DIETARY INTERVENTION

Dietary Approaches to Stop Hypertension Dietary Intervention Improves Blood Pressure and Vascular Health in Youth With Elevated Blood Pressure

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ABSTRACT: This randomized control trial assessed the post-intervention and 18-month follow-up effects of a 6-month dietary approaches to stop hypertension (DASH)-focused behavioral nutrition intervention, initiated in clinic with subsequent telephone and mail contact, on blood pressure (BP) and endothelial function in adolescents with elevated BP. Adolescents (n=159) 11 to 18 years of age with newly diagnosed elevated BP or stage 1 hypertension treated at a hospital-based clinic were randomized. DASH participants received a take-home manual plus 2 face-to-face counseling sessions at baseline and 3 months with a dietitian regarding the DASH diet, 6 monthly mailings, and 8 weekly and then 7 biweekly telephone calls focused on behavioral strategies to promote DASH adherence. Routine care participants received nutrition counseling with a dietitian consistent with pediatric guidelines established by the National High Blood Pressure Education Program. Outcomes, measured pre- and post-intervention and at 18-months follow-up, included change in BP, change in brachial artery flow-mediated dilation, and change in DASH score based on 3-day diet recalls. Adolescents in DASH versus routine care had a greater improvement in systolic BP (−2.7 mm Hg, P= 0.03, −0.3 z-score, P=0.03), flow-mediated dilation (2.5%, P=0.05), and DASH score (13.3 points, P<0.0001) from baseline to post-treatment and a greater improvement in flow-mediated dilation (3.1%, P=0.03) and DASH score (7.4 points, P=0.01) to 18 months. The DASH intervention proved more effective than routine care in initial systolic BP improvement and longer term improvement in endothelial function and diet quality in adolescents with elevated BP and hypertension.

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Hypertension prevalence in youth is increasing, with current estimates of ≈3.5% of the pediatric population[1,2] and higher rates among children and adolescents with overweight and obesity.[1–3] Hypertension risk increases with age in childhood,[3] tracks into adulthood,[1,2] and has been linked with damage to the heart and blood vessels.[4–6] Clinical practice guidelines regarding high blood pressure (BP) in youth strongly recommend early screening and intervention efforts to promote cardiovascular health into adulthood.[2]

Lifestyle approaches are recommended as first line treatment for BP lowering including strategies that promote a dietary approaches to stop hypertension (DASH) dietary pattern that is high in fruits, vegetables, and low fat dairy and is low in fat, sugar, and sodium.[2,7] Randomized controlled trials (RCTs) and feeding studies in adults with hypertension showed that a DASH diet dramatically lowered systolic and diastolic BP compared with a standard Western diet or one only high in fruits and vegetables.[8–10] In youth, cross-sectional and

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Novelty and Significance

What Is New?

- Adolescents with elevated blood pressure (BP) who received a dietary approaches to stop hypertension (DASH) dietary intervention achieved greater improvement over the short-term in systolic BP and over the long-term in endothelial function and dietary quality compared with adolescents who received routine care for BP management.

What Is Relevant?

- Adherence to a DASH-type diet may have an ongoing favorable impact on vascular health in adolescents with elevated BP independent of BP control.

Summary

Adolescents with elevated BP can improve their diet quality and achieve long-term cardiovascular benefits in response to a DASH-dietary intervention.

Nonstandard Abbreviations and Acronyms

BMI	body mass index
BP	blood pressure
DASH	dietary approaches to stop hypertension
FMD	flow-mediated dilatation
RC	routine care
RCT	randomized controlled trial

nonintervention cohort studies demonstrated positive associations between a DASH-style eating pattern and lower BP.[11–14] Only 2 short-term trials have been conducted in youth on the DASH diet and BP. In one, our research group showed greater improvement in systolic BP among adolescents with elevated BP who participated in a DASH-focused intervention compared with routine care (RC)[15]; the other showed lower prevalence of hypertension in girls with metabolic syndrome after counseling on the DASH diet compared with usual dietary advice.[16]

Current clinical practice guidelines advocate for a DASH diet for BP management in youth,[2] yet adherence to this dietary pattern is low.[17] In routine clinical practice, infrequent face-to-face diet counseling on DASH done in accordance with established BP treatment guidelines has yielded only modest adherence to this diet among at risk youth.[15] Intervention efforts involving more frequent dietary counseling contacts by telephone and mail have proven to be successful in changing dietary and health-related behaviors and are feasible for initiation in primary care settings.[15,18,19] However, no long-term trial evidence exists to demonstrate the effectiveness of these approaches for DASH diet intervention or adherence in youth with elevated BP. This RCT was designed to evaluate the post-treatment and 18-month follow-up effects of a 6-month DASH-focused behavioral nutrition intervention, initiated in clinic with telephone and mail follow-up, on BP and vascular health in adolescents with elevated BP and hypertension relative to adolescents provided RC.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Design and Participants

This RCT was conducted at the Hypertension Center at Cincinnati Children's Hospital Medical Center. Ethical approval was obtained from the Cincinnati Children's Hospital Medical Center and the University of Cincinnati Institutional Review Boards. Parental consent and adolescent assent were obtained. Adolescents 11 to 18 years of age with a clinic-based systolic or diastolic BP ≥90th and ≤99th percentile +5 mm Hg for age, sex, and height on first visit to the hypertension clinic were screened. Adolescents with a clinical diagnosis of elevated BP or stage 1 hypertension (3 persistent systolic BP and/or diastolic BP ≥90th and ≤99th percentile+5 mm Hg for age, sex, and height)[20] and who met the following criteria were enrolled: (1) were free of BP altering medications; (2) had not received formal nutrition counseling for BP management, (3) were free of psychological or medical conditions that precluded participation; and (4) were English speaking. Once enrolled, participants were further screened before randomization and excluded if they had diagnosed secondary hypertension or left ventricular hypertrophy determined by echocardiography (left ventricular mass index ≥51 g/m$^{2.7}$).[20] When Ambulatory Blood Pressure Monitoring (ABPM) was performed for clinical use to identify white coat hypertension, adolescents thus diagnosed were excluded from participation. Figure provides details of study flow and the number of participants screened, enrolled, and randomized. All study personnel were blinded to dietary treatment group except for study dietitians and participants.

Trial Conduct

Participants were enrolled between January 2008 and May 2013, and data collection was completed in October 2014.

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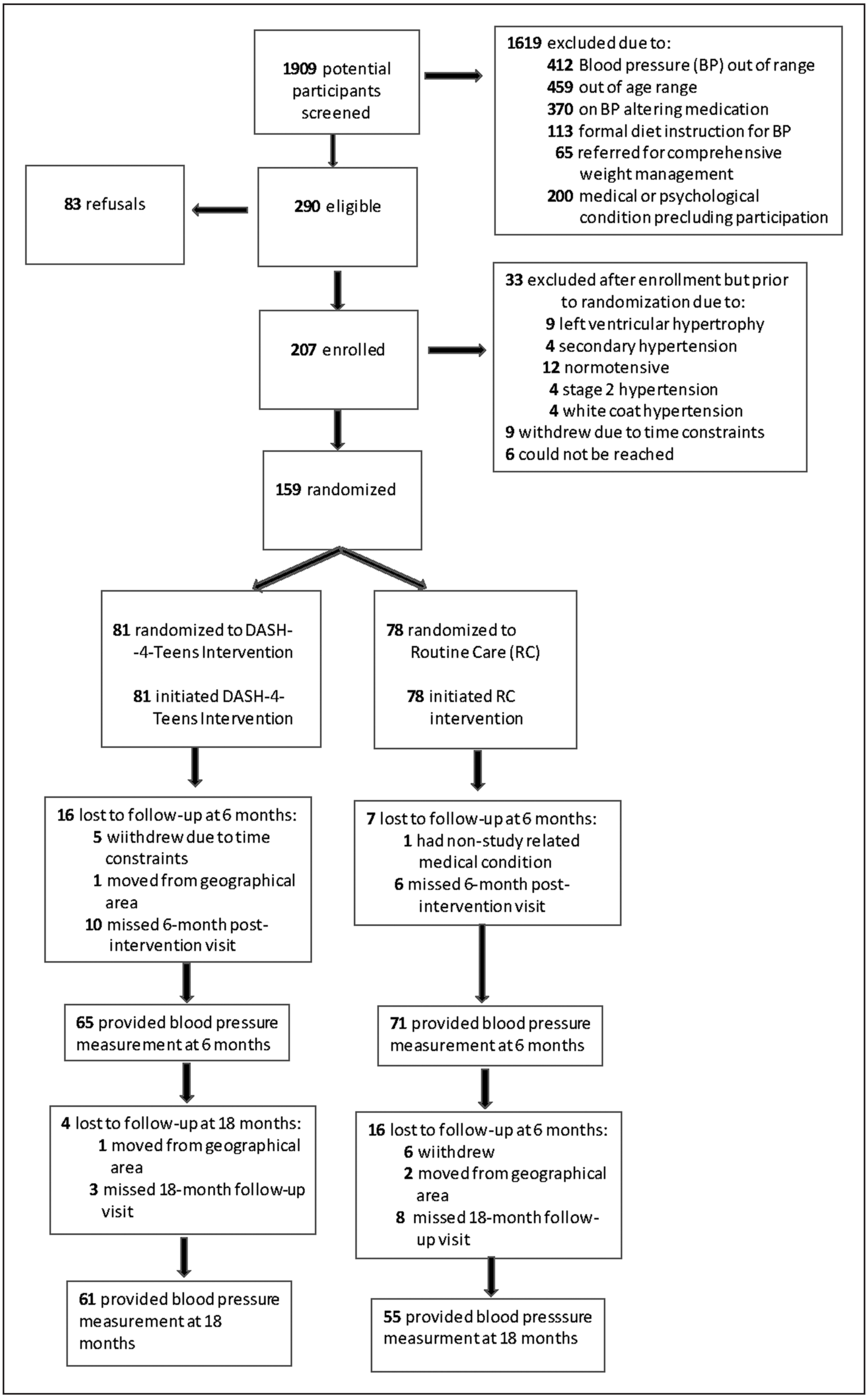

Figure. Flow of participants through dietary approaches to stop hypertension (DASH)-4-Teens Study.
BP indicates blood pressure; and RC, routine care.

Baseline data were collected during 3 screening visits to establish a diagnosis of elevated BP or hypertension[20] at least 7 days before randomization. Follow-up data were collected at 2 assessment visits: once at 6 months (post-intervention) and then at 18 months (1-year follow-up) after randomization. All participants received $20 for assessment visit attendance.

Randomization was stratified by age (11–14 and 15–18 years), sex, and hypertension status (elevated BP or stage 1 hypertension) using a computer generated table of randomly selected blocks of 2 assignments at a time completed by the study biostatician.

Conditions

DASH-4-Teens Intervention

Table 1 provides details of the intervention format, pattern of contact, content, behavioral skills component, and food plan. Participants were encouraged to make gradual changes in their diet to achieve age-specific DASH food goals that were set weekly to ultimately achieve DASH diet recommendations. To assess progress toward goals, DASH participants were asked to record their intake of fruit, vegetables, low-fat dairy, and high fat/high sodium foods for 5 of 7 days/week. Incentives were awarded for meeting weekly DASH dietary goals ($2/goal met; maximum $8/week). In accordance with established pediatric BP guidelines, physical activity was encouraged but was not a target for change.[20]

RC Intervention

The RC intervention content, delivery format, and pattern of contact are summarized in Table 1. RC did not deviate from the nutrition counseling that was routinely performed with all newly seen patients to the Hypertension Clinic.

Shared Intervention and Assessment Characteristics

Participants were scheduled to receive face-to-face check-ins with a RD in accordance with clinical practice guidelines at the Hypertension Clinic at 3 months, after the study assessment at 6 months, at 1 year, and after the study assessment at 18-months post-randomization. Referral for antihypertensive medication therapy was made in accordance with established pediatric BP guidelines.[20]

Measures

Measures were collected at baseline, 6 months, and 18 months unless otherwise noted. All measurements were made in the Hypertension Center by trained staff blinded to treatment assignment.

Outcomes

BP measurements were performed with a mercury sphygmomanometer according to standardized procedures.[20] BP was calculated from the average of 2 BP measurements. Systolic and diastolic BP *z* scores and hypertension status determination were made based on established norms.[20]

Flow-mediated dilatation (FMD) assessment was performed using B-mode ultrasound vascular imaging done with the GE Vivid 7–V7916 ultrasound system (Horton, Norway). The diameter of the left brachial artery was measured with a high resolution linear array M12L, 5.0 to 11.0 MHz vascular ultrasound transducer. Brachial artery FMD was assessed according to published guidelines[25] with diameter measurements obtained at baseline and immediately, 60, 90, and 120 seconds post-BP cuff deflation. Peak FMD (% FMD max) was calculated as (maximum diameter−baseline diameter)/(baseline diameter)×100. FMD area under the response curve (mm^2) from 60 to 120 seconds was calculated using the trapezoidal rule.[26]

Dietary intake was assessed using 3 random 24-hour recalls (2 weekdays and 1 weekend day) collected in the 2 weeks before each assessment visit using the validated multipass method.[27,28] Adolescents were trained in the use of 2-dimensional food portion models (Nutrition Consulting Enterprises, Framingham, MA) to assist with portion estimation. Recalls were collected from the adolescent by telephone interview by a trained RD and analyzed for average calories, nutrients, and food group servings using the Minnesota Nutrient Data Systems software, version 2.94 (2014). A DASH score was calculated according to Günther et al[29] modified to include a 10-point sodium component score. DASH score ranged from 0 to 90, with a higher score indicating greater DASH adherence.

Medication Referral

For those prescribed antihypertensive medication before a study assessment at 6 or 18 months, we obtained an official set of BP, vascular function, and dietary intake measures usually at or after the 3- and 12-month check-in visits (as was possible), before medication initiation, and these were used as the 6- or 18-month values, respectively.

Covariates

Demographics were self-reported by adolescents and included birth date, sex, and race/ethnicity. Parents self-reported race/ethnicity and household income.

Body mass index (BMI) was calculated as weight in kg/height in meter square. Weight was measured with participants wearing light indoor clothing and no shoes using a calibrated triple-beam balance scale. Standing height was measured using a wall-mounted stadiometer. Measures were taken twice and averaged. Age- and sex-specific BMI *z* scores were determined from Centers for Disease Control (CDC) growth charts using the Lambda-Mu-Sigma (LMS) method.[30]

Physical activity was assessed using a validated 7-day physical activity recall interview.[31] Metabolic equivalents were assigned to 30-minute blocks of activities[32] and summed over each day and averaged.

Table 1. Intervention Format and Pattern of Delivery, Content, Behavior Change Elements, and Food Plan: DASH-4-Teens and Routine Care

Intervention elements	DASH intervention				RC intervention
Format and pattern of delivery	60-min face-to-face session with dietitian (RD), participant, and parent at baseline; 30-min face-to-face follow-up session with RD, participant, and parent at 3 mo; DASH-4-TEENS manual (10-module illustrate manual) provided to participant at baseline; 4 factsheets provided to parent; 8 weekly and 7 biweekly phone calls to the teen by trained interventionist,* 6 monthly mailings sent to participant and parent.† Six and 12 mo check-ins with RD after study assessments.				60-min face-to-face counseling session with dietitian, participant, and parent at baseline; booklet your guide to lowering blood pressure# provided to participant at baseline; 30-min face-to-face follow-up session with dietitian, participant, and parent at 3 mo; fact sheets provided to address dietary deficiencies or excesses at 3 mo; 6 and 12 mo face-to-face check-ins with RD after study assessments.
Content	The manual and counseling included an explanation of the benefits of the DASH diet, DASH food group serving recommendations (see below), DASH-compliant food lists by food group, tips for incorporating DASH foods into the diet, and theory-based† behavioral skills to promote compliance to the DASH dietary plan.‡ Parent factsheets for creating a DASH-friendly home environment, shopping and meal planning tips that emphasized the importance of family meals.				The booklet included dietary recommendations consistent with the National High Blood Pressure Education Program's pediatric dietary recommendations** including strategies to reduce weight if overweight, reducing sodium and fat intake, and eating more fruits and vegetables. The DASH food plan was also included and serving recommendations provided.
Food plan	Female		Male		The booklet encouraged consumption of fruits and vegetables and eating a DASH dietary pattern. A table of the DASH food plan was included with serving recommendations for a 2000 calorie diet. The booklet also included tips for weight reduction although no specific calorie recommendations were made for weight loss. Charts were provided for foods high and low in sodium and fat. Participant education promoted dietary sodium reduction to a level of 2400 mg per d.
Age range, y	11–13	14–18	11–13	14–18	
Calories§	1600	1800	1800	2200	
Servings/d‖					
Bread, cereal, rice, and pasta (1 oz)¶	5	6	6	8	
Vegetables (1/2 cup)	4	5	5	6	
Fruit (1/2 cup)	3	3	3	4	
Low-fat dairy (1 cup)	3	3	3	3	
Lean meat, poultry, and fish (1 oz)	5	6	6	7	
Dry beans, nuts, seeds, and eggs (1/4 cup)	1	1	1	1	
Fats and oils (1 tsp)	2	2	2	3	
Sweets and desserts (1 tbsp sugar)	1	1	1	2	

DASH indicates dietary approaches to stop hypertension; RC, routine care; and RD, registered dietitian.
*Nutrition interventionist were Master's degree-level RDs.
†See study by Glanz et al[21] and Montgomery.[22]
‡Sections of the manual related to behavioral skills were mailed to participants during wks 4,6, 8, 10, 14, 18, of the intervention, parents were mailed fact sheets for creating a home environment supportive of the DASH food plan.
§Calorie recommendations were determined for a sedentary lifestyle and for weight maintenance.
‖Energy contributions from each food group were calculated according to the nutrient dense forms of foods in each group and modified from study by Karanja et al.[23]
¶Usual servings size for each food group in indicated in parentheses.
#See study by US Department of Health and Human Services.[24]
**See study by National High Blood Pressure Education Program and Working Group on High Blood Pressure in Children and Adolescents.[20]

Statistical Methods

Sample size estimation was based on a repeated measures design with 3 time points (0, 6, and 18 months), a correlation between intrasubject measurements of 0.5, and a mean difference in systolic BP z-score of 0.43 at post-treatment, based on preliminary studies.[15] Seventy-four subjects per group was calculated to allow for the posited group difference to be detected as significant at the 5% level (2-tailed) with 80% power and an attrition rate of 13%.[33]

Descriptive statistics were used to summarize the participants' data in the 2 intervention conditions. Statistical significance of group differences in the proportion of participants referred for antihypertension medication and with change in hypertension status at post-intervention and follow-up was tested using Pearson χ^2 test. For our primary analysis, it was expected that the likelihood of missingness could be predicted by the observed data, so missing data were assumed to be at random and a likelihood-based analysis using all available data was used. The primary hypothesis of DASH participants achieving different BP change than RC participants was tested by fitting a linear mixed-effects model via maximum likelihood with change in BP over time as the outcome, including time (baseline, 6 and 18 months), group (DASH versus RC), group×time interaction and age, sex, race, income, metabolic equivalents/day, and BMI z-score. Identical models were fit to test group differences for change in endothelial function and change in dietary variables, BMI z-score, and physical activity measures. The equality of mean change at 6 and 18 months from baseline by group was tested and is presented as least square means by intervention group along with the corresponding 95% CI. All tests were 2-sided, and $P \leq 0.05$ was used as the cutoff for statistical significance. The analysis was carried out using the SAS version 9.4 (SAS Institute, Cary, NC).

RESULTS

Descriptive characteristics for the DASH and RC participants are shown in Table 2. For the primary outcome (BP), participant retention was 80% in the DASH intervention and 91% in RC at post-intervention and 75% and 71%, respectively at 18 months (Figure). Compared with those with 6-month data, the 23 adolescents with missing data at 6 months reported lower baseline daily fruit servings (mean [SD]: 1.2 [1.3] versus 0.6 [0.7], $P=0.04$) and percent of calories from fat (32.1 [6.0] versus 34.8 [4.5], $P=0.04$); compared with those with 18 month data, the 43 with missing data at 18 months reported lower mean (SD) baseline intake of these same dietary components (daily fruit servings: 1.3 [1.4] versus 0.7 [0.7], $P=0.01$ and percent of calories from fat: 31.8 [5.8] versus 34.4 [5.6], $P=0.01$). In addition to the initial counseling session attended by all participants at randomization, 72% of DASH and 65% of RC participants attended the 3-month face-to-face diet education session. Sixty percent of DASH intervention participants completed at least 11 of the 15 behaviorally oriented telephone calls (mean±SD: 10.6±5.1 calls).

Mean reduction in systolic BP (mm Hg and z-scores) from baseline to 6 months was greater in DASH compared with RC participants (Table 3); mean change in systolic BP and diastolic BP (mm Hg and z-scores) from baseline to 18 months did not differ by intervention condition. Greater improvement in FMD (% max and area under the response curve, 60–120) from baseline to 6 months and baseline to 18 months was found in DASH compared with RC (Table 3). From baseline to 6 months, 35 of 65 (54%) DASH participants compared with 28 of 71 (39%) RC participants achieved an optimal BP (<90th percentile for systolic or diastolic BP); from baseline to 18 months, 21 of 61 (34%) DASH and 19 of 55 (35%) RC participants achieved optimal BP. By 6 months, antihypertensive medications had been started in 5 DASH and 7 RC participants. At 18 months, a total of 9 DASH and 11 RC participants had been started on antihypertensive medication. Intervention groups did not differ at 6 or 18 months in percentage who achieved optimal BP or referral for antihypertension medication.

DASH compared with RC participants showed more favorable mean change in daily DASH score, servings of low-fat dairy and intake of % kcals from total and saturated fat from baseline to 6 months and baseline to 18 months (Table 4). Conditions also differed in intake of fruit servings and mgs/day of calcium, potassium, magnesium, and sodium with more favorable mean change from baseline to 6 months in DASH compared with RC participants. Mean change in BMI z-score, energy expenditure (metabolic equivalents minutes/day), and energy intake (kcal/day) did not differ by intervention group (Table 4).

Table 2. Baseline Characteristics of Participants by Randomized Group

Characteristics*	DASH (n=81)	RC (n=78)
Age, y; means (SD)	14.7 (2.0)	14.7 (2.0)
Age distribution, n (%)		
≥14 y	35 (43)	32 (41)
<14 y	46 (57)	46 (59)
Sex, n (%)		
Males	53 (65)	49 (63)
Females	28 (35)	29 (37)
Race/ethnicity, n (%)		
White participants	49 (61)	51 (65)
Non–white participants	32 (39)	27 (35)
Hispanic/latino		
Yes	1 (1)	2 (3)
No	80 (99)	76 (97)
Family income, n (%)		
<$20 000	16 (20)	16 (21)
$20 000–$80 000	48 (59)	44 (56)
>$80 000	17 (21)	18 (23)
Hypertension status,† n (%)		
Elevated blood pressure	47 (58)	50 (64)
Stage 1 hypertension	34 (42)	28 (36)
Weight classification,‡ n (%)		
BMI ≤85th percentile	18 (22)	14 (18)
BMI >85th to <95th percentile	9 (11)	10 (13)
BMI ≥95th percentile	54 (67)	54 (69)

BMI indicates body mass index; DASH, dietary approaches to stop hypertension; and RC, routine care.

*All values are expressed as means (SD) unless otherwise indicated.

†Hypertension status was determined based on 3 blood pressure readings made on 3 separate occasions.[20]

‡Weight classification was based on age- and sex-specific BMI percentiles according to Centers for Disease Control growth charts.[34]

DISCUSSION

This RCT provides evidence of the efficacy of a 6-month behavioral nutrition intervention initiated in clinic with subsequent telephone and mail follow-up emphasizing the DASH diet on systolic BP and vascular function for adolescents with elevated BP and stage 1 hypertension. DASH-4-Teens participants increased their intake of fruits, low-fat dairy foods, and related nutrients and lowered their intake of total and saturated fat and sodium to achieve a significant increase in DASH dietary adherence from pre- to post-intervention relative

Table 3. Change (Δ) in Blood Pressure and Vascular Function by Intervention Group

Outcome	Time	Least square means (95% CI)		Least square mean Δ from baseline		Estimate of difference for change	*P* value‡
		DASH*	RC†	DASH	RC		
Systolic blood pressure, mm Hg	Baseline	127.0 (124.3 to 129.7)	126.0 (123.1 to 128.8)				
	6 mo	122.8 (119.6 to 125.9)	124.3 (121.1 to 127.6)	−4.3 (−6.1 to −2.5)	−1.6 (−3.4 to 0.2)	−2.7 (−5.2 to −0.1)	0.03
	18 mo	124.6 (121.5 to 127.8)	125.2 (123.1 to 128.8)	−2.4 (−4.1 to −0.7)	−0.8 (−2.6 to 1.1)	−1.7 (−4.2 to 0.9)	0.20
Systolic blood pressure, *z*-score	Baseline	1.5 (1.2 to 1.7)	1.3 (1.1 to 1.6)				
	6 mo	1.0 (0.7 to 1.2)	1.1 (0.8 to 1.4)	−0.5 (−0.7 to −0.3)	−0.2 (−0.4 to −0.1)	−0.3 (−0.5 to −0.03)	0.03
	18 mo	1.0 (0.7 to 1.3)	1.0 (0.7 to 1.3)	−0.5 (−0.7 to −0.3)	−0.3 (−0.5 to −0.1)	−0.2 (−0.4 to −0.03)	0.09
Diastolic blood pressure, mm Hg	Baseline	77.1 (73.7 to 80.5)	75.8 (72.2 to 79.4)				
	6 mo	76.5 (72.9 to 80.1)	75.1 (71.4 to 78.8)	−0.7 (−2.8 to 1.5)	−0.7 (−2.8 to 1.4)	0.01 (−2.9 to 3.0)	>0.99
	18 mo	76.6 (72.8 to 80.5)	72.4 (68.4 to 76.4)	−0.5 (−3.2 to 2.2)	−3.4 (−6.2 to −0.6)	2.9 (−1.0 to 6.8)	0.14
Diastolic blood pressure, *z*-score	Baseline	1.1 (0.8 to 1.4)	0.9 (0.6 to 1.3)				
	6 mo	1.0 (0.6 to 1.3)	0.8 (0.5 to 1.2)	−0.1 (−0.3 to 0.1)	−0.1 (−0.3 to 0.1)	0.01 (−0.3 to 0.3)	0.93
	18 mo	0.9 (0.5 to 1.2)	0.5 (0.1 to 0.9)	−0.2 (−0.4 to 0.04)	−0.4 (−0.7 to −0.2)	0.2 (−0.1 to 0.6)	0.19
FMD (% max)§	Baseline	6.3 (4.0 to 8.6)	7.5 (5.2 to 10.0)				
	6 mo	7.5 (5.0 to 9.9)	6.2 (4.1 to 9.0)	1.1 (−0.7 to 2.9)	−1.4 (−3.2 to 0.4)	2.5 (0.001 to 5.1)	0.05
	18 mo	8.3 (5.9 to 10.7)	6.5 (4.1 to 9.0)	2.0 (0.1 to 3.9)	−1.1 (−3.1 to 0.9)	3.1 (0.3 to 5.8)	0.03
FMD AUC, 60–120 s‖	Baseline	6.1 (2.1 to 10.0)	8.6 (4.5 to 12.7)				
	6 mo	8.4 (4.3 to 12.6)	5.1 (0.8 to 9.5)	2.4 (−0.7 to 5.3)	−3.5 (−6.5 to −0.4)	5.8 (1.5 to 10.1)	0.01
	18 mo	10.2 (6.2 to 14.3)	6.0 (1.8 to 10.1)	4.2 (1.1 to 7.3)	−2.6 (−5.9 to 0.6)	6.8 (2.3 to 11.3)	0.003

AUC indicates area under the response curve; BMI, body mass index; DASH, dietary approaches to stop hypertension; FMD, flow-mediated dilation of the brachial artery; MET, metabolic equivalent; and RC, routine care.

*DASH: n=81

†RC: n=78.

‡Significance testing differences in change in response to intervention from baseline to 6 mo (post-treatment) and baseline to 18 mo (follow-up) were obtained with all-in-case repeated measures mixed models adjusted for age, sex, race/ethnicity, income, metabolic equivalents (MET) min/d, and BMI *z* score.

§FMD (% max)=(lumen vessel diameter post-inflation−lumen diameter at baseline)/lumen diameter at baseline, where the maximum=the maximum of the mean values at 60, 90, and 120 s post-deflation.

‖FMD area under the response curve (AUC), 60–120 s=area under the response curve calculated using the trapezoid rule where the sum of the average between FMD 60 and 90+ average between FMD 90 and 120 is determined.[26]

to adolescents receiving RC. In DASH-4-Teens participants, an average 11.8 point improvement in DASH dietary score was accompanied by a mean 4.3 mm Hg improvement in systolic BP compared with a more modest change in DASH adherence and systolic BP among RC participants at post-treatment. Neither group showed change in diastolic BP, consistent with our earlier findings[15] and those of others.[11–13] While the BP benefits achieved at 6 months were not fully sustained long term, endothelial function showed greater improvement from baseline to 6 months and to 18 months in the DASH group compared with RC suggesting long term benefits of DASH-style eating on vascular health. Notably, favorable changes in systolic BP and vascular function were achieved independent of changes in weight status or physical activity, which were not intervention targets and did not substantively or differentially change between intervention groups. These findings support the efficacy of the DASH-4-Teens approach on cardiovascular health in youth.

Endothelial dysfunction as measured by reduced FMD of the brachial artery has been shown to be an independent predictor of cardiovascular morbidity and mortality in adults.[35] In previous studies, this measure responded adversely to hypertension and favorably to pharmacotherapy and lifestyle intervention.[35,36] However, few trials have examined FMD in response to a DASH dietary pattern. Hodson et al[37] showed that a 30-day DASH intervention lowered systolic and diastolic BP in adults with normal BP but did not alter FMD compared with no intervention. In the Exercise and Nutritional Interventions for Cardiovascular Health (ENCORE) study, adults with elevated BP treated with a 4-month DASH intervention showed significant lowering in systolic and diastolic BP and a trend for greater improvement in FMD compared with usual care.[38] The present study is the first to examine changes in FMD in response to a DASH intervention in adolescents with elevated BP and hypertension. Our finding of FMD improvement independent of BP control from baseline to 18 months in DASH participants compared with RC suggest dietary changes achieved in response to DASH-4-Teens may have an ongoing, favorable impact on vascular health in adolescents with elevated BP.

While change in some DASH-related food groups achieved post-intervention were not fully sustained from baseline to 18 months, moderate long-term changes in

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Table 4. Change (Δ) in Weight Status, Physical Activity, and Diet by Intervention Group

Outcome	Time	Least square means (95% CI)		Least square mean Δ from baseline		Estimate of difference for change	*P* value‡
		DASH*	RC†	DASH	RC		
BMI, *z*-score	Baseline	1.9 (1.5 to 2.3)	1.9 (1.5 to 2.3)				
	6 mo	1.8 (1.4 to 2.2)	1.8 (1.4 to 2.3)	−0.1 (−0.1 to −0.002)	−0.04 (−0.1 to 0.02)	−0.04 (−0.1 to 0.02)	0.33
	18 mo	1.8 (1.4 to 2.2)	1.8 (1.4 to 2.2)	−0.1 (−0.2 to 0.002)	−0.1 (−0.2 to 0.02)	−0.01 (−0.2 to 0.03)	0.84
Physical activity (METs/d)	Baseline	34.2 (32.8 to 35.7)	33.9 (32.4 to 35.5)				
	6 mo	34.1 (32.6 to 35.7)	33.9 (32.3 to 35.4)	−0.1 (−1.2 to 1.0)	−0.1 (−1.2 to 0.9)	−0.003 (−1.5 to 1.5)	>0.99
	18 mo	33.5 (31.9 to 35.1)	34.0 (32.4 to 35.5)	−0.7 (−2.1 to 0.7)	0.01 (−1.4 to 1.5)	−0.7 (−2.7 to 1.3)	0.48
Energy intake, kcal/d	Baseline	1565.4 (1345.9 to 1784.9)	1504.8 (1274.3 to 1735.3)				
	6 mo	1492.7 (1255.2 to 1730.2)	1513.1 (1267.9 to 1758.2)	−72.6 (−212.7 to 67.5)	8.3 (−129.1 to 145.7)	−80.9 (−277.1 to 115.5)	0.42
	18 mo	1519.8 (1286.2 to 1753. 5)	1534.3 (1274.3 to 1735.3)	−45.5 (−193.4 to 102.3)	29.5 (−127.9 to 187.0)	−75.0 (−290.7 to 140.7)	0.49
DASH score §	Baseline	41.0 (37.2 to 44.9)	43.8 (39.8 to 47.8)				
	6 mo	52.8 (48.5 to 57.2)	42.3 (37.8 to 46.8)	11.8 (8.7 to 14.9)	−1.5 (−4.6 to 1.5)	13.3 (8.9 to 17.7)	<0.0001
	18 mo	46.1 (41.6 to 50.6)	41.5 (36.8 to 46.2)	5.0 (1.6 to 8.5)	−2.3 (−6.0 to 1.4)	7.4 (2.3 to 12.5)	0.01
Fruit servings/d	Baseline	0.8 (0.3 to 1.4)	1.2 (0.6 to 1.7)				
	6 mo	2.8 (2.2 to 3.5)	0.8 (0.1 to 1.5)	2.0 (1.5 to 2.5)	−0.4 (−0.9 to 0.1)	2.3 (1.7 to 3.0)	<0.0001
	18 mo	1.7 (1.0 to 2.4)	1.3 (0.6 to 1.7)	0.9 (0.4 to 1.4)	0.1 (−0.5 to 0.7)	0.8 (−0.02 to 1.5)	0.06
Vegetables, servings/d	Baseline	0.9 (0.5 to 1.3)	1.0 (0.6 to 1.4)				
	6 mo	1.6 (1.1 to 2.1)	1.3 (0.8 to 1.8)	0.7 (0.4 to 1.1)	0.3 (−0.04 to 0.7)	0.4 (−0.1 to 0.9)	0.11
	18 mo	1.2 (0.6 to 1.7)	1.2 (0.7 to 1.8)	0.3 (−0.1 to 0.7)	0.2 (−0.2 to 0.7)	0.09 (−0.5 to 0.7)	0.77
Low-fat dairy, servings/d	Baseline	0.5 (0.1 to 0.9)	0.6 (0.2 to 1.0)				
	6 mo	1.5 (1.0 to 1.9)	0.4 (−0.004 to 0.9)	1.0 (0.7 to 1.2)	−0.2 (−0.4 to 0.1)	1.1 (0.8 to 1.5)	<0.0001
	18 mo	0.9 (0.5 to 1.3)	0.5 (0.2 to 1.0)	0.5 (0.1 to 0.7)	−0.1 (−0.4 to 0.2)	0.5 (0.1 to 1.0)	0.01
Total fat, % kcals/d	Baseline	32.2 (30.0 to 34.4)	30.8 (28.5 to 33.1)				
	6 mo	26.1 (23.7 to 28.5)	30.9 (28.4 to 33.3)	−6.1 (−7.9 to −4.3)	0.1 (−1.7 to 1.9)	−6.2 (−8.8 to −3.6)	<0.0001
	18 mo	28.7 (26.2 to 31.3)	32.7 (30.0 to 35.4)	−3.5 (−5.5. to −1.5)	2.0 (−0.2 to 4.1)	−5.5 (−8.4 to −2.5)	0.0003
Saturated fat, % kcals/d	Baseline	10.8 (9.6 to 11.8)	10.1 (9.1 to 11.1)				
	6 mo	8.7 (7.6 to 9.7)	10.6 (9.6 to 11.6)	−2.2 (−2.9 to −1.4)	0.6 (−0.2 to 1.3)	−2.7 (−3.8 to −1.7)	<0.0001
	18 mo	9.3 (8.3 to 10.3)	10.7 (9.7 to 11.8)	−1.5 (−2.3 to −0.8)	0.7 (−0.1 to 1.4)	−2.1 (−3.2 to −1.1)	0.0001
Calcium, mg/d	Baseline	785.4 (614.3 to 956.4)	779.2 (599.5 to 958.8)				
	6 mo	1034.6 (852.5 to 1216.8)	801.1 (612.4 to 989.8)	249.9 (149.6 to 248.9)	21.9 (−76.5 to 120.3)	227 (−87.4 to 367.3)	0.002
	18 mo	900.1 (713.7 to 1086.4)	771.1 (577.7 to 964.5)	114.7 (−3.7 to 233.1)	−8.1 (−134.6 to 118.4)	122.8 (−50.2 to 295.8)	0.16
Potassium, mg/d	Baseline	1682.6 (1362.7 to 1997.4)	1660.8 (1330.1 to 1991.5)				
	6 mo	2359.1 (1998.9 to 2719.3)	1667.8 (1296.6 to 2038.9)	676.5 (460.8 to 892.3)	6.9 (−205.9 to 219.8)	669.6 (366.7 to 972.5)	<0.0001
	18 mo	1952.3 (1601.4 to 2303.1)	1724.7 (1362.2 to 2087.2)	269.7 (39.5 to 499.9)	63.8 (−179.2 to 306.9)	205.9 (−128.4 to 540.1)	0.23
Magnesium, mg/d	Baseline	198.4 (167.0 to 229.8)	189.5 (156.5 to 222.5)				
	6 mo	246.8 (211.3 to 282.3)	191.2 (154.6 to 227.8)	48.4 (27.1 to 69.7)	1.8 (−19.2 to 22.7)	46.6 (16.8 to 76.5)	0.002
	18 mo	221.9 (187.6 to 256.2)	201.8 (166.4 to 237.2)	23.4 (1.1 to 45.8)	12.3 (−11.3 to 35.9)	11.1 (−21.2 to 43.6)	0.50
Sodium, mg/d	Baseline	2631.4 (2251.1 to 3011.8)	2424.4 (2024.9 to 2823.9)				
	6 mo	2301.8 (1870.1 to 2733.2)	2639.9 (2196.5 to 3083.2)	−329.6 (−627.2 to −32.1)	215.4 (−78.6 to 509.5)	−545.1 (−963.3 to −126.9)	0.01
	18 mo	2595.6 (2158.7 to 3032.5)	2685.8 (2231.2 to 3140.4)	−35.8 (−338.2 to 266.6)	261.4 (−62.2 to 584.9)	−297.2 (−739.6 to 145.3)	0.19

BMI indicates body mass index; DASH, dietary approaches to stop hypertension; MET, metabolic equivalent; and RC, routine care.

*DASH: n=81.

†RC: n=78.

‡Significance testing differences in change in response to intervention from baseline to 6 mo (post-treatment) and baseline to 18 mo (follow-up) were obtained with all-in-case repeated measures mixed models adjusted for age, sex, race/ethnicity, income, METs min/d, and BMI *z* score.

§DASH score was based on a scale of 0 to 90 with higher score=higher DASH adherence.[29]

overall DASH score and low fat dairy foods and decreased intake of total and saturated fat may have contributed to favorable changes in vascular health among DASH participants compared with RC. Diets high in total and saturated fat have been shown to impede nitric oxide production from the vascular endothelium.[39] This effect may be related to higher free fatty acid concentrations with higher fat intakes. Several studies have shown positive relationships between fat intake, free fatty acid levels, and impaired nitric oxide production, which is necessary for vessel dilation.[40,41] In addition, endothelial protection may be awarded by antioxidant nutrients, which are high in the DASH dietary pattern. These nutrients are beneficial for remediating harmful effects of oxidative stress and inflammation, which can be worsened by chronic BP elevation.[42] Given that unmanaged hypertension may lead to vascular dysfunction at a young age, it is important to consider lifestyle approaches that offer lasting cardiovascular benefit to at-risk youth.

While moderate adherence to the DASH diet was achieved with the DASH-4-Teens program, further improvement and maintained dietary change toward the ultimate DASH diet recommendations would be expected to lead to greater and more sustained effects on BP. As evidence, BP changes resulting from controlled feeding studies of a DASH dietary pattern in adults with high compliance to treatment resulted in more substantive changes to both systolic and diastolic BP.[8] In this study, both groups received counseling from a RD that included DASH dietary education. However, the increased contact with behaviorally based nutrition counseling through the DASH intervention was likely an important differentiator between the 2 interventions in allotting more time for behavioral skill development around DASH food selection and planning. While the number of dietitian contacts necessary to achieve significant changes in dietary intake in youth is unknown, a systematic review of adult dietary intervention trials in hypertension management suggests 3 to 6 visits over 12 months are needed to favorably alter diet and BP.[43] The remote counseling approach used in DASH-4-Teens may be a useful way to provide a low cost delivery option for patient follow-up especially with the increasingly common use of remote technologies, allowing more time for skill building to enhance compliance to diet. In addition, including strategies that facilitate weight management and physical activity has been shown to favorably alter BP in youth[17] and including these elements may prove more efficacious than the current version of DASH-4-Teens to lower BP in adolescents with elevated BP. Others have shown positive benefits of this combination of lifestyle behaviors on BP change in young adults.[44]

This study has many strengths including the focus on hypertensive adolescents, who are understudied in the cardiovascular disease (CVD) prevention literature. Several design elements of this trial, including randomization to treatment condition, blinding of staff to outcome assessment, a longer duration and follow-up than RCTs reported to-date, are also study strengths. However, several limitations deserve note. Differences in group retention were noted over time with lower attrition among DASH compared with RC participants at 18 months. Greater contact and engagement of participants has been suggested as an effective way to promote participant retention,[45] and this could have contributed to a higher level of motivation among DASH participants compared with RC. As well, the drop in participant retention from baseline to 18 months may have impacted our ability to detect group differences in BP, although the all-available-case mixed model analysis used in this trial is considered a powerful intention-to-treat approach compared with other methods.[46] Adolescents who dropped out of the study were those with lower baseline fruit and higher fat intake, which may suggest that youth with poorer dietary quality may be less inclined toward dietary treatment for BP management or may have had more social, environmental, socioeconomic, or other barriers that made it more difficult for them to improve their diet. The potential for a self-reporting bias toward dietary improvements might be greater in the DASH group versus RC because of more dietitian contact. However, both groups received education on portion size estimations and had experience completing dietary recalls by the end of the study.

This study provides evidence of the acceptability and efficacy of a clinic initiated behavioral nutrition intervention with telephone and mail follow-up emphasizing the DASH diet for adolescent BP management. It would be important to consider how such programs might be implemented in current practice settings, given that most health insurers do not cover behavioral interventions for the prevention and treatment of hypertension. The lower intensity and limited direct provider contact involved in DASH-4-Teens might make this approach inherently easier to translate directly into existing health care delivery services.

Perspectives

Our finding of endothelial function improvement in response to a DASH dietary intervention independent of BP, weight, or physical activity changes from baseline to 18 months in DASH participants compared with RC suggests long-term adherence to a DASH-type dietary pattern may have an ongoing, favorable impact on vascular health in adolescents with elevated BP.

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