·453592.

consuming less (P_{trend}: 0·009 and <0·001, respectively). Higher FV intakes (panels B, C) were also strongly inversely associated with both SBP and DBP (P_{trend}: 0·002 and 0·027, respectively).

Since higher combined intakes of dairy products and FV are used to reflect the main components of a DASH-style eating pattern, we examined these combined intakes (online Supplementary Table S1) irrespective of the original PREMIER study group assignment. Those with higher intakes of both dairy products and FV had the greatest weight loss (12·5 pounds (5·7 kg) in the high dairy/high FV group *v.* 5·6 pounds (2·5 kg) lost in the low dairy/low FV group, $P < 0·0001$) and the greatest reductions in SBP and DBP. Since weight loss is strongly associated with physical activity and level of obesity, we also stratified by these factors. Regardless of activity level, participants with higher intakes of both dairy products and FV had greater reductions in weight than those with lower intakes of dairy products or

Table 2. Change in intakes of dairy products and fruits and vegetables (FV) and change in weight and blood pressure (Adjusted mean values with their standard errors)

		Weight change (lbs)*			SBP change (mmHg)			DBP change (mmHg)		
Intake change category	*n*	Adjusted mean†	SE	*P*	Adjusted mean†	SE	*P*	Adjusted mean†	SE	*P*
Baseline/intervention dairy product intakes‡										
Low/low	276	−7·0	0·70	Ref	−10·0	0·57	Ref	−5·2	0·39	Ref
Low/high	142	−10·6	0·95	0·002	−10·6	0·77	0·518	−6·0	0·54	0·229
High/low	94	−7·1	1·17	0·976	−9·4	0·95	0·616	−5·2	0·66	0·981
High/high	153	−9·9	0·96	0·018	−10·3	0·77	0·730	−5·9	0·54	0·351
Baseline/intervention FV intake‡										
Low/low	256	−6·2	0·72	Ref	−9·3	0·58	Ref	−5·1	0·41	Ref
Low/high	200	−11·0	0·80	<0·0001	−10·5	0·65	0·191	−5·8	0·45	0·197
High/low	56	−5·0	1·51	0·504	−8·2	1·23	0·402	−4·8	0·86	0·817
High/high	153	−10·4	0·92	0·0004	−11·7	0·75	0·016	−6·2	0·53	0·097

SBP, systolic blood pressure; DBP, diastolic blood pressure; Ref, referent.
* To convert pounds to kg, multiply by 0·453592.
† Mean differences adjusted for age, sex, race and physical activity using ANCOVA models.
‡ Low/low = low baseline intake/low intervention intake (<1·5 for dairy products, <5 for FV); low/high = low baseline intake/high intervention intake (≥1·5 for dairy products, ≥5 for FV); high/low = high baseline intake/low intervention intake; high/high = high baseline intake/high intervention intake.

FV. Similarly, both obese and non-obese subjects with higher intakes of both dairy products and FV had the greatest weight loss and reductions in BP.

Table 2 shows changes in weight and BP associated with the change in dairy products and FV intakes from baseline to the intervention period. In these analyses, those who started with low baseline intakes (<1·5 servings/d of dairy products or <5 servings/d of FV) but who then increased their intakes (to ≥1·5 servings of dairy products and ≥5 servings of FV) during the intervention had the greatest weight loss. Of note, participants with lower dairy product intakes during the intervention period (low/low and high/low groups) lost similar amounts of weight (7·0 and 7·1 lbs (3·18 and 3·22 kg), respectively). Likewise, those with higher intakes of dairy products during the intervention period also lost comparable amounts of weight (10·6 and 9·9 lbs (4·81 and 4·49 kg) in the low/high and high/high groups, respectively). Patterns were similar for FV intake. As a result of the comparable amounts of weight loss in the low/low and high/low groups (and to improve statistical power), we combined these two categories for the analyses in Table 3.

To determine whether the effect of change in dairy product intake was modified by the concurrent intake of FV (and vice versa), we carried out stratified analyses in Table 3. As seen in Table 2, participants who increased their intakes of dairy products or FV during the intervention period (low/high) as well as those who had higher intakes throughout (high/high) had greater reductions in weight than those having low intakes during the intervention. This was also the case for SBP and DBP, although most changes did not reach statistical significance. When stratifying by concurrent intake of FV, it is evident here that the beneficial effect of increasing dairy product intake (low/high) is modified by FV intake. Compared with the referent group (low dairy products among those with low FV intakes) with an average weight loss of 5·7 pounds (2·6 kg), those who increased their dairy product intake and who also consumed at least 5 servings of FV/d had an average weight loss of 13·6 pounds (6·2 kg). In contrast, those who increased their dairy product intakes but who had lower FV intakes lost only 8·7 pounds (3·9 kg). The same pattern was evident for BP change. Finally, higher FV intake (high/high) and increasing FV intake (low/high) led to the greatest weight loss and reductions in BP among those with higher dairy product intakes during the intervention.

Discussion

The original PREMIER randomised clinical trial studied the impact of two lifestyle-based interventions, one with a DASH-style dietary pattern and one without, on weight loss and BP reduction. These present secondary analyses examined how baseline intakes of dairy products and FV, the two primary DASH components, may have influenced the effects of the intervention on weight loss and changes in BP.

We found that baseline intake, especially for dairy products, may have influenced the effects of the original DASH intervention in PREMIER since those participants consuming ≥2 servings of dairy products per d at baseline and who were assigned to the DASH intervention group actually reduced their dairy product intake during the intervention period. In contrast, participants in the DASH intervention arm of the trial increased their intakes of FV regardless of baseline intake.

We found that the amount of both dairy products and FV consumed during the intervention was directly associated with weight loss and BP reduction, with higher intakes being associated with greater declines in weight and BP. Further, higher combined intakes of both dairy products and FV (as recommended by DASH) were associated with greater weight loss and greater SBP and DBP reductions than seen in those with lower intakes of both. We found that those who increased their intakes of either dairy products (to ≥1·5 servings/d) or FV (to ≥5 servings/d) had substantially greater weight loss after 6 months than those with lower intervention intakes. In addition, more active participants and those who were obese at baseline lost more weight than their more sedentary or non-obese counterparts (online Supplementary material). Finally, the effects of dairy consumption on mean weight and BP change during the trial were found

British Journal of Nutrition

https://doi.org/10.1017/S0007114520000112 Published online by Cambridge University Press

Table 3. Changes in weight and blood pressure according to change in intakes of dairy products and fruits and vegetables (FV), stratifying by intervention intake
(Adjusted mean values with their standard errors)

		Weight change			SBP change			DBP change		
	n	Adjusted mean*	SE	*P*	Adjusted mean*	SE	*P*	Adjusted mean*	SE	*P*
Baseline/intervention intakes†										
Dairy products										
Low dairy‡	370	−7·0	0·60	Ref	−9·8	0·49	Ref	−5·2	0·34	Ref
Low/high dairy	142	−10·7	0·95	0·002	−10·6	0·77	0·399	−6·0	0·54	0·208
High/high dairy	153	−9·9	0·96	0·013	−10·3	0·77	0·589	−5·9	0·54	0·327
FV										
Low FV‡	312	−5·9	0·64	Ref	−9·1	0·52	Ref	−5·0	0·37	Ref
Low/high FV	200	−11·0	0·80	<0·0001	−10·5	0·65	0·102	−5·9	0·45	0·154
High/high FV	153	−10·4	0·92	<0·0001	−11·7	0·75	0·005	−6·2	0·52	0·071
Dairy change†, stratifying by FV intake										
Low intervention FV										
Low dairy‡	206	−5·7	0·79	Ref	−9·6	0·65	Ref	−5·3	0·45	Ref
Low/high dairy	57	−6·3	1·49	0·702	−7·8	1·22	0·212	−4·5	0·85	0·395
High/high dairy	49	−6·5	1·62	0·700	−8·7	1·33	0·548	−4·5	0·93	0·429
High intervention FV										
Low dairy‡	164	−8·7	0·88	0·010	−10·1	0·72	0·542	−5·1	0·50	0·810
Low/high dairy	85	−13·6	1·21	<0·0001	−12·4	0·99	0·016	−7·1	0·69	0·034
High/high dairy	104	−11·6	1·13	<0·0001	−11·1	0·92	0·175	−6·5	0·64	0·130
FV change†, stratifying by dairy intake										
Low intervention dairy										
Low FV‡	206	−5·6	0·79	Ref	−9·5	0·65	Ref	−5·3	0·45	Ref
Low/high FV	104	−8·4	1·10	0·038	−10·0	0·90	0·678	−5·1	0·63	0·857
High/high FV	60	−9·2	1·45	0·033	−10·4	1·19	0·529	−5·1	0·83	0·839
High intervention dairy										
Low FV‡	106	−6·4	1·10	0·571	−8·2	0·90	0·238	−4·5	0·63	0·299
Low/high FV	96	−13·7	1·15	<0·0001	−11·0	0·94	0·216	−6·6	0·66	0·099
High/high FV	93	−11·3	1·17	<0·0001	−12·5	0·96	0·012	−6·9	0·67	0·048

SBP, systolic blood pressure; DBP, diastolic blood pressure; Ref, referent.
* Models adjusted for age, sex, race and physical activity.
† Low *v.* high intake: <1·5 *v.* ≥1·5 servings/d for dairy products; <5 *v.* ≥5 servings/d for FV.
‡ Low intake here combines low/low and high/low categories from Table 2.

to be modified by FV intake and vice versa. Increasing dairy consumption led to the greatest weight loss and reductions in SBP and DPB among those with higher FV intakes. Similarly, the greatest FV benefits were seen among those with higher dairy consumption during the intervention. Thus, these analyses support a beneficial effect of the DASH pattern on both weight loss and BP reduction and demonstrate that these benefits were more apparent for dairy product intake in particular among those whose baseline intakes were lower.

The original PREMIER study was designed to evaluate a DASH eating plan as part of a multicomponent intervention that simultaneously targeted weight loss (of 15 lbs (6·8 kg) or more) and BP reduction[11]. While the primary outcome was SBP reduction, it is difficult to separate fully the BP changes from weight reduction in this trial since most subjects lost substantial weight. In the report of the main results, both the lifestyle-only intervention and the lifestyle plus DASH intervention led to statistically significant reductions in weight and BP[12]. However, participants in the lifestyle plus DASH group had only very slightly greater declines in BP than the established lifestyle intervention (i.e. 0·6 mmHg greater decline in SBP, 0·9 mmHg greater decline in DBP). These results contrast with a previous meta-analysis of seventeen controlled trials that found a DASH diet to be associated with an average reduction in SBP of 6·74 mmHg and in DBP of 3·54 mmHg[16]. These results are also at odds with a recent randomised crossover trial showing that a high-dairy product diet alone resulted in greater reductions ($P = 0·009$) in both SBP (4·6 mmHg) and DBP (3·0 mmHg) than a diet with lower intakes of dairy products[17]. Since the high-dairy diet in that study comprised 5 or 6 servings for men and women, respectively, compared with <1 serving in the low-dairy group, it is possible that the lower intakes of dairy products in the DASH arm of the PREMIER may explain the weaker dairy product-related effects in that study.

The effects observed in the PREMIER study were much weaker than those seen in the earlier DEW-IT trial in which subjects in a lifestyle intervention group (a low-energy, low-Na DASH plus exercise) had substantially greater reductions in BP than those in the advice-only group[18]. In an editorial accompanying the publication of the PREMIER study, Pickering explored the possible explanations for this weaker effect of the DASH intervention arm on BP[19]. One potential explanation for these weaker effects was poorer adherence to the DASH plan in the PREMIER study (since foods were purchased and prepared by the subjects rather than provided). Adherence issues are supported by the finding that the lifestyle plus DASH group in the PREMIER study had only a 28·3 % increase in K intake[20]; in contrast, the K intake in the combined diet group in the original DASH study was 152·0 % higher than that of the control diet[6]. The weaker observed effects of DASH in the PREMIER study could also have resulted from a greater reduction in BP in the control group than that was observed among controls in previous studies[6,7]. Further, the PREMIER authors speculated that weaker effects on BP in the PREMIER study might have resulted from a subadditivity of intervention effects (i.e. the total effect of the lifestyle intervention plus DASH may have been less than the sum of the two individual interventions), since it may have been difficult for subjects to self-manage two interventions simultaneously[11].

In the present analyses, we propose an additional explanation for the weaker effects of the DASH intervention on BP in PREMIER. Specifically, we propose that subjects with higher baseline intakes of dairy products should likely have been excluded from the trial. Alternatively, they could have maintained their already-adequate intake of dairy products rather than decreasing intake during the intervention. Our present analyses suggest that subjects who increased their intake (e.g. from low to high) had a somewhat greater benefit (although not statistically significant) than those who had higher intakes throughout. It is possible that those who increased their intakes may have replaced less healthy food choices with healthier foods recommended as part of the DASH pattern. Previous substitution analyses have suggested that replacement of red meat, for example, with low-fat dairy products, fish or other protein sources could lower CVD occurrence and mortality risk[21,22]. However, in confounding analyses in the present study, we controlled for changes in snacking behaviours and other changes in diet but we found that none of these altered the results.

In the present study, we focused on dairy products and FV intakes as the primary components of the DASH pattern. There are several mechanisms by which these foods may benefit BP. FV are rich in polyphenols and also raise antioxidant capacity, lowering oxidative stress. These mechanisms have been linked with beneficial effects on BP regulation and downstream effects on cardiovascular health[23,24]. Glutamic acid, an amino acid in vegetable protein, has also been inversely associated with BP[25]. Further, K, Mg and Ca (all of which are found in abundance in fruits, vegetables and dairy products) have been linked with lower BP through regulation of vascular resistance and promotion of vasodilation[26]. A higher K:Na ratio has been linked with decreases in renal Na retention, thereby lowering BP[27]. Higher K intakes have also been shown to reduce salt sensitivity, while Mg aids in the regulation of intracellular Ca, K and Na, thereby promoting insulin sensitivity and reducing vascular resistance. The role of dairy products *per se* in BP regulation has been somewhat controversial. However, at least one meta-analysis of nine randomised controlled trials found that dairy-derived tripeptides lower BP[28]. Specifically, angiotensin-I-converting enzyme inhibitory peptides that inhibit the renin-angiotensin system have been found in both milk and cheese[29].

There are some limitations to the present study but the biggest may be the limited power for stratified analyses. We were unable to look at sex- or race-specific differences and some categories in the present analyses had small numbers. In addition, we used lower cut-off values to define 'higher' intakes of both dairy products (1·5 servings/d) and FV (5 servings/d) since too few subjects consumed the recommended 2–3 servings of dairy products and 9–12 servings of FV. Another limitation of the present study relates to the self-report of diet (since the PREMIER study was not a feeding trial) which could have introduced bias in the reported intakes of dairy products and FV. In addition, dietary intake in the present study was assessed at each time point using only two 24-h recalls, which may have yielded less precise estimates of intake than would have been obtained if more days of recall had been available[30]. However, a previous study from the EFCOSUM group shows that 2 d of dietary records may be used to estimate intakes of frequently-consumed foods in different population groups[31]. Nonetheless, the present study is strengthened by the use of carefully controlled measured data for the weight and BP outcomes as well as important potential confounders.

The present study adds important new data supporting the beneficial effects of a DASH intervention on weight loss among overweight individuals and BP reduction in those with borderline high BP or stage 1 hypertension. It also demonstrates that the combined benefits of dairy products and FV are greater than that seen with individual food groups. Finally, the present study demonstrates that the DASH pattern is most beneficial to those with lower baseline intakes of dairy products and FV.

Acknowledgements

These secondary analyses were supported by the National Heart Lung and Blood Institute (NHLBI; grant no. 5T32HL125232) and the National Dairy Council. None of the funders had any role in the analysis, design or writing of this manuscript. This manuscript was prepared using A Trial of Lifestyle Interventions for Blood Pressure Control (PREMIER) Research Materials obtained from the NHLBI Biologic Specimen and Data Repository Information Coordinating Center and does not necessarily reflect the opinions or views of the PREMIER or NHLBI.

Author contributions were as follows: L. L. M. and R. T. P.: study concept and design; L. L. M.: acquisition of data; R. T. P. and M. R. S.: management and analysis of data; R. T. P., L. L. M. and M. L. B.: drafting of manuscript; R. T. P., L. L. M., M. L. B. and M. R. S.: critical revision of manuscript. All authors approved the final manuscript.

None of the authors has conflicts of interest to declare.

Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520000112

References

1. Centers for Disease Control and Prevention (2011) Vital signs: prevalence, treatment, and control of hypertension – United States, 1999–2002 and 2005–2008. *MMWR Morb Mortal Wkly Rep* **60**, 103–108.
2. Stamler J, Stamler R, Neaton JD (1993) Blood pressure, systolic and diastolic, and cardiovascular risks. US population data. *Arch Intern Med* **153**, 598–615.
3. Vasan RS, Larson MG, Leip EP, *et al.* (2001) Impact of high-normal blood pressure on the risk of cardiovascular disease. *N Engl J Med* **345**, 1291–1297.

4. Ezzati M, Lopez AD, Rodgers A, *et al.* (2002) Selected major risk factors and global and regional burden of disease. *Lancet* **360**, 1347–1360.
5. Whelton PK, He J, Appel LJ, *et al.* (2002) Primary prevention of hypertension: clinical and public health advisory from The National High Blood Pressure Education Program. *JAMA* **288**, 1882–1888.
6. Appel LJ, Moore TJ, Obarzanek E, *et al.* (1997) A clinical trial of the effects of dietary patterns on blood pressure. DASH Collaborative Research Group. *N Engl J Med* **336**, 1117–1124.
7. Sacks FM, Svetkey LP, Vollmer WM, *et al.* (2001) Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. DASH-Sodium Collaborative Research Group. *N Engl J Med* **344**, 3–10.
8. Blumenthal JA, Babyak MA, Hinderliter A, *et al.* (2010) Effects of the DASH diet alone and in combination with exercise and weight loss on blood pressure and cardiovascular biomarkers in men and women with high blood pressure: the ENCORE study. *Arch Intern Med* **170**, 126–135.
9. Azadbakht L, Fard NR, Karimi M, *et al.* (2011) Effects of the Dietary Approaches to Stop Hypertension (DASH) eating plan on cardiovascular risks among type 2 diabetic patients: a randomized crossover clinical trial. *Diabetes Care* **34**, 55–57.
10. Chiu S, Bergeron N, Williams PT, *et al.* (2016) Comparison of the DASH (Dietary Approaches to Stop Hypertension) diet and a higher-fat DASH diet on blood pressure and lipids and lipoproteins: a randomized controlled trial. *Am J Clin Nutr* **103**, 341–347.
11. Svetkey LP, Harsha DW, Vollmer WM, *et al.* (2003) Premier: a clinical trial of comprehensive lifestyle modification for blood pressure control: rationale, design and baseline characteristics. *Ann Epidemiol* **13**, 462–471.
12. Appel LJ, Champagne CM, Harsha DW, *et al.* (2003) Effects of comprehensive lifestyle modification on blood pressure control: main results of the PREMIER clinical trial. *JAMA* **289**, 2083–2093.
13. Wang YF, Yancy WS, Yu D, *et al.* (2008) The relationship between dietary protein intake and blood pressure: results from the PREMIER study. *J Hum Hypertens* **22**, 745–754.
14. Sallis JF, Haskell WL, Wood PD, *et al.* (1985) Physical activity assessment methodology in the Five-City Project. *Am J Epidemiol* **121**, 91–106.
15. Blair SN, Haskell WL, Ho P, *et al.* (1985) Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. *Am J Epidemiol* **122**, 794–804.
16. Saneei P, Salehi-Abargouei A, Esmaillzadeh A, *et al.* (2014) Influence of Dietary Approaches to Stop Hypertension (DASH) diet on blood pressure: a systematic review and meta-analysis on randomized controlled trials. *Nutr Metab Cardiovasc Dis* **24**, 1253–1261.
17. Rietsema S, Eelderink C, Joustra ML, *et al.* (2019) Effect of high compared with low dairy intake on blood pressure in overweight middle-aged adults: results of a randomized crossover intervention study. *Am J Clin Nutr* **110**, 340–348.
18. Miller ER, Erlinger TP, Young DR, *et al.* (2002) Results of the Diet, Exercise, and Weight Loss Intervention Trial (DEW-IT). *Hypertension* **40**, 612–618.
19. Pickering TG (2003) Lifestyle modification and blood pressure control: is the glass half full or half empty? *JAMA* **289**, 2131–2132.
20. Elmer PJ, Obarzanek E, Vollmer WM, *et al.* (2006) Effects of comprehensive lifestyle modification on diet, weight, physical fitness, and blood pressure control: 18-month results of a randomized trial. *Ann Intern Med* **144**, 485–495.
21. Bernstein AM, Sun Q, Hu FB, *et al.* (2010) Major dietary protein sources and risk of coronary heart disease in women. *Circulation* **122**, 876–883.
22. Song M, Fung TT, Hu FB, *et al.* (2016) Association of animal and plant protein intake with all-cause and cause-specific mortality. *JAMA Intern Med* **176**, 1453–1463.
23. Lopes HF, Martin KL, Nashar K, *et al.* (2003) DASH diet lowers blood pressure and lipid-induced oxidative stress in obesity. *Hypertension* **41**, 422–430.
24. Medina-Remón A, Zamora-Ros R, Rotchés-Ribalta M, *et al.* (2011) Total polyphenol excretion and blood pressure in subjects at high cardiovascular risk. *Nutr Metab Cardiovasc Dis* **21**, 323–331.
25. Stamler J, Brown IJ, Daviglus ML, *et al.* (2009) Glutamic acid, the main dietary amino acid, and blood pressure: the INTERMAP Study (International Collaborative Study of Macronutrients, Micronutrients and Blood Pressure). *Circulation* **120**, 221–228.
26. Houston MC, Harper KJ (2008) Potassium, magnesium, and calcium: their role in both the cause and treatment of hypertension. *J Clin Hypertens (Greenwich)* **10**, 3–11.
27. Gallen IW, Rosa RM, Esparaz DY, *et al.* (1998) On the mechanism of the effects of potassium restriction on blood pressure and renal sodium retention. *Am J Kidney Dis* **31**, 19–27.
28. Xu JY, Qin LQ, Wang PY, *et al.* (2008) Effect of milk tripeptides on blood pressure: a meta-analysis of randomized controlled trials. *Nutrition* **24**, 933–940.
29. Kris-Etherton PM, Grieger JA, Hilpert KF, *et al.* (2009) Milk products, dietary patterns and blood pressure management. *J Am Coll Nutr* **28**, Suppl. 1, 103S–119S.
30. Basiotis PP, Welsh SO, Cronin FJ, *et al.* (1987) Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *J Nutr* **117**, 1638–1641.
31. Biro G, Hulshof KF, Ovesen L, *et al.* (2002) Selection of methodology to assess food intake. *Eur J Clin Nutr* **56**, Suppl. 2, S25–S32.

British Journal of Nutrition