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Original Article

Effect of diverse low energy-dense versus healthy diet on metabolic outcomes in overweight/obese adolescents: a randomized controlled trial

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Summary. *Background:* Dyslipidemia and impaired glucose metabolism are prevalent among overweight/obese adolescents. Although several dietary interventions used to reduce these complications, no study has been conducted regarding the effect of a diverse low energy-dense diet (DLED) on metabolic outcomes. *Objective:* To assess the effect of diverse low energy-dense diet on anthropometric variables, lipid profile and fasting blood sugar in overweight/obese adolescents aged 8-18 years. *Methods:* For this parallel clinical trial, 40 overweight/obese adolescents were randomly assigned to a DLED or a healthy recommendation based diet for 10 weeks. Physical activity and dietary intakes were recorded during the study. Total energy expenditure was estimated by Harris Benedict equations for each subject. To reduce energy density, a low-fat (25% fat, 15% protein and 60% carbohydrate) diet rich in dietary fiber and water was prescribed. The dietary variety was increased by recommending adolescents to consume at least one-half of subgroups of each main food group daily. Healthy nutritional recommendations were focused on limiting fast foods, fatty foods, added sugar, sugar sweetened beverages, French fries and unhealthy fat intake. Also, these recommendations encourage adolescents to consume more fruits and vegetables, whole grains, low-fat diary and water. Total cholesterol, low density lipoprotein, high density lipoprotein, triglyceride, fasting blood sugar and anthropometric variables were assessed at baseline and end-point. *Results:* The data of 40 adolescents were analyzed. Within groups analysis showed that there was a significant reduction in triglyceride (p=0.04) and low density lipoprotein (p<0.01) in DLED group. We could not find any significant difference in baseline relative to end-point measurements in both groups. Changes of anthropometric and biochemical variables were compared in a crude and adjusted models. We could not find any significant changes in anthropometric and biochemical variables between two diet groups. *Conclusion:* This study showed that compliance to a DLED diet may result in a significant decrease in TG and LDL after 10 weeks. However, we did not observe any significant difference in changes of variables between members of DLED group and those who consumed a healthy diet.

Keywords: dietary diversity, dietary energy density, lipid profile, adolescents

Introduction

During the recent decades, childhood obesity becomes a global concern (1). Obese children have greater risk for hypercholesterolemia and hypertension in adulthood (2). Also, elevated concentration of C-reactive protein (CRP) has been reported in obese children (3). The prevalence of obesity among American 2- to 19-year-olds children was 16.9% in 2011-2012 (4). In Iran, the range of the prevalence of obesity among children was estimated 3.2-11.9% (5). Dietary intervention is an effective choice for prevention of obesity complications. As low calorie diets are not recommended by some guidelines for individuals with childhood obesity (1), investigators focused on the other aspects of nutritional management such as manipulating dietary energy density (DED) and increase dietary diversity. DED is an index of diet quality which shows the ratio of energy content to gram of diet (6). It has an important role in nutritional intervention against obesity (7). Evidence showed a direct association between DED and obesity in different populations (6, 8). Also, it was observed that DED was related to dyslipidemia and cardiometabolic risk factors (9). Although some clinical trial studies have focused on the effects of low energy-dense diets on obesity in adults (10) and children (11), data regarding the effects of a low energy-dense diet on complications of obesity (e.g., hypertension, dyslipidemia and increased level of inflammatory markers) are scarce, especially among children.

Dietary diversity is another index of diet quality. Although the results of observational studies are not consistent (12), most studies have reported an indirect association between obesity and dietary variety (13, 14). Indeed, when diversity was in selective (not all) food groups, favorable association was observed (12). Moreover, studies reported that dietary diversity was inversely related to risk of hypertension, metabolic syndrome and cardiometabolic risk factors in adults (14, 15). However, we did not find any evidence regarding adolescents. Also, there is no clinical trial in which the effects of a diverse diet on metabolic markers have been assessed. Moreover, clinical trials which manipulated DED, overlooked dietary variety in their intervention and a diverse low energy-dense diet was not prescribed in previous studies. Therefore, the aim of present study was to examine the effect of a diverse low energy-dense diet on complications of obesity among obese adolescents.

Methods

Subjects

From subjects referred to pediatric clinics (Nour and Ali Asghar Hospital Isfahan, Endocrinology and Metabolism Research Center, Isfahan Sedigheye Tahere) 40 adolescents (aged 10-18 years) with excess body weight were recruited for the current randomized parallel clinical study from subjects referre to the pediatric clinics. The individulas of BMI were between body mass index (BMI) 85^{th} to 95^{th} percentiles of BMI for age in accordance with guidliness by WHO (16). All participants signed informed written consent form. Individuals with poor compliance were excluded. Present study was conducted in 2015 in Isfahan, Iran. Data regarding general characteristics of subjects were collected by a questionnaire. We estimated sample size by following formula (type one and type two error were 0.05 and 0.20, respectively): $N=2[(Z_{1-\alpha 2}+Z_{1-\alpha})^2 \times S^2]/d^2$ where S (variance of waist circumference) was 5.49 and d was 55 cm(17). According to this formula, 16 adolescents in each group were sufficient for present study. The study groups were matched for age of participants. Research Council and Ethical Committee of School of Nutrition and Food Science, Isfahan University of Medical Sciences, Isfahan, Iran and Food Security Research Center, Isfahan University of Medical Sciences, Isfahan, Iran approved this study. The Registration code of current clinical trial in IRCT was IRCT201109272839N4.

Study procedure

Eligible subjects were randomly assigned to consume a diverse low energy-dense diet or a diet based on healthy nutritional recommendations for 10 weeks. We used random number table for randomization. As this was a dietary intervention, we could not blind adolescents to the type of study intervention. Total energy expenditure (based on the age, sex and physical activity) was estimated by Harris Benedict equations for each subject. According to the intervention groups, an individualized diet was prescribed to each subject. Exchange list for meal planning was taught to the all parents and adolescents. The macronutrient composition of prescribed diet in the healthy nutritional recommendations group was 35% of energy from fat, 15% of energy from protein and 50% energy from carbohydrate. To reduce DED, we prescribed a low-fat (25% of energy from fat, 15% of energy from protein and 60% energy from carbohydrate) diet rich in dietary fiber and water in diverse low energy-dense diet group. Also, a list of five main food groups (grains, dairies, fruits, vegetables and meats) and their subgroups was provided to members of this group. The dietary variety was increased by recommending adolescents to consume at least one-half of subgroups of each main food group daily. Parents were asked to contribute to the intervention. Healthy nutritional recommendations were focused on limiting fast foods, fatty foods, added sugar, sugar sweetened beverages, French fries and unhealthy fat intake. Also, these recommendations encourage adolescents to consume more fruits and vegetables, whole grains, low-fat diaries and water. Periodical individual visits (one visit per each 2 weeks) were conducted. All subjects were asked to fill in a one-day food diary and a one-day physical activity record and deliver them in each visit. Mean physical activity time multiplied by metabolic equivalent (MET) to calculate physical activity level.

Anthropometric measurements

Anthropometric variables were assessed at baseline and after 10 weeks. Body weight was measured to the nearest 0.1 kg while participants wore light clothes. We measured height to the nearest 1 cm while adolescents were without shoes and stand with his/her back against the wall. To calculate BMI, we divided weight (kg) by height squared (m^2). Waist circumference (WC) was measured at the line below the last rib by using standard type to the nearest 1 cm (18).

Biochemical measurements

Biochemical variables were measured at baseline and after 10 weeks of intervention. Blood specimens were collected after 12 hours overnight fasting. After coagulating and centrifuging at 3,000×g for 10 min, serum was separated. We run Enzymatic colorimetric tests to measure the concentration of triglyceride (TG) and total cholesterol (TC). After blocking low density lipoprotein (LDL), very low density lipoprotein and chylomicrons, the level of high density lipoprotein (HDL) was enzymatically measured. We blocked HDL, VLDL and chylomicrons by enzymatic colorimetric tests and then LDL concentration was assessed. To measure fasting blood sugar (FBS), a glucose oxidase method was used. All biochemical variables were measured by an inter- and intra-assay coefficients lower than 5%. We used biochemical kits provided by Pars Azmoon Inc (Tehran, Iran) for the current study. The measurement was repeated at 10^{th} week of the trial.

Other variables

Education level of subjects was orally asked. Physical activity records analyzed and converted to MET/h (19).

Statistical Analysis

To test the normal distribution of variables, we run Kolmogorov–Smirnov test and drew a histogram curve. We used intention-to-treat analysis according to the last-observation-carried-forward (LOCF) method. Student t test was run to compare changes, baseline and endpoint measurements between two groups. Within groups differences between baseline and endpoint values was tested by paired t test. Change of each variable was calculated by this formula: "(endpoint value-baseline value)/baseline value". We adjusted the effects of potential confounders by run analysis of the covariance (ANCOVA). All values were presented as means ± SD. SPSS 20.0 (SPSS Inc) was used for statistical analysis.

Results

As illustrated in Figure 1, we enrolled a total of 40 volunteers and 38 subjects completed the study (from Jan 2013 to Aug 2015). . Characteristics of participated adolescents at baseline in the table healthy diet are shown in Table 1. There was no significant difference in age (P=0.53), sex (P=0.49) ratio, height (P=0.77), weight (P=0.42), body mass index percen-

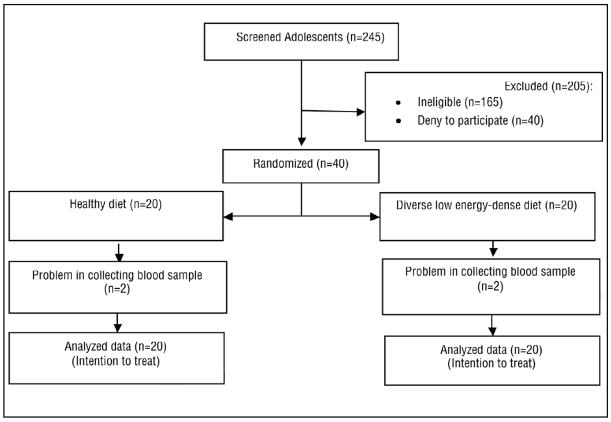

Figure 1. Study procedure

tile (P=0.16) and physical activity (P=0.19) between the two groups.

Dietary intake during study in two groups is shown in Table 2. There was no significant difference in intake of protein, carbohydrate, fat and several mineral and vitamins between the groups .

Baseline and endpoint measures of anthropometric and biochemical variables in adolescents are presented in Table 3. Between the groups analysis showed that subjects in the diverse low energy-dense group had higher level of TG at baseline in compared with healthy diet (100.78±8.88 vs. 135.78±10.80 mg/dl; P=0.02). Similar result was observed for end-point values of TG (90.94±7.47 vs. 117.22±9.84 mg/dl; P=0.04). between the groups analysis showed that there was a significant reduction in TG in diverse low energy-dense group (135.78±10.80 vs. 117.22±9.84 mg/dl; P=0.04). A significant reduction was also observed for LDL in diverse low energy-dense group after 10 weeks of intervention (106.00±4.90 vs. 89.56±3.68 mg/dl; P<0.01). We could not find any significant results for other variables in both within and between groups analysis. Changes of anthropometric and biochemical variables in adolescents are displayed in Table 4. Results are presented in crude and adjusted models (adjusted for age, sex and education). We could not find any significant changes in anthropometric and biochemical variables between the two diet groups.

Discussion

The findings of the present study revealed that compliance to a diverse low energy-dense diet may result in a remarkable reduction in TG and LDL after 10 weeks. However, we did not observe any significant difference in changes of other variables (i.e.,TC, HDL, FBS) between two diet groups. To the best of our knowledge, this is the first randomized clinical trial in which a diverse low energy-dense diet was prescribed.

Our previous observational studies conducted in Iran showed that there was a favorable association between dietary diversity score (DDS) and health outcomes in adults (13, 14, 20). Similar findings were reported from US, a developed country (21). These results have not been confirmed by a comprehensive

Table 1. Characteristics of participated adolescents at baseline in the two groups groups.

Variables	Healthy diet (n=20)	Diverse low energy-dense diet (n=20)	P value[1]
Age (yr)	10.97±2.54	11.44±2.10	0.53
Female (%)	66.7	10(55.6)	0.49
Height (cm)	147.86±16	146.46±13.63	0.77
Weight (Kg)	11(56.72±18.95%)	11(52.53±13%)	0.42
BMI percentile ≥ 95	16(77.8%)	11(55.6%)	0.16
Physical activity (MET-h/wk)	1861.74±1097.30	1497.44±506.05	0.19

[1]P for continuous variables generated from independent student t test and for categorical variables by chi-square test. As the distribution of physical activity was not normal, we used Mann-Whitney test for this variable.

Table 2. Reported dietary intake of energy and nutrients of participants.

Variables	Healthy diet (n=20)	Diverse low energy-dense diet (n=20)	P value[1]
Energy (kcal)	1225.39±1136.93[2]	930.35±773.79	0.34
Carbohydrate (g)	82.67±61.77	121.25±61.77	0.05
Protein (g)	50.87±22.10	50.00±22.11	
Fat (g)	61.59±26.33	45.47±26.35	0.06
Fiber (g)	7.50±6.19	9.51±6.20	0.31
Zinc (mg)	7.09±3.42	7.33±3.44	0.83
Calcium (mg)	856.19±900.37	999.61±900.37	0.62
Vitamin B_3 (mg)	7.54±3.00	9.23±2.88	0.07
Folate (mcg)	172.78±74.86	176.77±74.58	0.87
Vitamin C (mg)	56.22±27.52	57.74±27.53	0.86
Potassium (mg)	1201.76±1351.40	1955.05±1352.85	0.09
Magnesium (mg)	133.03±83.59	177.86±83.54	0.10
Energy density (kcal/g)	1.31±0.35	1.19±0.35	0.22

[1] *Independent T test (for energy and energy density) and Analysis of covariance were used for calculating P value.*
[2] *Variables are presented as mean±SD. All values were adjusted for total energy intake except for energy and energy density*

systematic review and meta-analysis which reported that there was no significant relationship between DDS and BMI (22). Observational studies conducted in Iranian adolescents showed that there was no significant association between BMI, WC and DDS (23). Therefore, the findings regarding the association between DDS and health outcomes are controversial. It is possible that the duration of our study (10 weeks) may not be sufficient for significant change in anthropometric variables. Moreover, we compared two healthy diets (a diverse low energy-dense vs. a diet based on the healthy nutritional recommendations) and therefore, we did not find any significant changes between these two diets.

You conclude the studies related to DDS but your study did not include this score

The results of the current study showed a remarkable reduction in TG after 10 weeks of consuming a diverse low energy-dense diet. We could not find any clinical trial regarding the effect of dietary diversity on metabolic outcomes in adolescents, however, an observational study conducted in Iranian women revealed a direct association between DED and serum concentration of TG (23). Another Iranian study reported that compliance to a high energy-dense diet may be associated with elevated LDL concentration (9).

In this study, we observed a significant reduction in TG and LDL after 10 weeks of consuming a diverse low energy-dense diet. A low energy-dense diet is limited in refined grains, added sugar, added fat, saturated fatty acids and *trans* fatty acids which may result in insulin resistance and metabolic abnormalities (24).

DED was introduced as a marker of diet quality in adolescents (25). The results regarding the association between DED and obesity in adolescents are similar . Although a systematic review suggested lowering DED as a strategy of obesity management in children and adolescents (26), O'Sullivan et al. (27) reported a non-significant association between DED and obesity in adolescents. Also, Kring et al. (28) did not find any significant relation between DED and subsequent change in BMI among children.

We could not find a clinical trial in which a diverse low energy-dense diet was prescribed and there-

Table 3. Baseline and endpoint measurements of anthropometric and biochemical variables in the two groups

Variables	Healthy diet (n=20)	Diverse low energy-dense diet (n=20)	P value[2]
Weight (Kg)			
Baseline	56.74±18.86[3]	52.91±13.67	0.42
End	56.67±18.86	53.46±14.25	0.55
P value[1]	0.96	0.54	
Body mass index (kg/m2)			
Baseline	25.41±3.39	24.25±2.23	0.23
End	24.93±3.66	24.11±2.54	0.42
P value[1]0.23	0.71		
Waist circumference (cm)			
Baseline	87.36±11.04	86.67±8.62	0.83
End	86.46±9.34	85.94±10.05	0.87
P value[1]0.52	0.38		
Triglyceride (mg/dl)			
Baseline	100.78±39.69	135.78±48.28	0.02
End	90.94±33.39	117.22±43.98	0.04
P value[1]	0.40	0.04	
Total cholesterol (mg/dl)			
Baseline	198.33±32.58	177.56±31.78	0.45
End	162.61±34.77	171.61±47.47	0.46
P value[1]	0.38	0.52	
LDL (mg/dl)			
Baseline	95.28±19.98	106.00±21.90	0.11
End	88.31±19.35	89.56±16.45	0.83
P value[1]	0.02	<0.01	
HDL (mg/dl)			
Baseline	47.00±10.14	42.50±4.87	0.08
End	46.50±12.43	43.22±5.40	0.29
P value[1]	0.69	0.56	
FBS (mg/dl)			
Baseline	89.44±6.80	87.94±7.51	0.51
End	90.28±4.83	87.56±10.77	0.37
P value[1]	0.66	0.82	

FBS: fasting blood sugar, HDL: high density lipoprotein, LDL: low density lipoprotein

[1]P values are resulted from paired t test to compare values within each group.

[2]P values are resulted from independent t test to compare values between groups

[3]Mean±SD

Table 4. Changes of anthropometric and biochemical variables in adolescents.

Variables	Healthy diet (n=20)	Diverse low energy-dense diet (n=20)	P value[3]
Weight (Kg)			
Crude	0. 55±0.51[1]	-0.05±0.23	0.65
Model I[2]	-0.23±1.04	0.69±1.00	0.56
Body mass index (kg/m2)			
Crude	-0.14±0.24	-0.48±0.28	0.53
Model I[2]	-0.45±0.41	-0.17±0.41	0.66
Waist circumference (cm)			
Crude	-0.72±0.79	-0.90±1.35	0.89
Model I[2]	-1.47±1.18	-0.15±1.18	0.48
Triglyceride (mg/dl)			
Crude	18.55±8.27	-9.83±11.28	0.54
Model I[2]	-9.90±8.94	-18.48±8.94	0.53
Total cholesterol (mg/dl)			
Crude	-5.94±10.43	-5.72±6.63	0.98
Model I[2]	-5.54±8.83	-5.54±8.83	0.82
LDL (mg/dl)			
Crude	16.44±4.27	-6.94±2.82	0.07
Model I[2]	-13.78±3.40	-9.63±3.40	0.42
HDL (mg/dl)			
Crude	0.72±1.22	-0.50±1.25	0.49
Model I[2]	-0.75±1.33	0.53±1.33	0.52
FBS (mg/dl)			
Crude	-0.39±1.73	0.83±1.87	0.63
Model I[2]	-0.86±1.89	1.31±1.89	0.44

FBS: fasting blood sugar, HDL: high density lipoprotein, LDL: low density lipoprotein

[1] All values are mean change ± SD

[2] Adjusted for sex, age, physical activity, education and baseline values

[3] Calculated by ANCOVA

fore, we could not compare our findings with an absolutely similar study.

There are several potential reasons for different results obtained from researches: 1) There are several methods to assess dietary diversity (29). Therefore, these different methods may be responsible for a part of observed heterogeneity. 2) As dietary diversity, DED is measured by different methods through the studies (30). 3) Low compliance to prescribed diets is prevalent among adolescents (31, 32). This point may affect clinical trial conducted in adolescent. 4) The baseline values of biochemical variables were in the normal range in our study and several other researches. Therefore, we did not assess the effect of a diverse low energy-dense diet on subjects with unhealthy metabolic status.

In conclusion, this study showed that compliance to a diverse low energy-dense diet may result in a significant decrease in TG and LDL after 10 weeks. However, we did not observe any significant difference in changes of variables between members of diverse low energy-dense group and those who consumed a healthy diet.

This study had several limitations. We could not assess the compliance of subjects to the prescribed diets by a biochemical variable because there is no specific biochemical marker for dietary variety and DED. This is a short-term clinical trial and more long-term interventions should be designed in future.

There are several strength points in the current study. Although more previous studies which assessed dietary diversity had observational design, this was the first interventional study focused on dietary diversity in adolescents. This study was conducted in overweigh/obese adolescents. In comparison with the studies conducted in adults, the number of researches which have focused on adolescents is limited.

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